The first description of elbow problems in overhead athletes was published in 1941, in a report documenting elbow and shoulder injury in professional baseball players. It was not until 5 years later, however, that Waris specifically described rupture to the ulnar collateral ligament (UCL) of the elbow in a review of 17 elite javelin throwers. Thereafter, sports medicine specialists became increasingly cognizant.

The Outcome of Elbow Ulnar Collateral Ligament Reconstruction in Overhead Athletes

A Systematic Review

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Background: Tears of the ulnar collateral ligament (UCL) of the elbow are common injuries in overhead athletes that may be career-ending if left untreated.

Purpose: The goal of this systematic review was to review all published reports of UCL reconstruction in overhead athletes, determine which techniques were associated with better outcomes, and assess the strengths and weaknesses of current data.

Study Design: Systematic review.

Methods: A systematic review of published studies evaluating reconstruction of the UCL in overhead athletes was performed using the Ovid Medline database. All studies with a cohort of athletes who underwent UCL reconstruction with a minimum of 1 year follow-up were included, resulting in a total of 8 Level III (retrospective cohort) studies. A database compiled variables of interest, including demographic variables, surgical techniques, Conway-Jobe ratings, and percentage and type of complications. Additionally, studies were evaluated for evidence of selection, performance, detection, and exclusion biases.

Results: Demographic data were similar between studies. Overall, 83% of patients in all studies had an excellent result. There was an overall 10% complication rate, with the most common complication being postoperative ulnar neuropathy, which occurred in 6% of patients. Transition to the muscle-splitting approach was associated with better outcomes than detachment of the flexor-pronator mass, as there was only a 70% rate of excellent results and a 20% rate of postoperative ulnar neuropathy in patients treated with detachment of the flexor-pronator mass compared with 87% excellent results and a 6% rate of postoperative ulnar neuropathy in patients treated with a muscle-splitting approach. Abandoning obligatory ulnar nerve transposition was associated with better outcomes, as there was only a 75% rate of excellent results and a 9% rate of postoperative ulnar neuropathy in patients treated with obligatory ulnar nerve transposition compared with 89% excellent results and a 4% rate of postoperative ulnar neuropathy in patients who did not have obligatory ulnar nerve transposition. The docking technique was associated with better outcomes, as there was a 76% rate of excellent results and an 8% rate of ulnar neuropathy in patients treated with a figure-of-8 technique compared with 90% excellent results and a 3% rate of postoperative ulnar neuropathy in patients treated with the docking technique.

Conclusion: The evolution in surgical techniques, most notably use of a muscle-splitting approach to the flexor-pronator mass, decreased handling of the ulnar nerve, and use of the docking technique, have resulted in improved outcomes and reduced complications. Although injury to the UCL was once a career-ending injury in overhead athletes, development and continued evolution of UCL reconstruction have made return to previous or higher level of athletic participation in sports highly likely. Future research should continue to utilize higher levels of evidence and compare new graft fixation techniques in an attempt to further improve the ability of overhead athletes to return to sports.

Keywords: ulnar collateral ligament (UCL) reconstruction; valgus elbow instability; overhead athlete; Tommy John surgery

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The first description of elbow problems in overhead athletes was published in 1941, in a report documenting elbow and shoulder injury in professional baseball players. It was not until 5 years later, however, that Waris specifically described rupture to the ulnar collateral ligament (UCL) of the elbow in a review of 17 elite javelin throwers. Thereafter, sports medicine specialists became increasingly cognizant.
of injuries in overhead athletes. For instance, in the early 1970s, the annual incidence of shoulder and elbow pain in professional baseball pitchers was recognized to be approximately 50%. These findings stimulated investigation into the throwing mechanics and pathophysiology behind elbow injury in overhead athletes. Extreme valgus stress in overhead athletes, particularly during the late-cocking and acceleration phase of throwing for baseball pitchers, was thought to be the primary cause of "medial elbow-stress syndrome" as it was described in the early literature. Other sport activities requiring an overhead motion, such as serving a tennis ball or throwing a javelin, also were recognized to impart a valgus stress on the elbow normally resisted by the UCL. It was believed that repetitive valgus stress led to progressive failure of the structures of the medial elbow, starting with the medial elbow musculature, UCL, medial joint capsule, and finally the joint itself. Subsequent research revealed that the anterior border of the UCL complex specifically was the primary constraint to valgus and internal rotatory forces of the elbow, and this is the structure that often fails after repetitive microtrauma from the tremendous tensile forces directed toward the medial elbow in overhead athletes.

Overhead athletes with chronic injury to the UCL report medial elbow pain, especially associated with the acceleration phase of throwing, as well as decreased accuracy, velocity, stamina, or strength. Athletes with acute injury to the UCL often report a particular moment when they hear or feel a “pop.” Additionally, chronic valgus stress at the elbow can occasionally cause traction neurapraxia to the ulnar nerve, resulting in ulnar neuropathy, usually limited to sensory changes. Although these symptoms were well characterized, unfortunately there were few available treatments initially for injury to the UCL in athletes beyond rest and nonoperative management, and resulting valgus instability and pain often resulted in a career-ending injury in elite overhead athletes. After several initial attempts at surgical repair or reconstruction, the first successful UCL reconstruction was performed in 1974 by Dr Frank Jobe and his colleagues on Los Angeles Dodgers pitcher Tommy John, allowing the pitcher to return to baseball in 1976. Jobe et al published their initial results in a population of baseball pitchers and javelin throwers in a landmark study in 1986. The original technique utilized the palmaris longus tendon as an autograft for reconstruction of the UCL, with detachment of the flexor-pronator musculature at its origin and obligatory submuscular transposition of the ulnar nerve. This series reported a 63% success rate, as defined by return to preinjury or better level of participation in athletic activity, but it was also associated with a 32% complication rate primarily related to postoperative ulnar neuropathy. Since the initially described technique by Jobe et al, interest in UCL reconstruction of the elbow in overhead throwing athletes has increased substantially. One report in the popular press estimated that 1 in 9 pitchers participating in Major League Baseball since 2001 has had this surgery. Another report has described that there has not only been a substantial increase in UCL reconstruction in athletes in general, but also about a 50% increase in UCL reconstruction in high school players 15 to 19 years of age from 1988 to 2003. Additionally, over the past 3 decades, modifications have been made to the initial surgical technique to decrease morbidity to the ulnar nerve and other soft tissues and improve the ability of athletes to return to their previous level of performance. Results with these modifications have generally been shown to be effective, and today the commonly quoted success rate of the surgery is approximately 85%

Despite the explosion of interest in injury to and reconstruction of the UCL of the elbow in overhead athletes, efforts to comprehensively review the currently existing techniques and outcomes for this procedure have been lacking in the orthopaedic literature. The goal of this systematic review was therefore to review all currently described studies of UCL reconstruction of the elbow in overhead athletes, determine whether different surgical techniques were associated with differences in outcomes, and assess the strengths and weaknesses of published data in an effort to suggest future directions for research.

METHODS

Literature Search

A systematic review of the current literature assessing reconstruction of the UCL of the elbow in athletes was performed using the Ovid Medline database from 1950 until November 1, 2007. Search terms used included “ulnar collateral ligament,” “UCL,” “medial collateral ligament,” “MCL,” “elbow instability,” “valgus instability,” “medial instability,” “ligament reconstruction” “Tommy John surgery,” “athletes,” and “overhead.” All studies with a cohort of athletes (recreational through professional levels) who underwent UCL reconstruction with a minimum of 1 year of follow-up were included. Studies that were only presented as abstracts were not included in the analysis. In addition, the references of relevant review articles and all included studies were manually cross-referenced to ensure that all possible articles were considered. A total of 11 studies met the inclusion criteria. Of these, the study by Jobe et al was excluded because the results from a later study by Conway et al at the same institution included all of the patients in the initial study with a longer follow-up period and additional subjects. For the study by Conway et al, there was a group of 14 patients with direct repair of the UCL and 56 with reconstruction of the UCL; only data from patients with reconstruction were included in this analysis. Similarly, the study by Rohrbough et al was excluded because the results from a later study by Dodson et al at the same institution included all of the patients in the initial study with a longer follow-up period and additional subjects. The studies from Conway et al and Thompson et al were from the same institution, but included different patient populations using a different surgical approach; therefore both were included. The studies by Andrews and Timmerman, Azar et al, and Petty et al were also from the same institution; although there was some overlap in subjects among these reports, they each
also included different patient populations from different time periods and therefore all were included. The study by Argo et al,\textsuperscript{3} reviewing 19 female athletes with UCL repairs or reconstructions, was excluded because only 1 of 19 patients received a UCL reconstruction, which was deemed to be an insufficient number for inclusion in this review. This resulted in a total of 8 articles that satisfied the inclusion and exclusion criteria for this analysis (Table 1).

**TABLE 1**
Demographics and Variables of Interest

<table>
<thead>
<tr>
<th>Authors</th>
<th>Data Collection Period</th>
<th>Overall N</th>
<th>Ulnar Collateral Ligament Reconstructions</th>
<th>Mean Age in Years (Range)</th>
<th>Number of Male Patients</th>
<th>Level of Competition of Baseball Players</th>
<th>Previous Elbow Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway et al\textsuperscript{10}</td>
<td>1974-1987</td>
<td>71</td>
<td>56</td>
<td>23.7 (15-24)</td>
<td>55/56 (98%)</td>
<td>39/56 (70%) professional; 13/56 (23%) collegiate; 4/56 (7%) recreational or high school</td>
<td>9/56 (16%)</td>
</tr>
<tr>
<td>Andrews and Timmerman\textsuperscript{2}</td>
<td>1986-1990</td>
<td>72</td>
<td>12</td>
<td>24.2 (range not reported)</td>
<td>12/12 (100%)</td>
<td>12/12 (100%) professional</td>
<td>5/9 (56%)</td>
</tr>
<tr>
<td>Azar et al\textsuperscript{5}</td>
<td>1988-1994</td>
<td>91</td>
<td>78</td>
<td>21.6 (15-39)</td>
<td>78/78 (100%)</td>
<td>37/85* (44%) professional; 41/85* (48%) collegiate; 7/85* (8%) recreational or high school</td>
<td>14/91 (15%)\textsuperscript{b}</td>
</tr>
<tr>
<td>Thompson et al\textsuperscript{48}</td>
<td>1992-1996</td>
<td>83</td>
<td>83</td>
<td>24.3 (range not reported)</td>
<td>82/83 (99%)</td>
<td>54/83 (65%) professional; 18/83 (22%) collegiate; 11/83 (13%) recreational or high school</td>
<td>14/83 (17%)</td>
</tr>
<tr>
<td>Petty et al\textsuperscript{38}</td>
<td>1995-2000</td>
<td>31</td>
<td>31</td>
<td>17.4 (15.9-19.0)</td>
<td>31/31 (100%)</td>
<td>31/31 (100%) recreational or high school</td>
<td>0/31 (0%)</td>
</tr>
<tr>
<td>Paletta and Wright\textsuperscript{37}</td>
<td>1998-2000</td>
<td>25</td>
<td>25</td>
<td>24.5 (19-27)</td>
<td>25/25 (100%)</td>
<td>20/25 (80%) professional; 5/25 (20%) collegiate</td>
<td>2/25 (8%)</td>
</tr>
<tr>
<td>Dodson et al\textsuperscript{14}</td>
<td>2000-2003</td>
<td>100</td>
<td>100</td>
<td>22.0 (16-43)</td>
<td>100/100 (100%)</td>
<td>17/96 (18%) professional; 63/96 (66%) collegiate; 16/96 (17%) recreational or high school</td>
<td>3/100 (3%)</td>
</tr>
<tr>
<td>Koh et al\textsuperscript{26}</td>
<td>Not reported</td>
<td>20</td>
<td>20</td>
<td>21.7 (17.9-25.3)</td>
<td>Not reported</td>
<td>13/20 (65%) professional; 7/20 (35%) collegiate</td>
<td>2/20 (10%)</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>493</td>
<td>405</td>
<td></td>
<td>383/385 (99%)</td>
<td>192/408 (47%) professional; 147/408 (36%) collegiate; 69/408 (17%) recreational or high school</td>
<td>49/415 (12%)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}This is the level of competition of patients who were baseball players among all patients receiving either UCL repairs or UCL reconstructions; level of competition of baseball players among patients receiving UCL reconstructions only not reported.

\textsuperscript{b}This is the number of patients with previous elbow surgery among all patients receiving either UCL repairs or UCL reconstructions; number of patients with previous elbow surgery among those receiving UCL reconstructions only not reported.

A database was compiled for data collection from the 8 studies compiled. Variables of interest included authors, institution, journal, year of publication, data collection period, type of study, initial sample size, average age of patients in years, percentage of male patients, type of sport of athlete (eg, baseball, tennis), level of competition (eg, professional, collegiate, recreational or high school), number of patients with previous surgery, number of patients at final follow-up, average length of follow-up, preoperative management, mean time from initial injury to surgery in months, approach to the flexor-pronator mass (eg, detachment of flexor-pronator mass, muscle-splitting technique), type of humeral tunnels (eg, posterior, anterior), graft fixation technique (eg, figure-of-8, docking technique), type of autografts used, performance of obligatory ulnar nerve transposition, type of ulnar nerve transposition technique, performance of diagnostic arthroscopy, additional procedures performed at time of surgery, number of surgeons, rehabilitation protocol, Conway-Jobe rating, mean time to return to sports, postoperative range of motion, and percentage and type of complications.

Although various measures have been reported to evaluate the outcome of UCL repair, such as change in preoperative and postoperative stress radiographs, surgical success for UCL reconstruction has generally been defined as the ability of afflicted athletes to return to a preinjury level of play for at least 1 year, which is captured by the Conway-Jobe rating.\textsuperscript{5,8,10,19} The Conway-Jobe rating grades players in terms of “excellent,” “good,” “fair,” or “poor” on the basis of return to competition; the result is considered excellent if the patient is able to compete at the same or a higher level of play.
level than before the injury for >12 months, good if the patient is able to compete at a lower level for >12 months or is able to throw in daily batting practices, fair if the patient is able to play regularly at a recreational level, or poor if the patient is unable to play. Although no statistical comparisons were performed as part of the systematic review, the rate of excellent results and rate of complications of patients were analyzed descriptively in patients with different surgical techniques—including different approaches to the flexor-pronator mass, graft fixation method, location of humeral tunnels, performance of obligatory ulnar nerve transposition, and performance of diagnostic arthroscopy—to determine if any of these techniques were associated with improved outcomes or lower rates of complications.15

Studies were evaluated for evidence of selection, performance, detection, and exclusion biases. Selection bias refers to grouping patients who are different at baseline in the same treatment group, which may bias outcomes on the basis of preoperative differences. Performance bias refers to including patients in which additional concomitant treatments were performed at the time of surgery that may bias outcomes on the basis of differences in number and type of additional procedures performed. Detection bias refers to the phenomenon of outcomes being measured differently between different studies, which may bias outcomes based on the method of measurement. Lastly, exclusion bias refers to different outcomes in patients who are lost to follow-up; this phenomenon occurs in studies with significant loss of patients at follow-up.

RESULTS

Literature Search

No prospective cohort or randomized control trials were identified, and all 8 studies were Level III (retrospective cohort). The earliest of these studies was published in 1992 (which includes data from the earliest and initial series published in 1986) and the most recent was published in 2006. Data collection periods ranged from 1974 to 2003, although the study by Koh et al26 did not report the period of data collection.

Demographic Data

Demographic data are summarized in Table 1. Compiling all of the published cases of UCL reconstructions resulted in a total of 405 reconstructions in the 493 total patients described with UCL injury, with the remaining 88 patients receiving UCL repairs and not included in the majority of the subsequent analyses. The range of sample size among studies ranged from a minimum of 12 to a maximum of 100 patients. The average age was similar in all studies, ranging from 17.4 years in a study specifically analyzing high school players to 24.5 years in the study with the oldest mean population. The vast majority of patients were male, with an overall total of 383 male patients out of 385 patients (99%) in the 7 of 8 studies reporting gender. In general, the athlete population was similar, but there was some variation in the proportions of professional, collegiate, and recreational or high school level players, introducing a degree of selection bias when comparing cohorts. Among the 408 baseball players described (this number includes a small number of UCL repairs as well as reconstructions because the study by Azar et al did not separate the number of reconstructions versus repairs when describing the level of competition of baseball players), overall there were 192 (47%) professional baseball players, 147 (36%) collegiate baseball players, and 69 (17%) recreational or high school level baseball players. The studies of Conway et al,10 Azar et al,5 Thompson et al,48 and Dodson et al14 predominantly included professional and collegiate baseball players, but also included a small percentage of other overhead athletes, including javelin throwers, softball players, tennis players, wrestlers, and football players. The studies by Andrews and Timmerman,2 Paletta and Wright,37 Koh et al,26 and Petty et al38 specifically included only baseball players, with the last of these studies focused solely on high school baseball players. The mean years of follow-up ranged from 2.5 to 6.3. The minimum follow-up for all studies was at least 2 years, with the exception of the study by Azar et al,5 which reported a range of 12 to 72 months. The overall number of patients with previous elbow surgery was 49 of 415 (12%), with all but 1 study having at least some patients with previous surgery.29 For studies that reported the number of surgeons performing the operative technique for patients in their series, this number ranged from 1 to 2 surgeons.

Preoperative Management

Most studies employed a preoperative trial of conservative management. Conway et al10 employed a nonoperative protocol for all patients of rest and nonsteroidal anti-inflammatory medications, followed by a supervised program of exercises for stretching and strengthening of the elbow with various physical therapy techniques, although the authors did not report the details or the duration of nonoperative management. The mean time from injury to surgery was 12.4 months (range, 0.5-64 months). The study by Andrews and Timmerman2 did not report on the use of a nonoperative protocol. The study by Azar et al5 reported that patients with partial-thickness tears of the UCL had a trial of 3 months of nonoperative management, while those with complete tears of the anterior bundle of the UCL did not have a nonoperative trial reported. On average, 11% (10 of 91) underwent surgery within 2 weeks of the onset of symptoms, 15% (14 of 91) underwent surgery between 2 to 6 weeks of onset of symptoms, and 74% (67 of 91) underwent surgery more than 6 months after onset of symptoms. The series by Thompson et al48 described a 2-month program of rest and physical therapy for patients who did not have gross instability before surgical consideration. The study by Petty et al38 reported that 78% (21 of 27) of patients underwent conservative therapy for at least 6 weeks before surgery, but they did not detail the exact
complete takedown of the flexor-pronator mass, resulting in
taking any preoperative conservative trial. The study by
Hart et al of the UCL, surgery was performed within 6 weeks with-
out any preoperative conservative protocol, but stated that the majority of patients had been man-
gaged nonoperatively with rest, physical therapy, and
nonsteroidal anti-inflammatory medications. The mean
time between onset of symptoms and reconstruction of the
UCL in this series was 7 months (range, 0.5-36 months) in
this group. Finally, the study by Koh et al26 did not detail a
specific preoperative protocol, but reported that patients
had a trial of relative rest and graduated levels of
increased activity. The patients in this series had a mean
time of 73 days between injury and surgical treatment.

Surgical Technique

The surgical techniques used in these 8 studies reflect the evo-
lution of this procedure as originally described by Jobe et al19 in
1986. Differences in the technique included approach to the
deflexor-pronator mass, location of humeral tunnels,
fixation of graft, choice of graft, performance of obligatory
ulnar nerve transposition and type of transposition, per-
formance of arthroscopy, and other additional procedures
performed at the time of UCL repair (Table 2). With respect
to approach to the flexor-pronator mass, the initial technique
by Jobe described detachment of the flexor-pronator mass,
but there was considerable variation in this technique.
Conway et al10 and Andrews and Timmerman2 described a
complete takedown of the flexor-pronator mass,
contacting 65 patients overall treated with this method. Azar et al5
described a dissection of the flexor-pronator mass at the
distal insertion of the anterior bundle of UCL with retraction
anteriorly but did not release the musculature from the
medial epicondyly; this resulted in another 59 patients
treated with this method. The remaining 5 studies employed a
muscle-splitting approach through the posterior third of
the common flexor bundle (ie, through the most anterior
fibers of the flexor carpi ulnaris), as initially described by
Smith et al,47 to preserve soft-tissue attachments; this
resulted in another 254 patients treated with this method.

The initial technique described by Jobe and colleagues19
reported a figure-of-8 graft fixation technique with
humeral tunnels placed posteriorly. In this technique, the
autograft is placed through 2 drill holes in the ulna and 3
in the medial epicondyly in a figure-of-8 fashion, with the
posterior cortex of the humerus penetrated and the graft
sutured to itself. This technique was used in the studies by
Conway et al,10 Andrews and Timmerman,2 Azar et al,5
and Petty et al,38 resulting in a total of 151 patients treated
with this technique. Thompson et al48 used a figure-of-8 graft
fixation technique, but they modified the initial technique
in that they placed tunnels in the anterior humeral cortex and
increased the size of the humeral tunnels to avoid
injury to the ulnar nerve, resulting in 83 patients treated
with this technique. A more significant change in graft fix-
uation and placement of humeral tunnels was developed by
David Altchek in 1996 and was initially reported in a clin-
ical series by Rohrbough et al.43 This technique was
designed to facilitate easier graft passing, tensioning, and
fixation. The ulnar tunnels are created in the same man-
ner as in the Jobe technique but the humeral tunnels are
created with a single inferior tunnel and two small super-
or and anterior exit tunnels. The graft is delivered into
the inferior tunnel and tensioned with sutures that exit
the superior tunnels and fixation is achieved by tying the
sutures over a bone bridge. This modification has been
termed the “docking technique”. Palletta and Wright uti-
lized the docking technique but with use of a double-
stranded graft, and Koh et al utilized the docking
 technique but with a 3-stranded graft that consisted of a
double anterior bundle and a single posterior bundle.26,37
There were a total of 144 patients treated with either the
docking technique or modified docking techniques.

All studies used a variety of autografts, but the most com-
monly used were ipsilateral or contralateral palmaris longus
tendon autograft. Overall, of the 7 studies reporting the num-er of different types of autografts, 188 of 389 patients (48%) received ipsilateral palmaris longus tendon grafts, 133 of 389
(34%) received contralateral palmaris longus tendon grafts,
39 of 389 (10%) received gracilis tendon grafts, 15 of 389 (4%)
received plantaris tendon grafts, 10 of 389 (3%) received extensor toe grafts, and 4 of 389 (1%) received Achilles
tendon grafts. Although ipsilateral palmaris longus tendon
tautograft was the most common graft choice, Koh et al26
pletely avoided the use of ipsilateral palmaris longus because
of concern of scar formation at the wrist flexion crease of the
throwing arm as well as concern that the palmaris may pro-
vide a varus movement at the elbow, resulting in dynamic
stabilization of the elbow against varus stress. The study by
Andrews and Timmerman2 reported that either palmaris
longus or toe extensor tendon grafts were used, but did not
report on the laterality or number of palmaris longus or toe
extensor tendon graft choices.

Although the initial technique developed by Jobe et al
describes obligatory submuscular ulnar nerve trans posi-
tion, this aspect of the technique varied considerably
among studies. Overall 175 of 378 patients (46%) received
ulnar nerve transpositions—55 submuscular trans posi-
tions and 120 subcutaneous transpositions via a fascial
sling. The studies by Conway et al,10 Andrews and
Timmerman,2 Azar et al,5 and Petty et al38 all used obliga-
tory transposition of the ulnar nerve, the latter 3 using
subcutaneous rather than submuscular transposition tech-
niques with the use of fascial slings. The study by
Thompson et al48 did not use any ulnar nerve transposition.
The studies by Dodson et al,14 Paletta and Wright,37 and
Koh et al26 used subcutaneous ulnar nerve transposition
only when there were preoperative ulnar nerve symptoms
(present in 5% to 22% of patients in these series).

Some surgeons reported routine use of diagnostic
arthroscopy to evaluate and treat intra-articular patho-
logic lesions. The diagnosis of UCL tear can be further
evaluated by the arthroscopic stress test of the UCL, as
described by Field and Altchek,16 which is defined as more
TABLE 2
Surgical Variables Including Approach, Humeral Tunnels, Graft Choice, and Ulnar Nerve Transposition<sup>a</sup>

<table>
<thead>
<tr>
<th>Authors</th>
<th>Approach to FPM</th>
<th>Humeral Tunnels</th>
<th>Graft Fixation</th>
<th>Graft Choice</th>
<th>Obligatory UNT</th>
<th>UNT Technique</th>
<th>Arthroscopy Performed</th>
<th>Additional Procedures Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway et al&lt;sup&gt;10&lt;/sup&gt;</td>
<td>FPM detachment</td>
<td>Posterior</td>
<td>Figure-of-8</td>
<td>15/56 (27%) ipsilateral palmaris; 30/56 (54%) contralateral palmaris; 7/56 (13%) plantaris; 3/56 (5%) Achilles tendon; 1/56 (2%) extensor tendon of 4th toe</td>
<td>Yes</td>
<td>55/56 (98%) submuscular transposition</td>
<td>0/56 (0%)</td>
<td>9/56 (16%) osteophyte excision; 24/56 (16%) excision of calcium deposits in remaining ligament</td>
</tr>
<tr>
<td>Andrews and Timmerman&lt;sup&gt;2&lt;/sup&gt;</td>
<td>FPM detachment</td>
<td>Posterior</td>
<td>Figure-of-8</td>
<td>Palmaris longus or extensor of toe (n not reported)</td>
<td>Yes</td>
<td>9/9 (100%) subcutaneous transposition</td>
<td>4/9 (44%)</td>
<td>5/9 (56%) posterosomedical olecranon osteophyte excision</td>
</tr>
<tr>
<td>Azar et al&lt;sup&gt;3&lt;/sup&gt;</td>
<td>FPM retracted</td>
<td>Posterior</td>
<td>Figure-of-8</td>
<td>50/78 (64%) ipsilateral palmaris longus; 13/78 (17%) contralateral palmaris longus; 9/78 (12%) ipsilateral toe extensor; 6/78 (8%) plantaris</td>
<td>Yes</td>
<td>56/56 (100%) subcutaneous transposition</td>
<td>56/56 (100%)</td>
<td>22/56 (39%) posterosomedical olecranon osteophyte excision; 2/56(4%) flexor pronator mass debridements; 1/56 (2%) LCL repair; 1/56 (2%) loose body removal; 1/56 (2%) ORIF of olecranon nonunion</td>
</tr>
<tr>
<td>Thompson et al&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Muscle-splitting of FPM</td>
<td>Anterior</td>
<td>Figure-of-8</td>
<td>43/83 (52%) ipsilateral palmaris longus; 37/83 (45%) contralateral palmaris longus; 2/83 (2%) plantaris; 1/83 (1%) contralateral Achilles</td>
<td>No</td>
<td>None performed</td>
<td>0/83 (0%)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Petty et al&lt;sup&gt;30&lt;/sup&gt;</td>
<td>Muscle-splitting of FPM</td>
<td>Posterior</td>
<td>Figure-of-8</td>
<td>19/27 (70%) ipsilateral palmaris longus; 2/27 (7%) contralateral palmaris longus; 6/27 (22%) gracilis</td>
<td>Yes</td>
<td>27/27 (100%) subcutaneous transposition</td>
<td>0/27 (0%)</td>
<td>4/27 (15%) posterosomedical olecranon osteophyte excision</td>
</tr>
<tr>
<td>Paletta and Wright&lt;sup&gt;37&lt;/sup&gt;</td>
<td>Muscle-splitting of FPM</td>
<td>Medial epicondyle Docking technique</td>
<td>21/25 (84%) contralateral palmaris longus; 2/25 (8%) ipsilateral palmaris longus; 1/25 (4%) gracilis</td>
<td>No</td>
<td>2/25 (8%) subcutaneous transposition</td>
<td>6/25 (24%)</td>
<td>1/25 (4%) removal of loose bodies</td>
<td></td>
</tr>
<tr>
<td>Dodson et al&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Muscle-splitting of FPM</td>
<td>Medial epicondyle Docking technique</td>
<td>59/100 (59%) ipsilateral palmaris longus; 11/100 (11%) contralateral palmaris longus; 30/100 (30%) gracilis</td>
<td>No</td>
<td>22/100 (22%) subcutaneous transposition</td>
<td>100/100 (100%)</td>
<td>29/100 (29%) had posterosomedical olecranon or coronoid process osteophyte excision; 9/100 (9%) microfracture surgery for trochlear defects; 7/100 (7%) loose body removal</td>
<td></td>
</tr>
<tr>
<td>Koh et al&lt;sup&gt;26&lt;/sup&gt;</td>
<td>Muscle-splitting of FPM</td>
<td>Medial epicondyle Modified docking technique</td>
<td>19/20 (95%) contralateral palmaris longus; 1/20 (5%) gracilis</td>
<td>No</td>
<td>1/19 (5%) subcutaneous transposition</td>
<td>0/19 (0%)</td>
<td>2/19 (11%) excision of posterosomedical osteophytes; 1/19 (5%) removal of loose bodies</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
than a 1 mm opening between the coronoid and medial humerus when the elbow is flexed to 90° with the forearm pronated and valgus stress applied to the elbow. Overall, 169 of 378 patients (45%) received diagnostic arthroscopic evaluation. The studies by Azar et al 5 and Dodson et al 14 routinely used diagnostic arthroscopy in all of their patients; the latter study reported a 29% rate of concurrent arthroscopic osteophyte removal from the posteroomedial olecranon or coronoid process, a 9% rate of concurrent arthroscopic microfracture surgery for cartilaginous defects involving the trochlea, and a 7% rate of arthroscopic loose-body removal. The studies by Andrews and Timmerman 2 and Paletta and Wright 37 had a 44% and 24% rate of diagnostic arthroscopy, respectively, and none of the other studies reported the use of arthroscopy during the initial UCL reconstruction. The variable presence of diagnostic and therapeutic arthroscopy introduced a degree of performance bias when comparing these 8 studies.

Many studies reported the performance of additional procedures concurrent with UCL reconstruction, and this introduced a fair degree of performance bias as well, as there was a great degree of variability in these additional procedures between studies. These additional procedures are reported in Table 2. Overall, 71 of 378 patients (19%) received posteroomedial olecranon or coronoid process osteophyte excisions, 24 of 378 (6%) received calcium deposit excisions from the remaining UCL, 10 of 378 (3%) received removal of loose bodies, 9 of 378 (2%) had microfracture surgery for trochlear defects, and 4 of 378 (1%) received other procedures summarized in Table 2.

### Rehabilitation Protocol

The rehabilitation protocols used by these studies were generally similar, with some variability in use of a hinged elbow brace and the time to return to throwing and competition. Among all patients in the 7 of 8 studies reporting on the use of postoperative immobilization, overall 212 of 351 patients (60%) used a postoperative hinged range of motion brace to gradually increase postoperative flexion and extension while limiting varus and valgus stress on the elbow. Postoperative rehabilitation protocols are summarized in Table 3.

### Return to Sports and Other Outcomes of Interest

The overall percentage of follow-up was 93% among all studies, ranging from 75% to 100%, with a subset of patients in 1 study having only a 40% follow-up at 2 years. 48 A commonly accepted standard is at least 70% follow-up as a minimum acceptable cutoff to minimize exclusion bias. 17 Exclusion bias was therefore minimal in all studies, but was greatest in the study by Andrews and Timmerman, 2 which had a 50% follow-up.

The common outcome measure used in all studies was the Conway-Jobe rating. 10 This rating grades players in terms of excellent, good, fair, or poor on the basis of return to competition, as detailed in the methods section. A result is considered excellent if the patient was able to compete at the same or a higher level than before the injury for >12 months. Overall, 271 of 328 responses (83%) were rated as excellent on the Conway-Jobe rating among all studies, ranging from 68% in the earliest study analyzed to 95% in the most recent study analyzed. The average time to return to sport was another statistic that 6 of 8 studies reported, a result which varied considerably, ranging from 9.8 months to 26.4 months. Because the Conway-Jobe rating system was used by all studies, detection bias was not an issue in these investigations.

Postoperative range of motion was another outcome that 3 of 8 studies analyzed postoperatively. Conway et al 10 reported an average postoperative loss of extension of 17° (range, 2°-25°) at final follow-up. Thompson et al 32 reported an average postoperative loss of extension of 4° (range, 0°-15°) and an average loss of flexion of 3° (range, 0°-9°) at final follow-up. Paletta and Wright 37 reported an average postoperative loss of extension of 3° and an average loss of flexion of 5° at follow-up. Lastly, Dodson et al 14 noted no postoperative deficits in range of motion, but did not record formal measurements.

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### Table 2 (continued)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Approach to FPM</th>
<th>Humeral Tunnels</th>
<th>Graft Fixation</th>
<th>Graft Choice</th>
<th>Obligatory UNT</th>
<th>UNT Technique</th>
<th>Arthroscopy Performed</th>
<th>Additional Procedures Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>65/378 (17%)</td>
<td>151/378</td>
<td>234/378</td>
<td>189/389 (48%)</td>
<td>55/378 (15%)</td>
<td>submuscular</td>
<td>169/378 (45%)</td>
<td>71/378 (19%)</td>
</tr>
<tr>
<td>FPM</td>
<td>1/378 (40%)</td>
<td>62/378</td>
<td>133/389</td>
<td></td>
<td></td>
<td>diagnostic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retraction; posterior; figure-</td>
<td>33/378</td>
<td>95/378</td>
<td>125/378</td>
<td>9/378 (1%)</td>
<td></td>
<td>transposition;</td>
<td>120/378 (32%)</td>
<td></td>
</tr>
<tr>
<td>0/378 (67%) muscle-</td>
<td>38/378</td>
<td>10/378</td>
<td>15/378</td>
<td></td>
<td></td>
<td>contralateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Splitting medial</td>
<td>19/378</td>
<td>10/378</td>
<td>(3%)</td>
<td></td>
<td></td>
<td>plantaris;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>of FPM epicondyle</td>
<td>5/378</td>
<td>(3%)</td>
<td>modified (1%)</td>
<td>4/378</td>
<td></td>
<td>extensor toe;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*FPM, flexor-pronator mass; UNT = ulnar nerve transposition; LCL, lateral collateral ligament; ORIF, open reduction and internal fixation.

---

The rehabilitation protocols used by these studies were generally similar, with some variability in use of a hinged elbow brace and the time to return to throwing and competition. Among all patients in the 7 of 8 studies reporting on the use of postoperative immobilization, overall 212 of 351 patients (60%) used a postoperative hinged range of motion brace to gradually increase postoperative flexion and extension while limiting varus and valgus stress on the elbow.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Use of Hinged ROM Brace</th>
<th>Rehabilitation Protocol</th>
<th>Mean Follow-up Years (Range)</th>
<th>Patients at Follow-up (%)</th>
<th>Excellent Results by CJ Rating</th>
<th>Mean Time to Return to Sport, in Months</th>
<th>Postoperative ROM</th>
<th>Number (%) of Patients with Complications</th>
<th>Type of Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway et al16</td>
<td>No</td>
<td>ROM at 10 days; strengthening program at 4-6 weeks; throwing at 4 months; return to competition at 12 months</td>
<td>6.3 (2-15)</td>
<td>68/71 (96%)§</td>
<td>38/56 (68%)§</td>
<td>Not reported</td>
<td>Average loss of extension of 17° (range, 2°-25°)</td>
<td>14/56 (25%)</td>
<td>12/56 (21%) ulnar neuropathy (10 transient, 7 requiring reoperation; 1/56 [2%] neuroma; 1/56 [2%] transient sensory nerve paresthesia; 1/56 [2%] hematoma</td>
</tr>
<tr>
<td>Andrews and Timmerman8</td>
<td>Yes</td>
<td>ROM followed by strengthening program gradually (time not reported); throwing at 5 months; progress to competition when ready</td>
<td>3.5 (2-6)</td>
<td>9/12 (75%)</td>
<td>7/9 (78%)</td>
<td>26.4° (range 12-60)</td>
<td>Not reported</td>
<td>1/9 (11%)</td>
<td>1/9 (11%) transient ulnar neuropathy</td>
</tr>
<tr>
<td>Azar et al5</td>
<td>Yes</td>
<td>ROM at 7 days; strengthening program at 4 weeks; throwing at 3.5 months; progress to competition when ready</td>
<td>3.0 (1-6)</td>
<td>59/78 (76%)</td>
<td>48/59 (81%)§</td>
<td>9.8 (range not reported)</td>
<td>Not reported</td>
<td>8/91 (9%)$</td>
<td>4/91 (4%) superficial infection, tightness, or tenderness at graft harvest site; 1/91 (1%) superficial elbow infection; 1/91 (1%) transient ulnar neuropathy; 1/91 (1%) postoperative stiffness requiring reoperation; 1/91 (1%) pain from postomedial olecranon osteophyte requiring reoperation</td>
</tr>
<tr>
<td>Thompson et al48</td>
<td>No</td>
<td>ROM at 7 days; strengthening program at 4 weeks; throwing at 4 months; return to competition at 12 months</td>
<td>3.1 (2-4)</td>
<td>83/83 (100%)</td>
<td>27/33 (82%)§</td>
<td>13 (range, 6-18)</td>
<td>Average loss of extension of 4° (range, 0°-15°); average loss of flexion of 3° (range, 0°-9°)</td>
<td>8/83 (10%)</td>
<td>4/83 (5%) transient ulnar neuropathy; 283 (2%) transient median palmar cutaneous nerve paresthesias; 1/83 (1%) retear of flexor-pronator muscle; 1/83 (1%) wound hematoma</td>
</tr>
<tr>
<td>Petty et al38</td>
<td>Not reported</td>
<td>Not reported</td>
<td>2.92 (1.5-6.25)</td>
<td>27/31 (87%)§</td>
<td>20/27 (74%)§</td>
<td>11 (range not reported)</td>
<td>Not reported</td>
<td>3/27 (11%)</td>
<td>2/27 (7%) transient ulnar neuropathy; 1/27 (4%) saphenous nerve sensory deficit</td>
</tr>
<tr>
<td>Paletta and Wright37</td>
<td>Yes</td>
<td>ROM at 10-14 days; strengthening program at 6 weeks; throwing at 4 months; return to competition at 19 months</td>
<td>2.5 (min 2, max not reported)</td>
<td>25/25 (100%)</td>
<td>23/25 (92%)§</td>
<td>11.5 (range, 10-16)</td>
<td>Average loss of extension of 3°; average loss of flexion of 5° (range not reported)</td>
<td>2/25 (8%)</td>
<td>1/25 (4%) transient ulnar neuropathy; 1/25 (4%) postoperative stress fracture of ulnar bridge</td>
</tr>
<tr>
<td>Dodson et al14</td>
<td>Yes</td>
<td>ROM at 7 days; strengthening program at 6 weeks; throwing at 4 months; return to competition at 12 months</td>
<td>3 (2-5)</td>
<td>100/100 (100%)</td>
<td>90/100 (90%)</td>
<td>Not reported</td>
<td>No deficits noted, but formal measurements not reported</td>
<td>3/100 (3%)</td>
<td>2/100 (2%) ulnar neuropathy requiring reoperation; 1/100 (1%) postoperative stiffness requiring reoperation</td>
</tr>
<tr>
<td>Koh et al26</td>
<td>Yes</td>
<td>ROM at 7 days; strengthening program at 6 weeks; throwing at 4.5 months; return to competition when ready</td>
<td>3.5 (0.5-5.6)</td>
<td>19/20 (95%)§</td>
<td>18/19 (95%)§</td>
<td>13.1 (range not reported)</td>
<td>Not reported</td>
<td>1/19 (5%)</td>
<td>1/19 (5%) ulnar neuropathy requiring reoperation</td>
</tr>
</tbody>
</table>

(continued)
Complications

Both the rate and percentage of complications varied significantly among studies. Overall, among the 410 total patients analyzed, 41 (10%) had a complication reported, with a range from 3% to 25% between studies. In the study by Azar et al., a 9% complication rate was reported, but this was the percentage of patients with complications in the overall sample size of patients available at follow-up, including patients undergoing UCL repairs; the percentage of patients with complications in patients undergoing UCL reconstructions only was not reported. Overall, 24 of 410 patients (6%) had postoperative ulnar neuropathies reported; 4 of 410 (1%) had graft site complications including superficial infections, tightness, or tenderness; 4 of 410 (1%) had postoperative sensory nerve paresthesias; and another 7 of 410 (2%) had other miscellaneous complications, which are summarized in Table 3.

Effect of Surgical Variables on Outcomes

Several categorical variables related to surgical technique were analyzed with regard to the rate of excellent results, overall rate of complications, and rate of postoperative ulnar neuropathy in a descriptive manner. When grouping all patients in all studies, approach to the flexor-pronator mass was associated with differences in outcomes, as only 45 of 65 patients (70%) with detachment of the flexor-pronator mass had excellent results, compared with 48 of 59 patients (81%) with retraction of the flexor-pronator mass with excellent results and 178 of 204 patients (87%) with the muscle-splitting approach to the flexor-pronator mass with excellent results. The overall complication rate was lower in patients without detachment of the flexor-pronator mass; 15 of 65 (23%) with detachment of the flexor-pronator mass had some type of postoperative complication, compared with only 8 of 91 patients (9%) with retraction of the flexor-pronator mass and 17 of 254 (7%) of patients with a muscle-splitting approach to the flexor-pronator mass. Lastly, postoperative ulnar neuropathy specifically was lower in patients without detachment of the flexor-pronator mass; 13 of 65 patients (20%) with detachment of the flexor-pronator mass had postoperative ulnar neuropathy, compared with only 1 of 91 patients (1%) with retraction of the flexor-pronator mass and 10 of 171 patients (6%) with a muscle-splitting approach to the flexor-pronator mass.

The method of graft fixation also appeared to influence the resultant Conway-Jobe rating as well; only 140 of 184 patients (76%) who had graft fixation with a figure-of-8 technique had excellent results, compared with 113 of 125 patients (90%) who had graft fixation with the docking technique with excellent results and 18 of 19 patients (95%) who had graft fixation with the modified docking technique with excellent results. The overall complication rate was lower in patients without a figure-of-8 technique as well; 34 of 266 patients (13%) with a figure-of-8 technique developed postoperative complications, compared with only 5 of 125 patients (4%) with a docking technique and 1 of 19 patients (5%) with a modified docking technique. The rate of postoperative ulnar neuropathy was also lower in patients without a figure-of-8 technique, as 20 of 266 patients (8%) with the figure-of-8 technique had postoperative ulnar neuropathy compared with only 3 of 125 patients (3%) with a docking technique and 1 of 19 patients (5%) with a modified docking technique.

Closely related to the method of graft fixation, placement of humeral tunnels also appeared to influence Conway-Jobe ratings; 113 of 151 patients (75%) who had humeral tunnels placed posteriorly had excellent results, 27 of 33 patients (82%) with humeral tunnels placed anteriorly had excellent results, and 131 of 144 patients (91%) with humeral tunnels placed in the medial epicondyles as part of the docking technique or modified docking technique had excellent

### TABLE 3 (continued)

<table>
<thead>
<tr>
<th>Use of Hinged ROM Brace</th>
<th>Rehabilitation Protocol</th>
<th>Mean Follow-up in Years (Range)</th>
<th>Patients at Follow-up</th>
<th>Excellent Results by CJ Rating</th>
<th>Mean Time to Return to Sport, in Months</th>
<th>Postoperative ROM Complications</th>
<th>Number (%) of Patients with Complications</th>
<th>Type of Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>138/351</td>
<td>390/420 (93%)</td>
<td>271/328 (83%)</td>
<td>41/410 (10%)</td>
<td>24/410 (6%) transient or persistent ulnar neuropathy requiring reoperation; 4/410 (1%) superficial infection, tightness, or tenderness at graft harvest site; 4/410 (1%) postoperative paresthesias; 7/410 (2%) other complications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without hinged ROM brace; 212/551 (65%) with hinged ROM brace</td>
<td></td>
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<td></td>
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</tbody>
</table>

\(^a\)CJ, Conway-Jobe; ROM, range of motion

\(^b\)This is the percentage of follow-up of all patients receiving either ulnar collateral ligament (UCL) repairs or UCL reconstructions; initial number of 56 UCL reconstructions at follow-up not reported.

\(^c\)This is the average time to return to competition of all patients receiving either UCL repairs or UCL reconstructions; average time to return to competition among patients receiving UCL reconstructions only not reported.

\(^d\)This is the number of patients with complications among all patients receiving either UCL repairs or UCL reconstructions; the number of patients with complications among those receiving UCL reconstructions only was not reported.
results. Postoperative complications developed in 26 of 183 patients (14%) who received posterior humeral tunnels, 8 of 83 patients (10%) with anterior humeral tunnels, and 6 of 144 patients (4%) with humeral tunnels in the medial epicondyles. Finally, postoperative ulnar neuropathy was present in 16 of 151 patients (11%) with posterior humeral tunnel placement, 4 of 83 patients (5%) with anterior humeral tunnel placement, and 4 of 144 patients (3%) with placement of humeral tunnels in the medial epicondyles.

The performance of obligatory ulnar nerve transposition also appeared to have some influence on Conway-Jobe ratings. Only 113 of 151 patients (75%) who had obligatory ulnar nerve transposition had an excellent result, compared with 158 of 177 patients (89%) who did not have obligatory ulnar nerve transposition. Performance of obligatory ulnar nerve transposition appeared to have some influence on overall complications, as postoperative complications of any kind developed in 26 of 183 patients (14%) with obligatory ulnar nerve transposition compared with 14 of 227 (6%) of patients without obligatory ulnar nerve transposition. Furthermore, the performance of obligatory ulnar nerve transposition was associated with an increased rate of subsequent postoperative ulnar neuropathy specifically; 16 of 183 patients (9%) who had obligatory ulnar nerve transposition were reported to have postoperative ulnar neuropathy, compared with only 8 of 227 patients (4%) who did not have obligatory ulnar nerve transposition.

Those studies in which diagnostic arthroscopy was performed had populations with slightly better Conway-Jobe ratings postoperatively; 168 of 193 patients (87%) in whom authors reported performing some diagnostic arthroscopy had an excellent result, as opposed to 103 of 135 patients (76%) in whom authors reported no instances of diagnostic arthroscopy. Postoperative complications were slightly higher in studies in which diagnostic arthroscopy was performed, as 26 of 185 patients (14%) in which authors reported on performing some diagnostic arthroscopy developed some postoperative complication as opposed to only 14 of 225 patients (6%) in which authors reported no instances of diagnostic arthroscopy. Lastly, postoperative ulnar neuropathy was slightly more frequent in studies in which diagnostic arthroscopy was performed, as 19 of 185 patients (10%) in which authors reported on performing some diagnostic arthroscopy developed postoperative ulnar neuropathy compared with only 5 of 225 patients (2%) in which authors reported no instances of diagnostic arthroscopy.

DISCUSSION

Although numerous authors have investigated ligamentous injuries to the elbow in athletes since the Waris report was published in 1946, a relatively small number have analyzed the outcome of operative management—specifically, reconstruction of the UCL. Some authors have reported on ligamentous injuries to the elbow in nonathletes and others have described tears of the UCL associated with dislocation of the elbow, but the mechanisms of those injuries are different than those in overhead athletes. There is 1 previous systematic review of UCL reconstruction by Purcell et al, but these authors only reported on 4 of the published reports of UCL reconstruction describing 253 patients with reconstructions, excluding the most recent series since 2005. The current review of 8 studies describing 493 patients with UCL injuries and 405 UCL reconstructions, therefore, represents the most current and comprehensive systematic review of UCL reconstruction to date.

Although UCL injury is seen most frequently in baseball pitchers, this lesion has been observed in many sports with overhead throwing. The studies reviewed also included javelin throwers, softball players, tennis players, wrestlers, and football players. Partial injuries may be managed nonoperatively, but complete tears with significant valgus instability often require surgical reconstruction to allow athletes to return to overhead activities. For instance, Barnes and Tullos reported that only 50% of symptomatic throwing athletes with UCL injuries receiving nonoperative treatment alone returned to play in a series of 100 subjects. More recently, Rettig et al found that only 42% of overhead throwing athletes returned to play more than 24 weeks after diagnosis in a series of 31 athletes. Isolated repair of the UCL has yielded poor results, with the body of literature supporting significantly better outcomes with reconstruction of the UCL complex. The initial report from Jobe et al showed that 63% of 16 throwing athletes were able to return to their preinjury level of competition for at least a year. Of the 6 patients who did not return to their previous level of competition, 1 returned to a lower level and 5 quit the sport. This technique was, however, associated with a high rate of complications of 32%, related primarily to postoperative ulnar neuropathy. Two of 5 patients with ulnar neuropathy required a secondary decompression. In this technique initially described by Jobe et al and subsequently used by Conway et al, the flexor-pronator mass was detached and elevated from the medial epicondyle of the humerus and obligatory submuscular ulnar nerve transposition was performed. The anterior bundle of the UCL was reconstructed with autograft fixated in a figure-of-8 fashion through 2 drill holes in the ulna and in the medial epicondyle. A drill hole was placed in the posterior cortex of the humerus and the graft was sutured to itself.

Our review did identify several key advances in the original technique that appear to be associated with improved ability to return to previous level of play and decreased rate of complications. One of the most significant modifications in the original technique was the development of the muscle-splitting approach as opposed to detachment of the flexor-pronator mass. This approach to the UCL is through the posterior third of the common flexor bundle (ie, through the most anterior fibers of the flexor carpi ulnaris), as initially described by Smith et al in 1996, in an effort to preserve soft-tissue attachments. This technique uses an interfemoral plane to the medial ulnohumeral articulation extending from the medial epicondyle to 1 cm distal to the insertion of the UCL on the sublime tubercle of the ulna, between the medial and ulnar nerve sites of innervation of surrounding muscles. In the original series of 22 patients described by Smith et al, there were no neuropathies or
denervations at follow-up of at least 1 year. The purported advantages of this approach are avoiding detachment of the flexor-pronator mass and avoiding routine ulnar nerve transposition. The clinical results of this technique were used and reported by Thompson et al 5 years later in a larger series of 83 UCL reconstructions. Once again, Thompson et al reported an 82% rate of return to previous level of sport for at least 1 year (a number that was increased to 93% in patients without previous surgery), which occurred at a mean of 13 months. In the immediate postoperative period, there was only a 5% rate of transient ulnar neuropathy, all of which resolved without surgery. Our systematic review supports the use of the muscle-splitting approach, as we found overall that patients treated with takedown of the flexor-pronator mass had nearly a 20% lower rate of excellent results (70% versus 87%), more than 3 times the rate of all complications (23% versus 7%) and more than 3 times the rate of postoperative ulnar neuropathy (20% versus 6%) compared with patients treated with a muscle-splitting approach.

Another significant change in surgical technique was the approach to ulnar nerve transposition, as the high complication rate of 32% was thought by some authors early on to be related primarily to obligatory submuscular transposition of the ulnar nerve. Subsequent modifications focused on simplifying the technique and decreasing handling of the ulnar nerve. In 1995, Andrews and Timperman reported a subcutaneous as opposed to submuscular ulnar nerve transposition by retracting the flexor carpi ulnaris anteriorly, which was an obligatory maneuver for all UCL reconstructions. This modification resulted in 78% of athletes returning to previous level of play for at least 1 year and only an 11% rate of postoperative ulnar neuropathy. Azar et al also used obligatory subcutaneous ulnar nerve transposition using two fascial slings, and their series reported an 81% rate of athletes returning to previous level of play for at least 1 year and only a 2% rate of transient ulnar neuropathy. Petty et al, using obligatory subcutaneous ulnar nerve transposition in a population of high school baseball players, reported a 74% rate of return to previous level of sport for at least a year and a 7% rate of transient ulnar neuropathy. Subsequent authors have reported that the ulnar nerve is transposed only if there are preoperative signs and symptoms of ulnar nerve dysfunction, and 1 study reported not performing any ulnar nerve transpositions concurrent with the UCL reconstruction. Our results support the abandonment of obligatory ulnar nerve transposition, as we found overall that patients treated with obligatory ulnar nerve transpositions had a nearly 15% lower rate of excellent results (75% versus 89%), more than double the rate of all complications (14% versus 6%), and more than double the rate of postoperative ulnar neuropathy specifically compared with those without obligatory ulnar nerve transpositions.

In 2002, Rohrbough et al reported on the docking technique, subsequently used in a larger series at the same institution by Dodson et al. Instead of placing the autograft in a figure-of-8 position via 3 large tunnels as described initially by Jobe, the graft was placed in a triangular configuration through a single humeral tunnel, and the limbs were brought out through 2 separate smaller drill holes in the bone and tied over a bone bridge. This reduction in the size of exit tunnels from 3.5 mm in the original technique to 1.5 mm was thought to theoretically reduce the risk of epicondylar fracture. Additionally, a Krackow stitch was placed at the end of each graft limb to maximally put tension in a double-stranded graft construct before securing it over the humeral bone bridge, which was believed to simplify tensioning of the graft. In the series by Dodson et al, there was a 90% rate of athletes returning to previous level of play for at least 1 year and only a 2% rate of ulnar neuropathy postoperatively requiring reoperation. The docking technique was also used by Paletta and Wright; in this series, there was a 92% rate of return to previous level of participation for at least a year with a 4% rate of transient ulnar neuropathy, none of which required subsequent reoperation. A modified docking technique was used by Koh et al, in which the authors further used a 3-strand construct with a double anterior bundle and a single posterior bundle. They believed that the double anterior bundle increased the amount of collagenous tissue in a critical area, similar to the way doubled hamstring grafts function in anterior cruciate ligament reconstructions of the knee. The authors used a 2-strand construct in their initial 12 patients and a 3-stranded modified docking technique in the remaining 8 patients; however, they did not find any significant difference between the 2-strand and 3-strand constructs in the time to return to play in their data set. They reported a 95% rate of return to sports at the athletes’ previous level of competition for at least a year and a 5% rate of ulnar neuropathy requiring reoperation. Our results support the use of the docking technique or modified docking technique, as we found overall that patients treated with a figure-of-8 fixation technique had about a 15% lower rate of excellent results (76% in those with the figure-of-8 technique versus 90% in those with the docking technique and 95% in those with the modified docking technique), about 3 times the rate of all complications (13% in those with the figure-of-8 technique versus 4% in those with the docking technique and 5% in those with the modified docking technique), and a higher rate of postoperative ulnar neuropathy (8% in those with the figure-of-8 technique versus 3% in those with the docking technique and 5% in those with the modified docking technique).

There have been other modifications to the technique of UCL reconstruction that have not yet been tested clinically but have been examined at the basic science level. For example, Ahmad et al reported on an interference technique for fixation of the UCL graft. Through a muscle-splitting approach, grafts are fixed with interference screws placed in single bone tunnels in the humerus and ulna; only 2 bone tunnels are needed, unlike Jobe’s original technique. The theoretical advantages of this technique include less risk to the ulnar nerve and elimination of risk of tunnel fractures without an intervening boney bridge on the ulna. In a biomechanical analysis comparing intact with reconstructed elbows using the interference technique, the normal elbow kinematics were restored with UCL reconstruction using interference screw fixation. The failure strength of UCL reconstruction with interference
screw fixation was similar to that of the intact UCL, with a mean of 30.55 N·m in the interference group versus 34.29 N·m in the native UCL group. Armstrong et al. compared 4 UCL reconstruction techniques biomechanically, including figure-of-8, the docking technique, interference screw fixation, and single-stranded UCL reconstruction using an Endobutton (Smith & Nephew Endoscopy, Andover, Massachusetts) for ulnar fixation. The authors placed cadaveric specimens in an apparatus, subjecting them to pneumatic valgus loading, and reported that the peak load to failure of the reconstructed UCL was less than that of the intact ligament. There was no difference in strength between the docking and single-stranded UCL reconstruction that used an Endobutton, and both of these reconstruction methods were stronger than the interference screw or figure-of-8 techniques. Most recently, McAdams and colleagues compared the docking technique versus bioabsorbable interference screw fixation in a cadaveric biomechanical evaluation. A cyclic valgus load was applied to 16 cadaveric elbows with an intact UCL complex and to elbows after UCL palmaris tendon reconstruction via the docking technique or bioabsorbable interference screw fixation, and the valgus angle was measured after up to 1000 cycles of repetitive loading. Bioabsorbable interference screw fixation resulted in significantly less valgus angle widening in response to early cyclic valgus load (after 10 and 100 cycles) compared with the docking technique. These new techniques appear promising but will need to be tested clinically before determination can be made as to whether they will provide improved results in overhead athletes.

The studies reviewed did suffer from some sources of bias. For instance, selection bias was present when comparing the study cohorts in terms of level of performance of athletes, as studies ranged from populations of exclusively high school athletes to populations of exclusively elite professional Major League Baseball players. Obviously, there may be differences in outcomes based on such demographic features alone. There was also a high degree of performance bias, as many studies reported different proportions of adjunctive procedures at the time of UCL reconstruction and different rates of concurrent elbow arthroscopy, ranging from never to always in different cohorts. With regard to exclusion bias, this was minimized in studies analyzed as there was universally a good percentage of follow-up in all cohorts. Finally, detection bias was not present when comparing these 8 studies because all authors used the ability to return to previous level of play for 1 year as noted by the Conway-Jobe rating scale as the ultimate outcome measure.

When interpreting the results presented in this systematic review, it is important to be mindful that our analysis of association of surgical techniques with outcomes and rates of complications was purely descriptive, and we have not performed statistical analyses; this was outside the scope of a systematic review. As such, we cannot make definitive statements as to the effects of advances such as the muscle-splitting approach, abandonment of obligatory ulnar nerve transposition, and the docking and modified docking techniques on outcomes, although the data are suggestive of clear trends that were reported. Furthermore, there are lacking in the current data any randomized controlled trials assessing UCL reconstruction. Indeed, it is difficult to conduct a meaningful randomized controlled trial with a group of demographically matched controls who do not receive surgical treatment compared with a cohort of subjects receiving surgical reconstruction because it would be impossible to blind the subject as to the assignment of treatment group. It would be instructive, however, to conduct prospective multicenter research comparing different graft fixation techniques, including figure-of-8, docking technique, and interference screw fixation, to clarify whether there are differences in outcome among these techniques and compare surgical methods in a more statistically rigorous manner.

In summary, in the past quarter decade, UCL reconstruction techniques have made successful return to preinjury level of competition or better more likely, changing this injury from a career-ending to a career-threatening one. When summarizing the experience of 8 studies of 405 reconstructions spanning approximately 3 decades of data collection, we found an 82% rate of excellent results, as defined by the ability to return to preinjury level of competition or better for at least 1 year. We also found an overall 10% rate of complications, with the most common complication being postoperative ulnar neuropathy, occurring at a rate of 6% among all studies. A muscle-splitting approach to the flexor-pronator mass, avoiding excessive handling of the ulnar nerve, and use of the docking technique have been associated with up to a 95% rate of return to previous level of overhead athletic participation and have minimized the development of postoperative ulnar neuropathy and overall complications. Future research should continue to use higher levels of evidence and statistical analysis and compare new autograft fixation techniques in an attempt to further improve the ability of overhead athletes to return to sports.

REFERENCES
