Return-to-Play and Competitive Outcomes After Ulnar Collateral Ligament Reconstruction Among Baseball Players

A Systematic Review

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Background: Ulnar collateral ligament (UCL) reconstruction (UCLR) is very common in baseball. However, no review has compared the return-to-play (RTP) and in-game performance statistics of pitchers after primary and revision UCLR as well as of position players after UCLR.

Purpose: To review, synthesize, and evaluate the published literature on outcomes after UCLR in baseball players to determine RTP and competitive outcomes among various populations of baseball players.

Study Design: Systematic review; Level of evidence, 4.

Methods: A literature search including studies between 1980 and November 4, 2019, was conducted for articles that included the following terms: ulnar collateral ligament, elbow, medial collateral ligament, Tommy John surgery, throwing athletes, baseball pitchers, biomechanics, and performance. To be included, studies must have evaluated baseball players at any level who underwent UCLR (primary or revision) and assessed RTP and/or competitive outcomes.

Results: A total of 29 studies with relatively high methodological quality met the inclusion criteria. After primary UCLR, Major League Baseball (MLB) pitchers returned to play in 80% to 97% of cases in approximately 12 months; however, return to the same level of play (RTSP) was less frequent and took longer, with 67% to 87% of MLB pitchers returning in about 15 months. RTP rates for MLB pitchers after revision UCLR were slightly lower, ranging from 77% to 85%, while RTSP rates ranged from 55% to 78%. RTP rates for catchers (59%-80%) were generally lower than RTP rates for infielders (76%) and outfielders (89%). All studies found a decrease in pitching workloads after UCLR. Fastball usage may also decrease after UCLR. Changes in earned run average and walks plus hits per inning pitched were inconclusive.

Conclusion: Pitchers returned to play after UCLR in approximately 12 months and generally took longer to return to their same level of play. Pitchers also returned to play less frequently after revision UCLR. After both primary and revision UCLR, professional pitchers experienced decreased workloads and potentially decreased fastball usage as well. Catchers may RTP after UCLR less frequently than pitchers, infielders, and outfielders possibly because of the frequency of throwing in the position. These results will help guide clinical decision making and patient education when treating UCL tears in baseball players.

Keywords: ulnar collateral ligament; elbow; baseball; Tommy John surgery

Baseball pitching has been described as the fastest motion that the human body can produce, with the shoulder rotating at over 7000 deg/s.[12,45] This extremely fast motion has been shown to create very large forces and torques at both the shoulder and the elbow.[19] Elbow valgus stress has been linked to injuries of the ulnar collateral ligament (UCL) in baseball players. Ultimately, repetitive valgus stress with inadequate dynamic medial elbow stability exposes the anterior band of the UCL to supraphysiological tensile strain. Over time, this can lead to partial tears, full-thickness tears, and the potential need for reconstructive surgery known as UCL reconstruction (UCLR).[29] Mahure et al[38] analyzed 890 patients between 2003 and 2014 in New York State and found a 343% increase in the number of UCLR procedures performed throughout the time period, with patients aged between 15 and 19 years undergoing

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significantly more UCLR procedures than do other ages. While 30% of athletes, 20% of coaches, and 44% of parents believe that UCLR actually improves athletic performance, the literature does not support this, and revision UCLR is still possible.[1,30,39,43]

Erickson et al[17] showed that between 2007 and 2011, patients aged between 15 and 19 years accounted for 56.8% of UCLR procedures, while patients aged between 20 and 24 years only accounted for 22.2% of UCLR procedures. The American Sports Medicine Institute documented that only 4 UCLR procedures were performed on high school–aged athletes between 1994 and 1997, whereas the number of patients who underwent UCLR among this population grew to about 30 per year by 2007.[21] Increased UCL injury rates among younger populations warrant greater investigation into injury mechanisms, rest allocation, and preventive care.[21] Pitch count regulations have been set throughout youth baseball; however, this may not be enough to limit accumulated microdamage, which ultimately weakens ligaments, tendons, and joint capsules.[21,52] This can lead to significant injuries in older populations, which may affect injury rates described at professional and collegiate levels.[9,10,21,49]

Baseball position players are less likely to undergo UCLR, whereas pitchers are the most prone to undergo this procedure.[16,18,23,24,26,29] Among professional baseball players, arm-related injuries accounted for 39% of all injuries between 2011 and 2016 in which pitchers were 3.6 times more likely to be injured than were catchers, 5.1 times more likely than were outfielders, and 5.8 times more likely than were infielders.[6] Conte et al[8] analyzed the number of Major League Baseball (MLB) players who underwent UCLR between 1974 and 2015 and found that 400 UCLR procedures were performed during this time frame, with nearly one-third (32.8%) of the procedures being performed in the last 5 years of the study. Posner et al[49] performed an epidemiological analysis of MLB injuries between 2002 and 2008 and found that pitchers had the most disabled list days (62.4% of the total) and that elbow injuries accounted for 26% of all injuries by anatomic region.

Several systematic reviews have looked at both return-to-play (RTP) and competitive outcomes after UCLR. Coughlin et al[11] found 14 studies assessing RTP and in-game performance statistics after UCLR in pitchers. Rates of return to the same level of play (RTSP) of 79% to 87% were found for MLB pitchers. Additionally, 2 of 5 studies showed an increase in earned run average (ERA), 1 of 5 studies showed a decrease in ERA, 3 of 4 studies showed decreased pitch velocity, and 5 studies found decreased pitching workloads after UCLR. Peters et al[46] conducted a systematic review and meta-analysis of RTP and in-game performance statistics after UCL injuries. They found that MLB players returned to play 89% of the time and returned to the same level of play 78% of the time with worse in-game pitching statistics, decreased innings pitched, and decreased fastball velocity after UCL injuries. However, no systematic review has compared RTP and in-game performance statistics of pitchers after primary and revision UCLR and/or position players after UCLR. The purpose of this systematic review was to identify the RTP and competitive outcomes for baseball players who undergo UCLR. The primary goal of this work was to identify the objective efficacy of reconstructive surgery among different baseball populations.

METHODS

Literature Search and Study Selection

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement guided this systematic review.[44] An initial systematic search of the literature was completed by a single reviewer (R.W.P.) in MEDLINE (PubMed), the Cumulative Index to Nursing and Allied Health (CINAHL), Embase, and SPORTDiscus between 1980 and November 4, 2019. Studies were pooled and filtered through Zotero reference management software (George Mason University).

A combination of search terms using Boolean search operators included the following: "Elbow" AND ["ulnar collateral ligament" OR "medial collateral ligament" or "Tommy John Surgery"] AND ["throwing athletes" OR "pitchers" AND ["biomechanics" OR "performance"]. Duplicates across databases were removed, followed by a screening of titles and abstracts. Full texts were then extracted and further evaluated for inclusion and exclusion criteria. The final inclusion of articles was then further inspected by all members of the research team, and disagreements regarding inclusion were solved by a consensus.

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Inclusion and Exclusion Criteria

To meet inclusion criteria, articles must have included baseball players at any level who had undergone primary or revision UCLR and assessed RTP and/or competitive outcomes. Articles were included if they were written in English and were published in a peer-reviewed journal. Acceptable study designs for inclusion were cohort studies, cross-sectional studies (retrospective and prospective), case studies, and case series. Research studies that assessed/included nonbaseball athletes, did not isolate baseball player position, or did not isolate level of competition (eg, amateur, collegiate, professional) were excluded.

Assessment of Methodological Quality

Because of the inclusion of cohort and cross-sectional studies, the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) statement was utilized to assess methodological quality. An overall score of a possible 22 was given for each included article. Two reviewers (R.W.P., S.J.W.) assessed each of the articles independently and then met to discuss differences in scoring. Disagreements in STROBE scoring were resolved via a discussion and consensus.

Data Extraction and Analysis

For included studies, information regarding study design, participants, UCL surgical interventions, RTP (the percentage of athletes who were able to compete at any level) and RTSP (the percentage of athletes who were able to compete at their previous level of play) rates, and competitive outcomes were extracted. Workload statistics (innings pitched, pitches thrown), rate statistics (statistics that are divided by workload, such as ERA, walks plus hits per inning pitched [WHIP], batting average, and walks per 9 innings), pitch velocity, and pitch usage were emphasized, while counting statistics (eg, wins, hits, strikeouts, and walks) were not discussed further because of the confounding effect of workload on counting statistics. Additionally, the major results of each of the studies were summarized and compared based on the types of outcomes that each of the studies reported.

RESULTS

Results for the search are shown in Figure 1. After the search, a total of 29 studies[††] met all inclusion criteria. STROBE scores indicated relatively high methodological quality across the included studies (mean ± SD, 18.9 ± 1.5 [range, 15-22]). After a methodological quality assessment, studies were subdivided by outcome measure assessments into competitive outcomes (n = 24) and RTP outcomes (n = 20).

Competitive Outcomes Related to UCL Injuries

Data extracted related to the 24 studies[‡‡] that assessed competitive outcomes are found in Appendix Table A1. Overall, 18 studies[§§] assessed primary UCL surgical interventions, while 2 studies[30,37] focused on revision UCLR, and 4 studies[15,32,33,43] assessed both primary and revision UCL surgery. Moreover, 19 of the competitive outcome studies[‖‖] assessed professional pitchers, with the majority utilizing publicly available data. There were 2 studies[4,53] that investigated amateur (nonprofessional) pitchers entering the MLB draft, 2 studies[2,27] that assessed professional position players, and 1 study[40] that identified professional catchers. For specific competitive outcome measures, the most commonly reported were ERA (n = 15), WHIP (n = 13), strikeouts (n = 10), walks (n = 10), pitch velocity (n = 10), wins above replacement (WAR; n = 9), and pitch usage (n = 8).

Although most studies[16,23,28,34,35,39,51] agreed on a decrease in workload in the first season after primary UCLR, the differences in pitching effectiveness as measured using rate statistics (most frequently ERA and WHIP) were less clear. Erickson et al[16] found ERA and WHIP to significantly decrease in the season after primary UCLR. However, other studies[23,39] did not show these significant differences in ERA and WHIP. When comparing ERA and WHIP in MLB pitchers after primary UCLR with controls, pitchers who underwent UCLR performed comparably with[23,28,34,39] or better than (lower ERA and WHIP)[16] controls.

Liu et al[37] found that a decrease in workload was the only difference when comparing before and after revision UCLR in MLB pitchers (ERA and WHIP did not differ). Marshall et al[43] observed the same results but also saw an increase in the walk rate from before (4.02 walks per 9 innings) to after (4.79 walks per 9 innings) revision UCLR, while controls only had 3.49 walks per 9 innings after surgery.

There were 3 studies[35,39,47] that agreed that fastball usage decreased significantly from before to after UCLR. The only study to disagree was Portney et al[48] in which no differences in pitch usage or pitch velocity were found. Conclusions about changes in pitch velocity were less clear, with 4 studies[28,35,39,51] observing decreases in pitch velocity and 2 studies[31,48] observing no change.

There were 2 studies[2,27] that looked at competitive outcomes before and after primary UCLR in MLB position players. Jack et al[27] found no differences in performance statistics from before and after primary UCLR for catchers or infielders; however, outfielders had a decrease in WAR from 1.5 before primary UCLR to 0.8 after primary UCLR, while all other performance statistics did not differ. Also, no differences were observed between cases and controls. Begly et al[2] only observed a decrease in at-bats, plate appearances, and WAR from before to after primary UCLR in MLB position players, but no differences were observed when performance statistics were compared with those of

[††]References 2-5, 13-16, 22, 23, 25, 27, 28, 30-35, 37, 39-43, 47, 48, 51, 53.

[‡‡]References 2, 4, 14-16, 23, 27, 28, 30-35, 37, 39-43, 47, 48, 51, 53.
[§§]References 2, 4, 14, 16, 23, 27, 28, 31, 34, 35, 39-42, 47, 48, 51, 53.
[‖‖]References 14-16, 23, 28, 30-35, 37, 39, 41-43, 47, 48, 51.

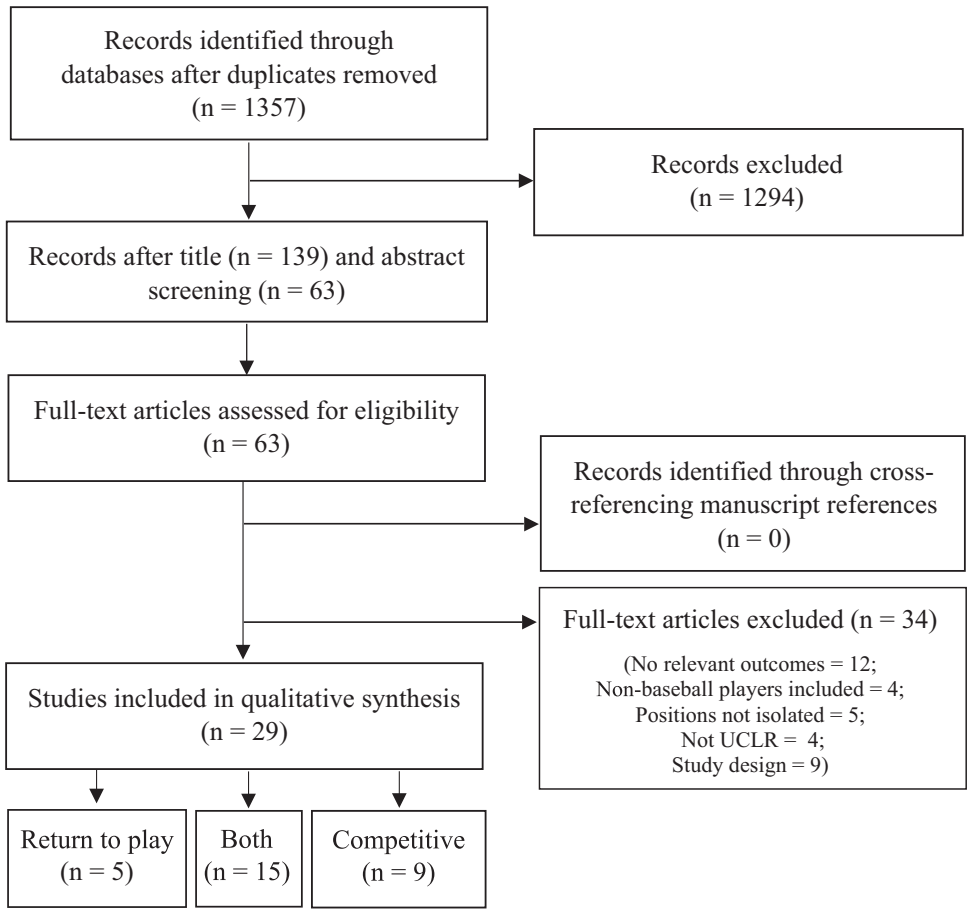

Figure 1. Flowchart of articles included in the systematic review. UCLR, ulnar collateral ligament reconstruction.

controls. Marshall et al[40] looked at 25 professional catchers only and found a decrease in games played to be the only difference when comparing competitive outcomes before and after primary UCLR. Surprisingly, catchers who underwent UCLR had a significantly higher slugging percentage (0.40) than did controls (0.37).

RTP Outcomes Related to UCL Injuries

Data extracted related to the 20 studies[¶¶] that assessed RTP outcomes are found in Appendix Table A2. Overall, 12 studies[##] assessed primary UCLR in pitchers, 4 studies[5,30,37,43] focused on revision UCLR in pitchers, 1 study[15] assessed both primary and revision UCLR in pitchers, 3 studies[2,3,27] analyzed primary UCLR in position players, and 1 study[40] looked at catchers after primary UCLR. All of the included RTP outcome studies assessed professional players. For specific RTP outcome measures, the most commonly reported were RTP rate (n = 13) and RTSP rate (n = 16).

RTP rates for MLB pitchers after primary UCLR ranged from 80% to 97% with a mean of 12 months until RTP,[16,22,23,25,28,34,41,42] while RTSP rates ranged from 67% to 87% with almost 15 months until RTP.[16,22,23,25,28,34,39,41,42] RTP rates for MLB pitchers after revision UCLR were slightly lower, ranging from 77% to 85%,[5,43] while RTSP rates ranged from 55% to 78%.[5,30,37,43]

There were 3 studies[2,3,27] that analyzed RTP of MLB position players, but only Camp et al[3] had a sufficient sample size after separating the position players into infielders (n = 34), outfielders (n = 35), and catchers (n = 24). For position players, infielders returned to play the fastest (294 days), outpacing outfielders (375 days) and catchers (363 days). Catchers had an RTP rate of 59% and an RTSP rate of 50%, infielders had an RTP rate of 76% and an RTSP rate of 78%, and outfielders had an RTP rate of 89% and an RTSP rate of 74%.[3] Marshall et al[40] looked at MLB and Minor League Baseball (MiLB) catchers and found higher RTP (80%; 20/25) and RTSP (76%; 19/25) rates, with 12.9 months until RTP.

DISCUSSION

The purpose of this systematic review was to identify the RTP and competitive outcomes for baseball players who underwent UCLR. RTP rates were lower for pitchers after revision UCLR than after primary UCLR. RTP rates for

[¶¶]References 2, 3, 5, 13-16, 22, 23, 25, 27, 28, 30, 34, 37, 39-43.
[##]References 13-16, 22, 23, 25, 28, 34, 39, 41, 42.

catchers were significantly lower than those for pitchers, infielders, and outfielders. Pitching workloads decreased after UCLR, and most studies found that fastball usage also decreased after UCLR. Surprisingly, after surgery, pitchers who underwent UCLR performed equal to or better than controls. For position players, the only statistics that differed before and after UCLR were workload related (at-bats, plate appearances, WAR), and no differences were seen when compared with controls.

The results of our methodology quality assessment using STROBE scores demonstrated that, on average, the included studies were of high quality. Looking at the results more closely, it was found that 3 of the 29 studies met the "study design" category (presented key elements of the study design early in the article). It was also found that 13 of 29 met the "main results" category (gave unadjusted estimates and/or confounder-adjusted estimates and their precision; reported category boundaries; and translated estimates of the relative risk into absolute risk). Title/abstract, background/rationale, objectives, setting, participants, study size, quantitative variables, statistical methods, key results, and limitations were met by all 29 studies.

MLB pitchers returned to play after primary UCLR at rates of 80% to 97% at a mean of 12 months.[16,22,23,25,28,34,40,41] RTSP was less frequent, with 67% to 87% of MLB pitchers returning in about 15 months.[16,22,23,25,28,34,40,41] These results do demonstrate variability in the RTP and RTSP rates. When returning to play at a professional level, several things need to be considered that could contribute to this variability: age of the pitcher, role in the organization (starter, reliever, and closer), additional injuries (bone spurs, chondral defects, valgus extension overload, etc), and comorbidities. In addition, extra time is required to return to the MLB level, as players can spend weeks or months in MiLB preparing for Major League play.

In an attempt to limit the injury risk of pitchers after UCLR, the pitching workload was often decreased during the first season after surgery.[16,32,33] Even after a structured throwing program is completed throughout rehabilitation, some tissues still may not be prepared to return to normal workloads. Disregarding the need to decrease workloads could result in worse pitching performance[34] and injuries.[32,53] However, when compared controls, pitchers who underwent UCLR had ERA and WHIP statistics equal to[23,28,34,39] or better than[16] controls. This may be caused by several factors, such as the integrity of the surgical procedure, decreased workloads after UCLR allowing pitchers to limit fatigue, or strengthening during the rehabilitation process.

Although it is often assumed that fastball velocity increases after primary UCLR, 4[28,35,39,51] of 7 studies[28,31,35,39,42,48,51] found that it actually decreased. Interestingly, following primary UCLR fastball usage was also shown to decrease in 4[35,39,42,47] of 5 studies[35,39,42,47,48]. Fastballs account for the largest forces of any pitch type,[20] and therefore, a decrease in fastball usage may help lessen the load frequency to the newly reconstructed ligament, allowing for integration and maturation of the graft. Another possible explanation may be that decreased fastball velocity results in less utilization of the pitch because of it not being as effective. Further research will need to be conducted to definitively confirm this.

Catchers may also require close monitoring after UCLR, with catchers (59%-80%)[3,40] returning to play after primary UCLR less frequently than pitchers (80%-97%),[16,22,23,25,28,34,40,41] infielders (76%),[3] and outfielders (89%).[3] Catchers throw much more often than other position players and play in more games than pitchers, possibly explaining their low RTP rates. Catchers are also sometimes required to throw out base runners, requiring maximal effort and accurate throws. Some of these throws are from their knees, requiring more force to be generated from the arm instead of the legs. Adjustments to workload and throwing mechanics may be warranted for catchers after UCLR.

RTP rates were lower after revision UCLR[5,43] than after primary UCLR.[16,22,23,25,28,34,40,41] Keller et al[32] found that pitchers who underwent revision UCLR pitched in more games and threw more pitches in the season after primary UCLR than pitchers who did not require revision surgery. Another study by Keller et al[33] had contradicting results, finding that pitchers who required revision UCLR threw fewer total pitches their first season after primary UCLR compared with pitchers who did not require revision surgery; however, the revision surgery group threw a higher percentage of fastballs, showing the effect that fastball usage has on UCL injury rates. [7,33,50] Suboptimal pitching mechanics and/or poor conditioning that are not corrected after primary UCLR may also increase the chances of needing revision UCLR. Also, pitchers who undergo revision UCLR are frequently older than pitchers who undergo primary UCLR, giving these pitchers a shorter career length and lower chances of RTP. Pitchers who undergo revision UCLR should be monitored similarly to how pitchers are monitored after primary UCLR; however, extra time for workload and throwing intensity progression should be given to a pitcher after revision surgery because of the surgical complications surrounding revision.

This study is not without limitations. First, the majority of studies that included professional players collected data from the MLB database and therefore included overlapping populations (2000-2015, 1990-2010, etc) and likely duplicated participants at times. As we would have liked to conduct a meta-analysis, this was a significant barrier, as any effect size calculated would have had substantial overlap, violating the assumptions of independence in observations within meta-analyses.[36] Second, there was a lack of data on RTP rates and competitive outcomes for younger populations. With such a rise in UCLR procedures performed on youth populations, these data would be valuable for understanding this trend. Because the only included studies that looked at the amateur population focused on players entering the MLB draft, these data cannot be extrapolated to the rest of the youth population. Third, there were inconsistencies in timelines used to collect means. For example, some studies averaged 3 years before and 3 years after UCLR, while some averaged 1 year before and 1 year after UCLR. Finally, only 4 studies featured position players after primary UCLR, only 4 studies featured pitchers after revision

UCLR, and no studies featured position players after revision UCLR. Therefore, the effects of UCLR on RTP and competitive success in pitchers and position players who underwent revision UCLR require additional research.

CONCLUSION

Pitchers returned to play after UCLR in approximately 12 months and generally took longer to return to their same level of play likely because of rehabilitation in lower levels of competition. Pitchers also returned to play less frequently after revision UCLR. After both primary and revision UCLR, professional pitchers experienced decreased workloads and potentially decreased fastball usage as well. Catchers may return to play after UCLR less frequently than pitchers, infielders, and outfielders possibly because of the frequency of throwing in the position. UCLR may only affect offensive workloads (at-bats, plate appearances) and statistics related to at-bats, such as WAR. These results will help guide clinical decision making and patient education when treating UCL tears in baseball players.

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R.L.C. dedicates this research publication to the late Tyler Skaggs. Tyler Skaggs was a beloved friend and fierce competitor pitching for the Los Angeles Angels.

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APPENDIX TABLE A1
Studies Included in Assessment of Competitive Outcomes[a]

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Erickson[14] (2019)	292 MLB + MiLB pitchers with primary UCLR	Strikeouts, hits, walks, home runs, FIP, pitching WAR, ERA, IP, WHIP	Both hamstring and palmaris autograft groups showed performance declines in WAR (0.86 [before UCLR] vs 0.35 [after UCLR] and 1.23 vs 0.34, respectively) and WHIP (1.33 vs 1.44, respectively, and 1.36 vs 1.51, respectively). IP (87.50 vs 68.01, respectively, and 88.42 vs 61.31, respectively) and counting statistics decreased postoperatively. FIP did not decline postoperatively (4.56 vs 5.27, respectively, and 4.51 vs 4.53, respectively).	20

(continued)

APPENDIX Table A1 (continued)

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Erickson[16] (2014)	MLB pitchers with primary UCLR: 179 for RTP analysis + 148 for competitive analysis	ERA, IP, hits, walks, strikeouts, WHIP	Performance declined significantly the year before UCLR (ERA: 7.31; WHIP: 1.79) compared with the year after UCLR (ERA: 3.85; WHIP: 1.35). For the following 3 y after surgery, pitchers with UCLR (ERA: 4.18 ± 1.36; WHIP: 1.39 ± 0.25; hits per inning: 1.01 ± 0.24) performed better than did controls (ERA: 6.36 ± 3.31; WHIP: 1.70 ± 0.46; hits per inning: 1.17 ± 0.34).	22
Erickson[15] (2016)	MLB pitchers: 135 with primary UCLR + 19 with revision UCLR	IP, No. of pitches thrown	There were no differences in IP the season after UCLR or IP during the career after UCLR between pitchers who underwent revision UCLR and those who did not. Also, there were no differences in No. of pitches thrown the season after UCLR or No. of pitches thrown during the career after UCLR.	18
Gibson[23] (2007)	MLB pitchers: 68 with primary UCLR + 112 controls	ERA, WHIP, IP	IP significantly decreased from 97.10 innings the year before surgery to 70.17 innings the year after surgery. ERA and WHIP did not significantly differ, with ERA increasing from 4.12 to 4.21 and WHIP decreasing from 1.362 to 1.356. Controls had a comparable decrease in IP and no change in ERA and WHIP.	17
Jiang[28] (2014)	MLB pitchers with primary UCLR: 38 for RTP analysis + 28 for competitive analysis	ERA, IP, pitch velocity	Fastball pitch velocity decreased significantly every year after surgery (before surgery: 91.5 mph; 1 y after surgery: 89.7 mph; 2 y after surgery: 88.7 mph; 3 y after surgery: 87.7 mph). However, changes in pitch velocity did not differ between pitchers with UCLR and controls. There were no differences in performance measures, such as ERA, BAA, or WHIP, between pitchers with UCLR and controls.	20
Keller[31] (2016)	MLB pitchers: 83 with primary UCLR + 83 controls	Pitch velocity, pitch usage (%), IP	Pitchers with UCLR pitched fastballs significantly more often than did controls (46.7% vs 39.4%, respectively); however, curveball, slider, and changeup usage did not differ. All pitch velocities, as well as IP, before surgery did not differ between pitchers with UCLR and controls.	17
Keller[34] (2014)	MLB pitchers: 168 with primary UCLR + 178 controls	ERA, WHIP, IP	ERA (4.15 vs 4.74, respectively), WHIP (1.40 vs 1.48, respectively), and IP (59.81 vs 50.28, respectively) worsened significantly from before to after UCLR. Performance the year before surgery was significantly worse than performance before and after that year.	19
Lansdown[35] (2014)	80 MLB pitchers with primary UCLR	Walks, strikeouts, FIP, WAR, ERA, IP, WHIP, pitch velocity, pitch usage (%)	Fastball pitch velocity (91.3 mph vs 90.6 mph, respectively), fastball usage (64.8% vs 60.4%, respectively), and IP (83.0 vs 57.3, respectively) significantly decreased from before to after UCLR. Curveball, changeup, and slider velocity, as well as ERA, WHIP, and FIP, did not differ from before to after UCLR.	18
Makhni[39] (2014)	MLB pitchers with primary UCLR: 147 for RTP analysis + 92 for competitive analysis	ERA, IP, WHIP, pitch velocity, percentage of pitches in strike zone, pitch usage (%)	Performance statistics, such as ERA (4.23 vs 4.63, respectively), BAA (0.249 vs 0.257, respectively), WHIP (1.368 vs 1.432, respectively), percentage of pitches in strike zone (51.9% vs 49.6%, respectively), IP (94.3 vs 77.3, respectively), fastball usage (63.9% vs 59.0%, respectively), and fastball pitch velocity (91.2 mph vs 90.8 mph, respectively) declined significantly from the 3 y before to the 3 y after UCLR. However, only percentage of pitches in strike zone (51.4% vs 48.5%, respectively), IP (85.5 vs 72.7, respectively), and fastball usage (62.8% vs 60.4%, respectively) differed significantly when comparing 1y before and 1y after UCLR. These 3 variables also differed when comparing 1y before with 2 y after UCLR. None of these performance variables differed when comparing pitchers with UCLR with controls.	20

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APPENDIX Table A1 (continued)

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Marshall[41] (2019)	MLB pitchers with primary UCLR: 45 for RTP analysis + 43 for competitive analysis	ERA, IP, WHIP, walks, strikeouts, WAR	Performance did not vary between the docking and modified Jobe techniques, as well as between the palmaris and gracilis autografts.	19
Marshall[42] (2018)	46 MLB pitchers with primary UCLR	Pitch velocity, ERA, IP, pitch usage (%), WHIP, walks, strikeouts, hits, home runs, WAR	Before UCLR, pitchers with distal tears (ERA: 3.93; WHIP: 1.32; WAR: 0.9; fastball pitch velocity: 93.0 mph) performed better than did pitchers with proximal tears (ERA: 5.11; WHIP: 1.47; WAR: 0.1; fastball pitch velocity: 90.6 mph). None of these differences were observed after UCLR, but IP was lower in the proximal tear group (58.3) versus the distal tear group (97.9). Pitchers with chronic tears had significantly higher ERA before UCLR (4.49) compared with after UCLR (3.80).	19
Peterson[47] (2018)	87 MLB pitchers with primary UCLR	No. of pitches thrown, pitch usage (%), pitching appearances	Pitching appearances (76.1 vs 62.3, respectively) and No. of pitches thrown (3026.2 vs 2219.9, respectively) decreased from the 2 seasons before UCLR to the 2 seasons after UCLR. Fastball usage also dropped every season, with fastballs accounting for 64.3% of pitches 2 y before, 62.2% 1 y before, 61.6% 1y after, and 61.3% 2 y after UCLR. All other pitch types did not differ significantly in usage.	18
Portney[48] (2017)	MLB pitchers: 50 with primary UCLR + 77 controls	Pitch usage (%), pitch velocity, strikes thrown (%)	No significant differences were observed in pitch usage, pitch velocity, or ball/strike percentage between the index year, 1 y after UCLR, and 2 y after UCLR. No differences were observed between pitchers with UCLR and controls.	20
Selley[51] (2019)	292 MLB pitchers with primary UCLR (192 for competitive analysis)	Hits, walks, strikeouts, home runs, FIP, pitching WAR, ERA, IP, WHIP, pitch velocity, WPA, LI, pitch usage (%), strikes thrown (%)	Performance decreased significantly from before to after UCLR, as shown for ERA (4.37 vs 4.83, respectively), IP (90.0 vs 61.8, respectively), hits per 9 innings (9.07 vs 9.38, respectively), home runs per 9 innings (1.00 vs 1.13, respectively), FIP (4.28 vs 4.57, respectively), WAR (1.13 vs 0.55, respectively), WPA (0.29 vs –0.03, respectively), and LI (1.07 vs 0.96, respectively). Fastball usage (63.9% vs 60.3%, respectively), fastball pitch velocity (91.8 mph vs 90.9 mph, respectively), and percentage of pitches in strike zone (49.2% vs 47.4%, respectively) all decreased significantly from before to after UCLR as well. When comparing statistics before surgery with statistics from years 2 and 3 after surgery, the only significant performance differences were fastball pitch velocity (91.39 mph vs 90.80 mph, respectively) and percentage of pitches in strike zone (49.2% vs 48.0%, respectively).	20
Jones[30] (2013)	14 MLB pitchers with revision UCLR	ERA, IP, strikeouts, and walks for after revision UCLR only; percentage of prerevision UCLR workload achieved from before to after surgery	Relief pitchers achieved 50% of their previous workload, with only 2 of 11 reaching a workload higher than that before revision UCLR (103% and 117% of workload). Starting pitchers achieved 35% of their previous workload, with 0 of 7 exceeding their previous workload.	16
Keller[33] (2017)	MLB pitchers: 29 with revision UCLR + 121 controls with only primary UCLR	IP, No. of pitches thrown, pitch velocity, pitch usage (%)	No differences in games pitched, IP, or No. of pitches thrown were observed between pitchers with revision UCLR and those with primary UCLR only. Fastball pitch velocity also did not differ between groups, but pitchers who required revision UCLR had higher fastball usage (69.5%) than did pitchers who did not require revision UCLR (60.7%).	19

(continued)

APPENDIX Table A1 (continued)

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Keller[32] (2017)	MLB pitchers: 28 with revision UCLR + 137 controls with only primary UCLR	IP, No. of pitches thrown, No. of games pitched	Pitchers who later required revision UCLR pitched near or above their previous workload, while pitchers who did not require revision UCLR decreased their workload after UCLR. Pitchers with revision UCLR increased games pitched by 14.1% and reduced IP by 9.8% after surgery, while those with no revision UCLR decreased games pitched by 13.6% and decreased IP by 26.0%.	17
Liu[37] (2016)	17 MLB pitchers with revision UCLR	ERA, strikeouts, BAA, IP, WHIP, FIP, pitch usage (%), pitch velocity, No. of pitches thrown	ERA, BAA, strikeouts, WHIP, fastball usage, fastball pitch velocity, and FIP did not differ from 3 seasons before to 3 seasons after revision UCLR. IP (83.97 vs 36.95, respectively) and No. of pitches thrown (1356 vs 636, respectively) decreased from before to after revision UCLR.	20
Marshall[43] (2015)	MLB pitchers: 33 with revision UCLR + 33 controls with only primary UCLR	IP, ERA, strikeouts, walks, hits, WHIP, WAR, runs above replacement, runs against per 9 innings	IP (67.18 vs 39.10, respectively), walks per 9 innings (4.02 vs 4.79, respectively), and runs against per 9 innings (4.64 vs 4.45, respectively) worsened significantly from before to after revision UCLR. When comparing the postoperative performance of pitchers with revision UCLR with that of controls, IP (36.95 vs 75.00, respectively) and walks per 9 innings (4.75 vs 3.49, respectively) differed significantly.	21
Begly[2] (2018)	MLB position players: 26 with primary UCLR + 26 controls	At-bats, WAR, isolated power, OPS, batting average, plate appearances	Plate appearances (460 vs 367, respectively), at-bats (460 vs 326, respectively), and WAR based on ±2 seasons (2.3 vs 1.0, respectively) decreased significantly from before to after UCLR, while all other performance statistics did not differ significantly. No performance declines were observed when comparing players with UCLR with controls.	20
Jack[27] (2018)	MLB position players: 33 with primary UCLR + 33 controls	WAR, OPS, plate appearances, batting average, OBP, SLG	No differences were observed between position players with UCLR and controls when comparing both pre- and post-UCLR performance. However, outfielder WAR decreased from 1.5 to 0.8 from before to after UCLR, but all other performance measures did not differ significantly.	20
Marshall[40] (2018)	Professional catchers: 25 with primary UCLR + 25 controls	Offensive: games started, innings played, at-bats, runs, hits, home runs, runs batted in, walks, strikeouts, batting average, OBP, SLG; defensive: errors, fielding percentage, passed balls, bases stolen against, players caught stealing, caught stealing percentage	The only performance statistic that significantly differed was games played from before UCLR (62.2) compared with the first year after UCLR (44.3). Catchers with UCLR had significantly higher SLG (0.40) than did controls (0.37). No other offensive or defensive statistics varied before and after the injury or between the UCLR and control groups.	19
Camp[3] (2018)	Amateur pitchers: 252 with UCLR before draft + 756 controls (50 with UCLR + 92 controls for competitive analysis)	WAR, IP, ERA, WHIP after UCLR only	No post-UCLR performance statistics differed significantly between pitchers with UCLR and their matched controls.	15
Wymore[53] (2016)	Amateur pitchers: 13 with UCLR before draft + 114 controls (38 with UCLR + 29 controls for competitive analysis)	IP, ERA, WHIP, pitch velocity, games, hits, home runs, strikeouts, walks after UCLR only	Home runs allowed per inning differed significantly between pitchers with UCLR (0.07) and their matched controls (0.08). All other performance variables did not differ significantly between pitchers with UCLR and controls.	22

[a]BAA, batting average against; ERA, earned run average; FIP, fielding independent pitching; IP, innings pitched; LI, leverage index; MiLB, Minor League Baseball; MLB, Major League Baseball; OBP, on-base percentage; OPS, on-base plus slugging; RTP, return to play; SLG, slugging percentage; STROBE, STrengthening the Reporting of OBservational studies in Epidemiology; UCLR, ulnar collateral ligament reconstruction; WAR, wins above replacement; WHIP, walks plus hits per inning pitched; WPA, win probability added.

[b]Score of a possible 22 points.

APPENDIX TABLE A2
Studies Included in Assessment of RTP Outcomes[a]

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Camp[5] (2019)	47 MLB + MiLB pitchers with revision UCLR	RTP rate, time to RTP, RTSP rate, time to RTSP	The overall RTP rate was 76.6%; however, the RTSP rate was only 55.3%. On average, pitchers returned in 484 ± 117.3 d, and those who returned to the same level of participation took 518 ± 158.9 d.	20
Erickson[15] (2016)	154 MLB pitchers underwent primary UCLR, 19 of whom later required revision UCLR	Revision rate, innings pitched, No. of pitches thrown	Overall, 12% of pitchers required revision UCLR. No significant differences existed in innings pitched in the season after UCLR or No. of pitches thrown in the season after UCLR. Additionally, no differences existed between pitchers needing revision and those not needing revision for innings pitched during the career and No. of pitches thrown during the career after UCLR.	18
Erickson[13] (2017)	569 professional pitchers with UCLR	Time to RTP, time to RTSP	Time to RTP was not significantly different between the no revision and revision groups (514 ± 225 vs 459 ± 183 d, respectively; $P = .148$). Time to RTSP was also not significantly different between the no revision and revision groups (554 ± 242 vs 476 ± 149 d, respectively; $P = .189$).	19
Jones[30] (2013)	18 MLB pitchers with revision UCLR	RTSP rate, time to RTSP	Overall, 77.8% of the pitchers requiring revision were able to return to the same level within 2 full seasons. Relievers were able to return to MLB approximately 2 mo earlier versus starters (mean time to RTSP, 18.3 vs 19.8 mo, respectively).	16
Liu[37] (2016)	38 MLB pitchers with revision UCLR	Revision rate, time between index surgery and revision, time between revision and RTP	Since 1999, 13.2% of pitchers undergoing UCLR required revision; 65.4% of MLB pitchers who required revision UCLR were able to return to pitching in at least 1 MLB game; however, only 42.3% were able to return to pitching in ≥10 games after revision. On average, MLB pitchers requiring revision UCLR pitched in 74.7 games over 2.64 seasons. The mean time between index and revision UCLR was 5.02 y.	20
Marshall[43] (2015)	33 MLB pitchers with revision UCLR	RTP rate, RTSP rate, MLB seasons after revision	The RTP rate after revision was 84.8%, with the RTSP rate being 65.5% after revision. MLB pitchers requiring revision UCLR, on average, competed in 3.2 MLB seasons (4.1 seasons combining MLB + MiLB) after revision.	21
Erickson[14] (2019)	292 MLB + MiLB pitchers with primary UCLR	RTP rate, time to RTP, RTSP rate, time to RTSP	When comparing autograft types, using a hamstring versus palmaris tendon graft yielded similar RTP rates (72.3% vs 77.4%, respectively) and times to RTP (417.99 ± 162.18 vs 409.22 ± 115.00 d, respectively). Additionally, using hamstring and palmaris tendon autografts demonstrated similar rates of RTSP (61.0% vs 68.7%, respectively) and similar times to RTSP (501.23 ± 230.35 vs 469.53 ± 173.64 d, respectively).	20
Erickson[16] (2014)	MLB pitchers with primary UCLR: 179 for RTP analysis + 148 for competitive analysis	RTP rate, RTSP rate, MLB seasons after primary UCLR	Pitchers undergoing primary UCLR had a 97.2% RTP rate in either MLB or MiLB and an 83.0% RTSP rate. On average, pitchers who returned to any level of baseball competed for 3.89 seasons after UCLR, demonstrating no significant difference when matched with controls.	22
Ford[22] (2016)	43 players from a single professional baseball organization	RTP rate, RTSP rate	Operatively treated injuries had an 87% RTP rate and a 71% RTSP rate.	19

(continued)

APPENDIX Table A2 (continued)

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Gibson[23] (2007)	68 MLB pitchers with primary UCLR	RTSP rate, time to RTSP	Overall, 82% of reconstructed pitchers were able to return to MLB after UCLR, 94% of whom were able to return to MLB within 3 seasons after UCLR. On average, players returned to MLB in 18.5 mo (range, 10-49mo) after surgery.	17
Griffith[25] (2019)	566 professional pitchers with primary UCLR	RTP rate, time to RTP, RTSP rate, time to RTSP	Overall, 79.9% of professional pitchers requiring UCLR were able to RTP, with 71.2% being able to RTSP. MLB pitchers were more likely to RTP ($P < .001$) and RTSP ($P < .001$) versus MiLB pitchers. RTP took a mean of 436 ± 146 d (range, 168-1643d), and RTSP took a mean of 518 ± 202 d (range, 173-1414d). There were no differences in RTP based on the surgical technique or graft type used. Similarly, there were no differences in RTSP based on technique or graft type.	19
Jiang[28] (2014)	38 MLB pitchers with primary UCLR	RTP rate, RTSP rate, time to RTSP	Overall, 97% of pitchers were able to RTP after primary UCLR, while 79% were able to return to pitching at the MLB level. For those who returned at the MLB level, it took a mean of 17.1 mo (range, 11-27 mo).	20
Keller[34] (2014)	168 MLB pitchers with primary UCLR	RTP rate	Overall, 87% of MLB pitchers undergoing primary UCLR were able to return to MLB pitching. Pitchers who were able to RTP noted a decline in performance statistics upon returning.	19
Makhni[39] (2014)	147 MLB pitchers with primary UCLR	RTP rate, RTSP rate	Of pitchers who pitched in >10 games per season (established) before surgery, only 66% of pitchers were able to RTSP, with only 12% able to return to pitching for 1-10 games per season after surgery. Also, 21% of established pitchers before surgery did not return to MLB play.	20
Marshall[41] (2019)	46 MLB pitchers with primary UCLR	RTP rate, RTSP rate, time to return	Overall, 96% of pitchers were able to RTP after surgery, with 82% of pitchers able to return to pitching at the MLB level. On average, it took 13.7 mo (range, 10-23 mo) to RTP.	19
Marshall[42] (2018)	46 MLB pitchers with primary UCLR	RTP rate, RTSP rate, time to return	Overall, 96% of pitchers were able to RTP after surgery, with 82% of pitchers able to return to pitching at the MLB level. On average, it took 13.7 mo (range, 10-23mo) to RTP. Pitchers were able to compete for a mean of 3.2 y in MLB and 4.6 y total after UCLR.	21
Begly[2] (2018)	26 MLB position players with primary UCLR	RTSP rate	The overall RTP rate was 80%. For infield players, 90% were able to return to MLB play. For outfield players, 87.5% were able to return to MLB play. However, for catchers, only 56% were able to return to MLB play.	20

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APPENDIX Table A2 (continued)

Lead Author (Year)	Participants	Outcome Measures	Major Results	STROBE Score[b]
Camp[3] (2018)	167 MLB position players with primary UCLR	RTP rate, RTSP rate, time to return	The overall RTP rate after UCLR at any level for all positions was 76.2%. For catchers, 58.6% returned to play at any level, taking a mean of 363 ± 121.6 d. Only 50.0% of catchers returned to the MLB level, taking a mean of 423 ± 215.8 d. For infielders, 75.6% were able to RTP at any level, taking a mean of 294 ± 87.1 d. Additionally, 77.8% of infielders were able to return to the MLB level, taking a mean of 357 ± 232.6 d. For outfielders, 88.9% were able to return at any level, taking a mean of 375 ± 144.0 d. Moreover, 74.1% of outfielders were able to return to MLB play, taking a mean of 392 ± 147.0 d. Catchers undergoing UCLR were less likely to RTP or RTSP compared with outfielders and infielders.	15
Jack[27] (2018)	33 MLB position players with primary UCLR	RTSP rate, time to return, age	Overall, 84.8% of position players were able to RTP at the MLB level, taking a mean of 336.9 ± 121.8 d after UCLR. Players aged ≥30 y had a 53.3% rate of returning to MLB compared with 89.4% returning to MLB for players aged <30 y ($P = .018$). Older position players were less likely to RTP at the MLB level compared with younger position players. For catchers, 71.4% were able to return to MLB play at a mean of 280.0 ± 100.2 d. For infielders, 91.7% were able to return to MLB play at a mean of 362.4 ± 144.9 d. For outfielders, 85.7% were able to return to MLB play at a mean of 337.3 ± 107.4 d. Catchers returned to MLB play at a lower rate compared with infield and outfield players. Catchers returned earlier than did infielders and outfielders.	20
Marshall[40] (2018)	25 professional catchers with primary UCLR	RTP rate, RTSP rate, time to RTSP, years played after injury	Catchers had an overall RTP rate of 80%, taking a mean of 12.9 ± 5.5 mo. Of the catchers able to RTP, 95% were able to RTSP. Catchers undergoing primary UCLR were able to participate for 4.3 ± 2.4 y after their injury.	19

[a]MiLB, Minor League Baseball; MLB, Major League Baseball; RTP, return to play; RTSP, return to the same level of play; UCLR, ulnar collateral ligament reconstruction.

[b]Score of a possible 22 points.