Clinical Sports Medicine Update

Ulnar Nerve Complications After Ulnar Collateral Ligament Reconstruction of the Elbow

A Systematic Review

Jason B. Clain,* MD, Mark A. Vitale,†‡ MD, MPH,
Christopher S. Ahmad,§ MD, and David E. Ruchelsman,‖¶#** MD
Investigation performed at ONS Foundation for Clinical Research and Education, Greenwich, Connecticut, USA, and Hand Surgery Research and Education Foundation, Newton, Massachusetts, USA

Background: While ulnar collateral ligament reconstruction (UCLR) of the elbow is an increasingly commonly performed procedure with excellent results reported in the published literature, less attention has been paid to specifically on the characterization of postoperative ulnar nerve complications, and it is unclear what operative strategies may influence the likelihood of these complications.

Purpose: The purpose of this study is to examine the prevalence and type of ulnar nerve complications after UCLR of the elbow based on the entirety of previously published outcomes in the English literature. In addition, this study examined how the rate of ulnar nerve complications varied as a function of surgical exposures, graft fixation techniques, and ulnar nerve management strategies.

Study Design: Systematic review and meta-analysis.

Methods: A systematic review of the literature was completed using the MEDLINE, PubMed, and Ovid databases. UCLR case series that contained complications data were included. Ulnar neuropathy was defined as any symptoms or objective sensory and/or motor deficit(s) after surgery, including resolved transient symptoms. Meta-analysis of the pooled data was completed.

Results: Seventeen articles (n = 1518 cases) met the inclusion criteria, all retrospective cohort studies. The mean prevalence of postoperative ulnar neuropathy was 12.0% overall after any UCLR procedure at a mean follow-up of 3.3 years, and 0.8% of cases required reoperation to address ulnar neuropathy. There were no cases of intraoperative ulnar nerve injury reported. The surgical approach associated with the highest rate of neuropathy was detachment of flexor pronator mass (FPM) (21.9%) versus muscle retraction (15.9%) and muscle splitting (3.9%). The fixation technique associated with the highest rate of neuropathy was the modified Jobe (16.9%) versus DANE TJ (9.1%), figure-of-8 (9.0%), interference screw (5.0%), docking technique (3.3%), hybrid suture anchor-bone tunnel (2.9%), and modified docking (2.5%). Concomitant ulnar nerve transposition was associated with a higher neuropathy rate (16.1%) compared with no handling of the ulnar nerve (3.9%). Among cases with concomitant transposition performed, submuscular transposition resulted in a higher rate of reoperation for ulnar neuropathy (12.7%) compared with subcutaneous transposition (0.0%).

Conclusion: Despite a perception that UCLR has minimal morbidity, a review of all published literature revealed that 12.0% of UCLR surgeries result in postoperative ulnar nerve complications. UCLR techniques associated with the highest rates of neuropathy were detachment of the FPM, modified Jobe fixation, and concomitant ulnar nerve transposition, although it remains unclear whether there is a causal relationship between these factors and subsequent development of postoperative ulnar neuropathy due to limitations in the current body of published literature.

Keywords: ulnar collateral ligament reconstruction; Tommy John surgery; ulnar neuropathy; ulnar nerve transposition

Elbow ulnar collateral ligament (UCL) injuries were first reported in 1946 by Waris[34] in 17 elite javelin throwers. Acute and chronic deficiency of the anterior band of the UCL complex as a result of repetitive valgus stress results in medial elbow pain, exacerbated with overhead throwing motions, and loss of velocity and accuracy in a variety of sports, including tennis, javelin, and baseball. Injuries to the UCL in elite overhead athletes were originally career ending as nonoperative management failed to return most players to the field.[17,34]

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In their initial 1986 report, Jobe et al[17] reported that 10 of 16 overhead athletes (63%) were able to return to their previous level of play or better after UCL reconstruction (UCLR) of the elbow. The authors reported a complication rate of 32%, primarily attributed to postoperative ulnar neuropathy, which some authors attributed to the fact that detachment of the flexor pronator mass (FPM) historically was performed with concomitant anterior transposition of the ulnar nerve.[1,33,35] Since the initial report of Jobe et al,[17] authors have described a number of surgical approaches, fixation techniques, and ulnar nerve management strategies.

Acute and chronic UCL injuries in overhead athletes are being diagnosed with increasing frequency, and UCLR is being performed with increasing incidence.[6,8,13,16] Three systematic reviews that examined the outcomes of UCLR each independently concluded that ulnar nerve neuropathy was the most common complication after this surgical procedure.[27,33,35] While previous studies have reported the complications of UCLR, no study to date has focused on ulnar nerve complications and the specific variables that may be associated with postoperative ulnar neuropathy.[14] The goal of this systematic review was to perform a comprehensive analysis of the overall incidence of postoperative ulnar neuropathy and to ascertain possible relationships between surgical technique on the rate of ulnar nerve complications.

METHODS

A systematic review of the literature from January 1, 1974, until June 1, 2016, was completed using the Medline, PubMed, and Ovid databases. A review of the English literature was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.[23] Inclusion criteria were established. Only randomized controlled trials, cohort studies (prospective and retrospective), and case series that examined UCLR and included complications data were considered for inclusion. Cases describing UCL repair, case reports, studies without a uniform approach to ulnar nerve management, and studies with less than 1 year of follow-up were excluded.

The following search terms were used: "ulnar collateral ligament," "UCL," "medial collateral ligament," "MCL," "medial ulnar collateral ligament," "MUCL," "elbow instability," "valgus instability," "medial instability," "ligament reconstruction," "Tommy John surgery," "athletes," and "overhead." A database was compiled with the following categories: author, year, number of patients in each series, age (mean), length of follow-up, patients available at follow-up, surgical approach, fixation technique, nerve transposition with subtypes (subcutaneous, intramuscular, submuscular), and presence of preoperative ulnar nerve symptoms. Data recording Conway Jobe (CJ) rating, total complications, ulnar nerve complications with subtypes (subluxation of nerve, transient sensory loss, permanent sensory loss, motor dysfunction, or a combination of sensory/motor findings), and neuropathy requiring reoperation were pooled and collected. Postoperative ulnar nerve complications were defined as transient or permanent sensory and/or motor deficit reported after surgery. Studies that reported postoperative neuropathy as a function of preoperative symptoms were specifically noted. Cases with postoperative ulnar neuropathy were stratified as a function of surgical approach, fixation technique, and approach to the ulnar nerve.

The following information was summarized: number of procedures performed, number of patients available for follow-up, number of complications, and number of reoperations. Meta-analysis of the pooled data was performed using confidence intervals for the proportion of complications and Fisher exact tests to compare complication rates between studies.

RESULTS

Overall, 812 articles were identified by the initial search. After duplication removal, 312 manuscripts remained. The titles/abstracts were screened for inclusion/exclusion criteria, and 239 articles were excluded. Full texts were accessed for 73 articles. Seventeen studies (n = 1518 cases) were identified that met inclusion criteria and were included in the meta-analysis.[††] Included studies were either retrospective cohort studies (level 3) or case series (level 4 evidence). In situations in which the authors published multiple studies with overlapping patient cohorts, the most recent publication was used to avoid duplication (excluded: Jobe et al,[17] Smith et al,[31] and Rohrbough et al[28]).

The mean age at the time of operation was 21.5 years. The mean length of follow-up was 3.3 years (range, 2.3-6.9 years). Overall, 82.5% (n = 1518/1840) of patients were available at follow-up. Fifteen of 17 studies reported preoperative ulnar nerve symptoms in 31.3% (n = 414/1323). However, the series were devoid of formal preoperative classification of sensory and/or motor findings via grading systems described by McGowan[22] or Posner.[26,29] No studies reported postoperative complications as a result of preoperative ulnar nerve symptoms. All studies included

[††]References 2-5, 7, 9-12, 15, 19, 20, 24, 25, 30, 32.

**Address correspondence to David E. Ruchelsman, MD, Newton-Wellesley Hospital, 2000 Washington Street, Blue Building, Suite 201, Newton, MA 02462, USA (email: druchelsman@partners.org).

*Division of Plastic Surgery, Harvard Integrated Plastic Surgery Program, Harvard Medical School, Boston, Massachussetts, USA.

†ONS Foundation for Clinical Research and Education, ONS, P.C., Greenwich, Connecticut, USA.

‡Greenwich Hospital, Yale–New Haven Health, Greenwich, Connecticut, USA.

§Center for Shoulder, Elbow and Sports Medicine, Columbia University Medical Center, New York, New York, USA.

‖Newton-Wellesley Hospital, Newton, Massachussetts, USA.

¶Department of Orthopaedic Surgery, Tufts University School of Medicine, Boston, Massachussetts, USA.

#Hand Surgery Research and Education Foundation, Newton, Massachussetts, USA.

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TABLE 1
Study Details[a]

Author	Year	Overall N	Patients at Follow-up (%)	Mean Age, y	Length of Follow-up, y (Range)	Surgical Approach	Fixation	Ulnar Nerve Transposition	Presence of Preoperative Ulnar Nerve Symptoms (%)	Excellent Results by Conway-Jobe Rating (%)	Ulnar Nerve Complication Rate (%)	Ulnar Nerve Neuropathy Requiring Reoperation (%)
Conway et al[7]	1992	71	55 (77)	23.7	6.3 (2-15)	Detachment of flexor pronator mass	Figure-of-8	Yes	5 (9.1)	38 (69)	13 (23.6)	7 (12.7)
Andrews and Timmerman[2]	1995	72	9 (100)	24.2	3.5 (2-6)	Detachment of flexor pronator mass	Figure-of-8	Yes	NR	7 (78)	1 (11.1)	0 (0)
Azar et al[3]	2000	91	59 (65)	21.6	3.0 (1-6)	Muscle retraction	Figure-of-8	Yes	10 (16.9)	48 (81)	1 (1.7)	0 (0)
Thompson et al[32]	2001	83	83 (100)	24.3	3.1 (2-4)	Muscle splitting	Figure-of-8	No	21 (25.3)	27/33 (82)	4 (4.8)	0 (0)
Petty et al[25]	2004	31	27 (87)	17.4	2.92 (1.5-6.25)	Muscle splitting	Figure-of-8	Yes	7 (25.9)	20 (47)	2 (7.4)	0 (0)
Paletta and Wright[24]	2006	25	25 (100)	24.5	2.5 (2-NR)	Muscle splitting	Docking	Excluded	2 (8)	23 (92)	1 (4)	0 (0)
Dodson et al[11]	2006	100	100 (100)	22	3 (2-5)	Muscle splitting	Docking	Excluded	22 (22)	90 (90)	2 (2)	2 (2)
Koh et al[20]	2006	20	19 (95)	21.7	3.5 (0.5-5.6)	Muscle splitting	Modified docking	Excluded	1 (5.3)	18 (95)	1 (5.3)	1 (5.3)
Dines et al[9]	2007	22	22 (100)	20.1	2.99 (1.6-4.6)	Muscle splitting	DANE TJ	No	9 (40.9)	19 (86)	2 (9.1)	0 (0)
Cain et al[5]	2010	942	743 (79)	21.5	3.2 (2-10.8)	Muscle	Modified Jobe	Yes	292 (39.3)	610 (65)	121 (16.3)	1 (0.1)
Bowers et al[4]	2010	21	21 (100)	20	2.3 (2-4.1)	Muscle splitting	Modified docking	No	0 (0)	19 (90)	0 (0)	0 (0)
Kodde et al[19]	2012	20	20 (100)	22	4.6 (3-7.8)	Muscle splitting	Interference screw	No	4 (20)	18 (90)	1 (5)	0 (0)
Dugas et al[12]	2014	120	120 (100)	21.7	2.8 (SD, 0.85)	Muscle retraction	Modified Jobe	Yes	31 (25.8)	105 (88)	25 (20.8)	NR (0)
Dines et al[10]	2012	10	10 (100)	18.5	2.4 (2-3.8)	Muscle splitting	Docking		1 (10)	9 (90)	0 (0)	0 (0)
Savoie et al[30]	2013	123	116 (94)	20.4	3.3 (2-6)	Muscle splitting	Docking	No	NR	114 (93)	3 (2.6)	1 (0.9)
Hechtman et al[15]	2011	34	34 (100)	20.2	6.9 (4.2-8.7)	Muscle splitting	Hybrid suture anchor–bone tunnel technique	Excluded	1 (2.9)	29 (85)	1 (2.9)	0 (0)
Jones et al[18]	2014	55	55 (100)	17.6	2.6 (2.0-3.1)	Muscle splitting	Docking	No	8 (14.5)	48 (87)	4 (7.3)	0 (0)
Averages and totals		1840	1518 (82.5)	21.5	3.3	–	–	–	414 (27.2)	1242 (81.8)	182 (12.0)	12 (0.79)

[a]NR, not reported.

were uniform in the approach to the ulnar nerve independent of the presence of ulnar nerve symptoms preoperatively. Studies that reported a mix of strategies to manage the ulnar nerve (eg, transposition or no transposition) were excluded as complications were not reported as a function of these variables. According to the CJ rating criteria, 81.8% of patients achieved excellent results (Table 1).

Postoperative Ulnar Neuropathy

The mean rate of postoperative ulnar nerve complications was 12.0% (n = 182/1518; range, 0%-23.6%) overall after any UCLR procedure at a mean 3.3 years of follow-up. The series that were included did not uniformly stratify ulnar nerve complications into sensory, motor, or both, precluding reporting of more detailed pooled data on the specific type of postoperative ulnar neuropathy encountered. Overall, 0.8% (n = 12) of patients in this review required reoperation for ulnar nerve neuropathy, which represents 6.6% (12/182) of patients with postoperative ulnar nerve symptoms. Of these 12 patients, 7 were reported in the Conway et al[7] series (ulnar nerve transposition without subtype specified), 2 in the Dodson et al[11] series (subcutaneous transposition), and 1 each in the Cain et al[5] (in situ neurolysis), Koh et al[20] (ulnar nerve transposition without subtype specified), and Savoie et al[30] (ulnar nerve release, procedure not specified) series. One patient requiring reoperation had no handling of the ulnar nerve at the index procedure,[30] and 7 were reported to have concomitant anterior ulnar nerve transposition.[5,7,11,20] There were no reported cases of intraoperative ulnar nerve injury.

Surgical Approach

Three surgical approaches were described: detachment of the FPM (n = 64), muscle splitting (n = 532), and muscle retraction (n = 922). Detachment of the FPM was associated with a significantly higher rate of ulnar nerve complications (21.9%) compared with the muscle-splitting approach (3.9%) ($P < .001$). In addition, muscle retraction was associated with a significantly higher rate of ulnar nerve complications (15.9%) compared with the muscle-splitting approach (3.9%) ($P < .001$). Detachment of the FPM was associated with a significantly higher reoperation rate (10.9%) compared with both muscle splitting (0.8%) and muscle retraction (0.1%) ($P < .001$) (Table 2).

Fixation Technique

There were 6 reported fixation techniques: figure-of-8 (n = 233), docking (n = 306), modified docking (n = 40), modified Jobe (n = 863), interference screw (n = 20), DANE TJ (n = 22), and hybrid suture anchor–bone tunnel (n = 34). The modified Jobe fixation technique was associated with the highest rate of postoperative ulnar neuropathy at 16.9%. This complication rate was significantly higher than figure-of-8 ($P < .001$), docking ($P < .001$), and modified docking ($P < .001$). There was no statistical difference between modified Jobe and interference screw, DANE TJ, or hybrid suture anchor–bone tunnel technique. Figure-of-8 fixation was associated with a significantly higher rate of ulnar neuropathy compared with the docking technique fixation ($P = .008$). Rates of reoperation were generally low, and there were no significant differences between techniques (Table 3).

Approach to the Ulnar Nerve

Twelve of the 17 studies (n = 1318) provided complication data after ulnar nerve transposition.[‡‡] Five studies were excluded from this subgroup analysis when the authors reported more than one strategy of ulnar nerve handling

[‡‡]References 2-5, 7, 10, 12, 18, 19, 25, 30, 32.

TABLE 2
Surgical Approach Versus Ulnar Neuropathy

	Ulnar Collateral Ligament Reconstructions	Patients at Follow-up	Ulnar Nerve Complications, n (% [95% CI])	Patients Requiring Reoperation, n (% [95% CI])
Detachment of flexor pronator mass[12,16]	68	64	14 (21.9 [12.5-34.0])	7 (10.94 [4.5-21.2])
Muscle splitting[14,17-19,21,23-28,33]	544	532	21 (3.9 [2.5-6.0])	4 (0.75 [0.2-1.9])
Muscle retraction[13,15,20]	1464	922	147 (15.9 [13.6-18.5])	1 (0.11 [0.0-0.6])
Grand total	2076	1518	182 (12.0)	12 (0.79)

TABLE 3
Fixation Approach Versus Ulnar Neuropathy

	Ulnar Collateral Ligament Reconstructions	Patients at Follow-up	Ulnar Nerve Complications, n (% [95% CI])	Patients Requiring Reoperation, n (% [95% CI])
Figure-of-8[12,13,16,26,28]	260	233	21 (9.0 [5.7-13.5])	7 (3.0 [1.2-6.1])
Docking[17-19,25,27,33]	313	306	10 (3.3 [1.6-5.9])	3 (1.0 [0.2-2.8])
Modified docking[14,24]	41	40	1 (2.5 [0.1-13.1])	1 (2.5 [0.1-13.2])
Modified Jobe[15,20]	1386	863	146 (16.9 [14.5-19.6])	1 (0.1 [0.0-0.6])
Interference screw[23]	20	20	1 (5 [0.1-24.9])	0 (0 [0.0-13.9])
DANE TJ[17]	22	22	2 (9.1 [1.1-29.2])	0 (0 [0.0-12.7])
Hybrid suture anchor–bone tunnel technique[21]	34	34	1 (2.9 [0.1-15.3])	0 (0 [0.0-8.4])
Grand total	2076	1518	182 (12)	12 (0.8)

(eg, nerve transposition and no nerve handling), as complications were not reported as a function of nerve handling technique.[9,11,15,20,24] In these 12 studies, 76.9% of patients underwent nerve transposition (n = 1013), whereas 23.1% (n = 305) had no handling of the ulnar nerve. Ulnar nerve transposition was associated with a higher rate of ulnar neuropathy (16.1%) compared with the group without ulnar nerve transposition (3.9%) ($P < .001$) (Table 4). There were no reported instances of isolated in situ release/neurolysis. Further breakdown of techniques of the ulnar nerve transposition used revealed that the Conway et al[7] (1992) report (inclusive of Jobe et al[17] [1986]) used a submuscular transposition (n = 55, 5.4% of all transpositions), while the remaining authors all reported the use of subcutaneous nerve transposition (n = 958, 94.6% of all transpositions). There were no reported instances of intramuscular ulnar nerve transposition.

There was no significant difference in the number of cases of neuropathy requiring reoperation between the transposition and no-handling groups ($P = .69$), with a rate of 0.3% (n = 1) in the no-handling group[30] and 0.7% (n = 7) in the transposition group (all submuscular transpositions).[7] Subgroup analysis revealed that the difference in the rate of postoperative ulnar neuropathy in those with a submuscular transposition (23.6%) compared with those with a subcutaneous transposition (15.7%) was not significantly different. However, submuscular transposition was associated with a significantly higher rate of reoperation (12.7%) compared with those undergoing subcutaneous transposition (0%) ($P < .001$) (Table 4).

DISCUSSION

The incidence of UCLR surgery continues to increase. In 2004, Petty et al[25] found that there was a 50% increase in the incidence of UCLR in high school baseball players. A 2016 review by Hodgins et al[16] found that there was a statistically significant increase (193%) in the number of reconstructions performed in New York State from 2002 until 2011 compared with other ambulatory orthopaedic surgeries, and there was a 400% increase in concomitant ulnar nerve transposition during the study period. In another study investigating coaches' and players' perceptions of UCLR, Ahmad et al[1] found that 30% of coaches and 50% of high school baseball players believed that UCLR should be done on players *without* elbow injuries to enhance performance. Degen et al[8] recently reported that the annual incidence of UCLR has increased from 1.52 to 3.46 cases per 10,000 ($P = .042$) among recent orthopaedic graduates based upon American Board of Orthopaedic Surgery (ABOS) case submission data 2004–2013.

Since the initial report of Jobe et al[17] in 1986 that many patients return to previous level of play or better, there has been a misperception that UCLR surgery may be performance enhancing with minimal morbidity.[6,21] Despite this perception, our systematic review demonstrates a 12.0% incidence of some degree of permanent or transient postoperative ulnar nerve injury after UCLR, although the magnitude and grade of sensory and/or motor symptoms were not available for analysis. Three previous systematic reviews independently concluded that ulnar

TABLE 4
Concurrent Ulnar Nerve Transposition Versus Ulnar Neuropathy[a]

	Ulnar Collateral Ligament Reconstructions	Patients at Follow-up	Ulnar Nerve Complications, n (% [95% CI])	Patients Requiring Reoperation, n (% [95% CI])
No[14,18,23,27,28,33]	312	305	12 (3.9 [2.0-6.8])	1 (0.3 [0.0-1.8])
Yes[12,13,15,16,20,26]	1563	1013	163 (16.1 [13.9-18.5])	7 (0.7 [0.3-1.4])
Subcutaneous[16]	71	958	150 (15.7 [13.4-18.1])	0 (0.0 [0.3-0.3])
Submuscular [12,13,15,16,20,26]	1492	55	13 (23.6 [13.2-37.0])	7 (12.7 [5.2-24.5])
Grand total	1875	1318	175 (13.3)	8 (0.6)

[a]Excluded are studies that had a mix of nerve transposition as well as no nerve handling as complications were not reported as a function of nerve technique.[9-11,15,20,24]

nerve neuropathy was the most common complication after this surgical procedure.[27,33,35] Purcell et al[27] noted a 21% rate of neuropathy after submuscular transposition, a 2% to 3% rate in those with subcutaneous transposition, and transient but not chronic neuropathy in 5% of patients where no transposition was performed after UCLR. Vitale and Ahmad[33] reported a 10% overall complication rate, with postoperative ulnar neuropathy occurring in 6% of patients. Specifically, abandoning ulnar nerve transposition was associated with a lower rate of ulnar nerve complications: there was a 9% rate of postoperative ulnar neuropathy in patients treated with anterior nerve transposition compared with 4% in patients treated without ulnar nerve transposition in this series. Watson et al[35] reported an 18.6% complication rate, with ulnar nerve neuropraxia occurring in 12.9% of patients. Furthermore, Degen et al[8] found that while concomitant ulnar nerve transposition was performed only 33% of the time with UCLR (as compared with 77% incidence in this meta-analysis), ulnar nerve palsy/injury was the most commonly reported complication, accounting for 56.3% of all complications after UCLR in the ABOS candidates.

Controversy remains on the role of concomitant transposition of the ulnar nerve at the time of UCLR. In the initial series by Jobe et al,[17] 5 of 16 cases of UCLR with submuscular transposition developed postoperative ulnar nerve complications, with 2 requiring revision nerve surgery. In a follow-up series by Conway et al,[7] 15 of 71 (21%) athletes who underwent UCLR and submuscular nerve transposition developed postoperative ulnar neuropathy, and 7 underwent further surgery for ulnar nerve symptoms. The muscle-splitting approach has been advocated as a strategy to avoid concomitant ulnar nerve transposition, as historically detachment of the FPM and the muscle retraction approaches have been described with concomitant ulnar nerve transposition. The current systematic review of patients undergoing UCLR (N = 1518) suggests that concomitant ulnar nerve transposition at the time of UCLR is associated with a higher rate of postoperative ulnar neuropathy based on the available previously published data. In the 12 studies meeting the inclusion criteria, 77% of patients underwent nerve transposition. Postoperative ulnar nerve symptoms were seen in 16% of the transposition group and 4% of the group without ulnar nerve transposition ($P < .001$) (Table 4). With the exception of the series of Conway et al[7] with its use of submuscular transposition, all other series used subcutaneous nerve transposition.[7,17] The current systematic review highlights apparent institutional and/or surgeon biases in published series for performance of concomitant subcutaneous transposition at the time of UCLR without supporting prospective, randomized level 1 or 2 data.

The current study found a higher number of transpositions performed at the time of UCLR (77%) than reported in a recent analysis of 164 cases submitted to the ABOS from 2004 to 2013, in which 33% of patients were treated with ulnar nerve transposition, a trend that did not change significantly over time.[8] The discrepancy in the number of cases with concurrent ulnar nerve transposition may reflect a growing awareness of possible complications associated with ulnar nerve transposition, as well as a growing comfort level with the muscle-splitting approach in which the ulnar nerve does not require transposition. Our analysis and that of Degen et al[8] suggest that the majority of UCLRs seem to continue to be performed by sports medicine and shoulder and elbow fellowship–trained surgeons. Degen et al[8] found that the rates of concomitant ulnar nerve transposition and the incidence of postoperative complication were independent of subspecialty training.

While the originally described surgical approach of detachment of the FPM[17] was universally performed with concomitant ulnar nerve transposition and resulted in postoperative ulnar neuropathy in 11% to 32% of patients, the muscle-splitting[§§] and muscle retraction exposures[3,5] preserve the FPM and leave management of the ulnar nerve to surgeon discretion. The Purcell et al[26] report on 253 patients in 4 studies found that the muscle-splitting approach had the lowest incidence of ulnar nerve complications. Vitale and Ahmad,[33] in a systematic review, also found that the muscle-splitting approach was associated with both improved outcomes and a decreased rate of ulnar nerve complications. The current systematic review found that detachment of the FPM was associated with the highest rate of postoperative ulnar neuropathy (22%) and the highest rate of reoperation (11%). This may be partially explained by the historical use of concomitant ulnar nerve transposition during this surgical

[§§]References 4, 9-11, 18-20, 24, 25, 30, 32.

approach, which was found to be an independent factor associated with postoperative ulnar neuropathy. The muscle-retracting approach was associated with the second-highest rate of postoperative ulnar neuropathy (16%). It is possible that excessive retraction on the ulnar nerve at the time of the muscle-retracting approach may contribute to neuropraxia at the index operation. Another possible explanation is that, most often, an ulnar nerve transposition was performed with the muscle-retracting approach, as in the case of detachment of the FPM, although ulnar nerve transposition is not required with this approach. Muscle splitting appeared to be associated with the lowest rate of problems with regard to the ulnar nerve, with only a 3.9% rate of postoperative ulnar neuropathy. The current systematic review found that the modified Jobe fixation technique was associated with the highest rate of ulnar neuropathy (17%), which was significantly higher than the figure-of-8, docking, or modified docking techniques. It is possible that many of the patients undergoing the modified Jobe technique also had an ulnar nerve transposition as part of the procedure, and the ulnar nerve transposition may actually be the cause of the postoperative neuropathy, but limitations in the current published data prevent further multivariate analysis of these relationships.

Limitations to this study include the lack of published prospective randomized controlled data, as well as the uneven distribution of patients across the surgical approaches, fixation techniques, and ulnar nerve management strategies. Another limitation was the inability to perform multivariate analysis to determine independent effects of ulnar nerve transposition, surgical approach, and fixation technique, as all published series of detachment of the FPM and muscle retraction approaches involved transposition of the ulnar nerve. Furthermore, reporting on preoperative ulnar nerve symptoms was inconsistent across the reviewed manuscripts, and author groups did not report postoperative complications as a function of preoperative symptoms. However, studies included that did report ulnar nerve transposition did so on all patients regardless of preoperative symptoms. In addition, the published series included in this systematic review did not allow for differentiation between acute and delayed ulnar neuropathy, which can be due to different causes. Acute neuropathy complications may be due to nerve handling issues at the time of index surgery or injury during ligament exposure and tunnel placements. Postoperative perineural cicatrix and fibrosis adjacent to the medial epicondyle and retroepicondylar groove and within the flexor carpi ulnaris (FCU) may tether the nerve and account for delayed symptoms or objective findings when the nerve is not transposed and may account for the 4% ulnar nerve complication rate in this subgroup. Insufficient resection of the medial intermuscular septum, inadequate release of the deep investing fascia between the 2 heads of the FCU, and postoperative scarring as the nerve transitions from the subcutaneous position back to the sub-FCU region creating acute kinking of the nerve may create delayed symptoms after subcutaneous transposition.[29] The studies also do not differentiate the type of sling used to support a subcutaneous transposition (ie, fasciodermal sling, flexor mass myofascial flaps, distally based intermuscular septal sling, adipofascial sling). Postoperative ulnar neuropathy may be the result of the surgical technique to stabilize the nerve in the subcutaneous position, as these fascial slings may cause local sites of nerve compression compared with techniques that use broader fixation strategies, such as an adipose flap. Future prospective studies should be designed to study the temporal difference in these presentations and their causes. Finally, the rate of reoperation for ulnar neuropathy after UCLR may be higher than revealed in this systematic review because of loss to follow-up bias (ie, symptomatic patients may have sought further care outside of the initial treating physician).

Despite these limitations, the current systematic review of all the published literature to date reveals that 12.0% of patients undergoing UCLR experienced postoperative ulnar nerve complications. Techniques associated with the highest rates of neuropathy were detachment of the FPM, DANE TJ fixation, and concomitant ulnar nerve transposition, although it remains unclear whether there is a causal relationship between these factors and subsequent development of postoperative ulnar neuropathy due to limitations in the current body of level 3 and level 4 retrospective data. Prospective analysis of preoperative ulnar nerve symptoms and intraoperative treatment of the ulnar nerve while controlling for surgical exposure, graft fixation technique, and subspecialty training will help elucidate these trends and minimize ulnar nerve complications after this procedure.

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REFERENCES

1. Ahmad CS, Grantham WJ, Greiwe RM. Public perceptions of Tommy John surgery. *Phys Sportsmed*. 2012;40(2):64-72.
2. Andrews JR, Timmerman LA. Outcome of elbow surgery in professional baseball players. *Am J Sports Med*. 1995;23(4):407-413.
3. Azar FM, Andrews JR, Wilk KE, Groh D. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. *Am J Sports Med*. 2000;28(1):16-23.
4. Bowers AL, Dines JS, Dines DM, Altchek DW. Elbow medial ulnar collateral ligament reconstruction: clinical relevance and the docking technique. *J Shoulder Elbow Surg*. 2010;19(2):110-117.
5. Cain EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. *Am J Sports Med*. 2010;38(12):2426-2434.
6. Conte S, Camp CL, Dines JS. Injury trends in Major League Baseball over 18 seasons: 1998-2015. *Am J Orthop (Belle Mead, NJ)*. 2015;45(3):116-123.
7. Conway J, Jobe FW, Glousman R, Pink M. Medial instability of the elbow in throwing athletes. Treatment by repair or reconstruction of the ulnar collateral ligament. *J Bone Joint Surg Am*. 1992;74(1):67-83.
8. Degen RM, Camp CL, Bernard JA, Dines DM, Altchek DW, Dines JS. Current trends in ulnar collateral ligament reconstruction surgery

among newly trained orthopaedic surgeons. *J Am Acad Orthop Surg*. 2017;25(2):140-149.
9. Dines JS, ElAttrache NS, Conway JE, Smith W, Ahmad CS. Clinical outcomes of the DANE TJ technique to treat ulnar collateral ligament insufficiency of the elbow. *Am J Sports Med*. 2007;35(12):2039-2044.
10. Dines JS, Jones KJ, Kahlenberg C, Rosenbaum A, Osbahr DC, Altchek DW. Elbow ulnar collateral ligament reconstruction in javelin throwers at a minimum 2-year follow-up. *Am J Sports Med*. 2012;40(1):148-151.
11. Dodson CC, Thomas A, Dines JS, Nho SJ, Williams RJ, Altchek DW. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34(12):1926-1932.
12. Dugas J, Chronister J, Cain EL Jr, Andrews JR. Ulnar collateral ligament in the overhead athlete: a current review. *Sports Med Arthrosc*. 2014;22(3):169-182.
13. Erickson BJ, Nwachukwu BU, Rosas S, et al. Trends in medial ulnar collateral ligament reconstruction in the United States: a retrospective review of a large private-payer database from 2007 to 2011. *Am J Sports Med*. 2015;43(7):1770-1774.
14. Erickson BJ, Romeo AA. The ulnar collateral ligament injury: evaluation and treatment. *J Bone Joint Surg Am*. 2017;99(1):76-86.
15. Hechtman KS, Zvijac JE, Wells ME, Botto-van Bemden A. Long-term results of ulnar collateral ligament reconstruction in throwing athletes based on a hybrid technique. *Am J Sports Med*. 2011;39(2):342-347.
16. Hodgins JL, Vitale M, Arons RR, Ahmad CS. Epidemiology of medial ulnar collateral ligament reconstruction: a 10-year study of New York State. *Am J Sports Med*. 2016;44(3):729-734.
17. Jobe FW, Stark H, Lombardo S. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68(8):1158-1163.
18. Jones KJ, Dines JS, Rebolledo BJ, et al. Operative management of ulnar collateral ligament insufficiency in adolescent athletes. *Am J Sports Med*. 2014;42(1):117-121.
19. Kodde IF, Rahusen FT, Eygendaal D. Long-term results after ulnar collateral ligament reconstruction of the elbow in European athletes with interference screw technique and triceps fascia autograft. *J Shoulder Elbow Surg*. 2012;21(12):1656-1663.
20. Koh JL, Schafer MF, Keuter G, Hsu JE. Ulnar collateral ligament reconstruction in elite throwing athletes. *Arthroscopy*. 2006;22(11):1187-1191.
21. Makhni EC, Lee RW, Morrow ZS, Gualtieri AP, Gorroochurn P, Ahmad CS. Performance, return to competition, and reinjury after Tommy John surgery in Major League Baseball pitchers: a review of 147 cases. *Am J Sports Med*. 2014;42(6):1323-1332.
22. McGowan AJ. The result of transposition of the ulnar nerve for traumatic ulnar neuritis. *J Bone Joint Surg Br*. 1950;32(3):293-301.
23. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg*. 2010;8(5):336-341.
24. Paletta GA, Wright RW. The modified docking procedure for elbow ulnar collateral ligament reconstruction: 2-year follow-up in elite throwers. *Am J Sports Med*. 2006;34(10):1594-1598.
25. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am J Sports Med*. 2004;32(5):1158-1164.
26. Posner MA. Compressive ulnar neuropathies at the elbow: I. Etiology and diagnosis. *J Am Acad Orthop Surg*. 1998;6(5):282-288.
27. Purcell DB, Matava MJ, Wright RW. Ulnar collateral ligament reconstruction: a systematic review. *Clin Orthop Relat Res*. 2007;455:72-77.
28. Rohrbough JT, Altchek DW, Hyman J, Williams RJ, Botts JD. Medial collateral ligament reconstruction of the elbow using the docking technique. *Am J Sports Med*. 2002;30(4):541-548.
29. Ruchelsman DE, Lee SK, Posner MA. Failed surgery for ulnar nerve compression at the elbow. *Hand Clin*. 2007;23(3):359-371.
30. Savoie FH, Morgan C, Yaste J, Hurt J, Field L. Medial ulnar collateral ligament reconstruction using hamstring allograft in overhead throwing athletes. *J Bone Joint Surg Am*. 2013;95(12):1062-1066.
31. Smith GR, Altchek DW, Pagnani MJ, Keeley JR. A muscle-splitting approach to the ulnar collateral ligament of the elbow: neuroanatomy and operative technique. *Am J Sports Med*. 1996;24(5):575-580.
32. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. *J Shoulder Elbow Surg*. 2001;10(2):152-157.
33. Vitale MA, Ahmad CS. The outcome of elbow ulnar collateral ligament reconstruction in overhead athletes: a systematic review. *Am J Sports Med*. 2008;36(6):1193-1205.
34. Waris W. Elbow injuries of javelin-throwers. *Acta Chir Scand*. 1946;93(6):563-575.
35. Watson JN, McQueen P, Hutchinson MR. A systematic review of ulnar collateral ligament reconstruction techniques. *Am J Sports Med*. 2014;42(10):2510-2516.