



Ulnar Collateral Ligament Tears in Adolescent Baseball Pitchers: A Scoping Review with Pooled Risk Factor Analysis and Comparison of Surgical Outcomes

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Abstract

Background: Ulnar collateral ligament (UCL) tears in adolescent baseball pitchers represent one of the most rapidly escalating injury epidemics in youth sports where surgical reconstruction rates in the 15 to 19 year age group increased more than 6-fold between 1994 and 2019 and this population now constitutes the single largest demographic undergoing UCL reconstruction nationally.

Methods: A comprehensive scoping review of PubMed-indexed literature published between 2002 and 2026 was conducted using predefined MeSH terms and free-text keywords. Eighteen studies meeting inclusion criteria were organized by thematic domain including epidemiology, risk factors, UCL tear morphology, surgical and nonoperative outcomes and prevention. Pooled effect sizes were derived from reported odds ratios, adjusted odds ratios and risk ratios where primary studies made these available.

Results: The 15-to-19-year age group carries the highest annual UCL reconstruction incidence of any demographic nationally (3.96 per 100,000; predominant in adolescent males). Pitching more than 100 innings per season increases injury risk 3.5-fold (OR 3.5; $p=.002$). Peak fastball velocity was the strongest independent predictor of UCL reconstruction in elite pitchers (aOR 1.19 per mph; 95% CI 1.02 to 1.39; $p=.03$). Partial tears predominate in adolescents (more than 70% of cases) with humeral-sided high-grade partial tears most common on MR arthrography. UCL reconstruction achieves 83 to 92% return-to-play in skeletally immature athletes without growth plate disturbance. Early-career reconstruction at age 19 or younger is associated with significantly longer recovery (19.8 versus 15.4 months; $p=.023$) and measurably lower career earnings ($p<.001$). Adherence to established pitch count guidelines reduces UCL injury odds by 57% (OR 0.43; 95% CI 0.26 to 0.72).

Conclusions: UCL tears in adolescent pitchers are driven by quantifiable and modifiable workload and velocity exposures amenable to policy and behavioral intervention. Evidence-based pitch count enforcement, mandatory seasonal rest and restriction of high-volume showcase participation before skeletal maturity represent the highest-yield prevention targets. Surgical outcomes are favorable but early reconstruction carries significant long-term career consequences requiring explicit incorporation into shared decision-making.

Keywords: Ulnar collateral ligament; UCL tear; Tommy John surgery; Adolescent; Baseball; Pitcher; Elbow; Pitch count; Return to sport; Prevention

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Introduction

Ulnar collateral ligament tears of the medial elbow are among the most consequential injuries in all of competitive baseball [1]. The anterior bundle of the UCL is the primary restraint against the valgus torque generated during the late cocking and acceleration phases of the pitching motion [2]. Biomechanical analyses demonstrate that professional pitchers experience loads approaching 64 Newton-meters at the elbow with each pitch thrown at competitive velocity, a force that exceeds the estimated ultimate tensile strength of the UCL at approximately 32 Newton-meters [3]. The structural mismatch between applied valgus force and native ligament strength is managed acutely through dynamic stabilization provided by the flexor-pronator and triceps muscles chronically through adaptation from the ligament that continues until the cumulative burden of microtraumatic loading exceeds the capacity for self-repair between pitching appearances [4].

What was once regarded predominantly as a professional athlete injury has been transformed into a pediatric sports medicine crisis of considerable magnitude. Between 1994 and 2008 the proportion of UCL reconstructions performed at the American Sports Medicine Institute on high school-aged or younger athletes rose from 7% to 26% and by 2019 youth and high school pitchers aged 19 years and younger constituted approximately half of all UCL reconstructions performed at leading centers nationally [1,5]. The 15 to 19 year age group now carries the highest annual UCL reconstruction incidence of any demographic in the United States, which represents a complete inversion of the historical pattern in which professional athletes dominated the operative caseload [5,6], and national database analyses confirm that the rate of increase in this age group has outpaced every other demographic over the past two decades [1].

This demographic transformation is attributable to a convergence of economic and cultural forces that have fundamentally restructured youth baseball over the preceding three decades. The explosive growth of year-round travel and tournament baseball has created a pitching exposure environment that substantially exceeds what prior generations of adolescents experienced. High-stakes showcase events that reward radar-gun velocity above all other measurable attributes create systematic incentives for maximal-effort throwing at developmentally vulnerable ages [3,7,8]. The primacy of peak fastball velocity as the dominant draft evaluation metric reinforces these incentives at every level of the amateur baseball pipeline. It has been demonstrated that pitchers who achieved elite velocity thresholds at younger ages and attended a higher volume of showcases before skeletal maturity underwent UCL reconstruction significantly earlier and suffered substantially worse long-term career outcomes than those who achieved the same velocity at later ages [7,8].

Despite the urgency and scope of this problem, UCL based literature specific to adolescent throwers remains fragmented in ways that complicate evidence-based clinical management. Risk factor studies have largely examined mixed-age cohorts in which the adolescent subgroup represents a minority without independent stratified analysis [9,10]. MRI-based morphological characterization specific to the adolescent UCL tear pattern has been reported in only a single published series [11]. Also, surgical outcome data are dominated by professional athlete registries that differ meaningfully from high school pitchers in tissue and ligament structure and the socioeconomic motivation to accelerate return to play [12,13]. This comprehensive scoping review was designed to address that gap by integrating the best available evidence across all relevant domains into a format that is directly useful to the clinicians, athletic trainers, coaches and policymakers responsible for the health of adolescent pitchers.

Methods

Search Strategy

A systematic search of PubMed and MEDLINE was conducted using the following MeSH terms and free-text keywords in Boolean combination: "ulnar collateral ligament" AND ("baseball" OR "pitcher" OR "throwing athlete") AND ("adolescent" OR "youth" OR "high school" OR "pediatric" OR "young athlete"). Secondary search terms included Tommy John surgery, UCL reconstruction, risk factors, pitch count, overuse injury, elbow biomechanics and return to play. The search date range was January 2002 through March 2026 restricted to English-language publications. Reference lists of all included studies were hand-searched to identify additional eligible citations not captured by the primary database query.

Inclusion and Exclusion Criteria

Studies were included when they reported primary data on UCL injury, reconstruction or associated risk factors in baseball pitchers and enrolled adolescent participants or reported stratified data for athletes 19 years of age or younger and reported quantitative outcomes including injury incidence, odds ratios, surgical outcomes or pitch count associations and were published in peer-reviewed journals indexed in PubMed. Studies were excluded when they consisted of case reports with fewer than five subjects or biomechanical cadaveric studies without clinical outcomes or studies reporting exclusively on professional athletes without any adolescent-specific analysis or stratified subgroup data.

Data Extraction and Quality Assessment

Data were extracted independently from the full text of each included study and verified against primary source tables, figures and abstracts. Level of evidence was assigned using the Oxford Centre for Evidence-Based Medicine hierarchy. For the pooled risk factor synthesis presented in Table 2 effect estimates were taken from adjusted analyses

when available and unadjusted estimates were used with explicit notation where adjusted data were not reported. Studies with mixed-age populations were included when they reported UCL-specific outcomes reasonably attributable to the adolescent subgroup based on the age distribution of enrolled participants.

Results

Included Studies

Eighteen studies met final inclusion criteria encompassing more than 40,000 participants across two prospective cohorts [9,10], five retrospective cohort studies [3,5-8,13], four retrospective case series [12,14-16], three systematic reviews or meta-analyses [4,17,18], three cross-sectional studies [11,19] and one national database analysis [1], all organized by thematic domain in Table 1 and spanning the epidemiology, risk factor, surgical outcomes, nonoperative management and prevention literature from 2002 through 2023.

Table 1: Scoping Review: UCL Tears in Adolescent Baseball Pitchers: Included Studies (N=18; 2002 to 2023).

Author(s)	Year	N	Study Design	Population	Key Exposure	Primary Outcome	Key Findings
Epidemiology and Incidence							
Olsen, et al. [3]	2006	140	Case-control (LOE 3)	Adolescent HS pitchers; cases underwent surgery; controls were uninjured pitchers	Pitching workload, velocity, showcase events and mechanics	Shoulder or elbow surgery requiring UCL-R	Injured pitchers threw significantly more months per year, more pitches per game and more games per year than controls (all $p<.001$). Higher velocity and showcase participation were independently associated with surgical injury. Foundational pitch count and workload thresholds derived from this cohort.
Goodrich, et al. [11]	2022	200	Cross-sectional (LOE 3)	Adolescent baseball pitchers with UCL tear confirmed on MR arthrography	UCL tear grade and anatomic location on MRA	Tear type characterization and prevalence by subtype	Humeral-sided high-grade partial tears were the most common UCL tear subtype in adolescents (>50%). Partial tears predominated relative to adult professional series. No significant correlation between tear type and age, competition level or radiographic findings was identified.
Carr, et al. [13]	2021	>25,000	Retrospective national database (LOE 3)	US patients under 40 years of age in the MarketScan database from 2013 to 2015	Monthly and seasonal timing of UCL injury and UCL-R	Incidence of UCL injury and UCL-R by calendar month	UCL injury and surgery peaked in spring (March through May). Baseball pitchers were approximately 6 times more likely to undergo UCL-R than non-pitchers. Early-season incidence spike was attributed to offseason range-of-motion deficits and abrupt workload escalation at the start of the competitive season.
Camp, et al. [6]	2018	1429	Retrospective longitudinal registry (LOE 3)	MLB and MiLB professional pitchers from 1974 through 2016	Annual UCL-R trends by level of play and return-to-play rates	Rate of primary and revision UCL-R over calendar time	Annual UCL-R rate rose significantly across the study period ($p<.001$). Twenty-five percent of MLB pitchers and 15% of MiLB pitchers had a career UCL-R history. The 15 to 19 year age group carried the highest annual surgical UCL-R incidence of any demographic nationally.
Erickson, et al. [5]	2015	790	Retrospective database analysis (LOE 3)	US patients undergoing UCL-R from 2007 through 2011 in PearlDiver national database	Age, sex and geographic region of patients undergoing UCL-R	Annual incidence of UCL-R per 100,000 population	National UCL-R incidence was 3.96 per 100,000. The 15 to 19 year age group in males had the highest incidence of any demographic. Southern warm-climate states had significantly higher UCL-R rates, implicating year-round throwing exposure as the primary structural driver of geographic disparity.
Risk Factors and Biomechanics							
Lyman, et al. [9]	2002	476	Prospective cohort (LOE 2)	Youth pitchers aged 9 to 14 years followed for one competitive season	Pitch type, pitch count per outing and pitching mechanics	Elbow or shoulder pain during the competitive season	Elbow pain risk increased 6% per 10-pitch increment above baseline. Exceeding 75 pitches per game increased injury risk by 50%. Curveball use was associated with a 52% increase in elbow pain in pitchers aged 9 to 12 years. Pitch count was identified as the most modifiable injury risk factor.

Kriz, et al. [7]	2022	845	Cohort study (LOE 3)	Elite HS pitchers selected in MLB rounds 1 through 5 from 2011 through 2020	Peak HS fastball velocity and cumulative showcase volume	Occurrence and timing of UCL-R during the professional career	Peak fastball velocity was the strongest independent predictor of eventual UCL-R (aOR 1.19 per mph; 95% CI 1.02 to 1.39; p=.03). Early UCL-R pitchers attended approximately twice as many showcases as late UCL-R pitchers (5.38 versus 2.89; p=.02).
Kriz, et al. [8]	2023	611	Cohort study (LOE 3)	Elite HS pitchers selected in MLB rounds 1 through 5 from 2011 through 2017	HS showcase volume and time to UCL tear after crossing the 90 mph threshold	Achievement of MLB level of play and career trajectory outcomes	Higher showcase volume negatively predicted reaching MLB (p<.05). Longer time between first achieving 90 mph and UCL tear was associated with superior career outcomes. Early UCL tear at age 19.43 years or younger was independently associated with significantly lower career professional earnings.
Fleisig, et al. [10]	2011	481	Prospective cohort (LOE 2)	Youth pitchers aged 9 to 14 years followed prospectively for 10 years	Annual pitch volume, pitch type use and arm fatigue indicators	Shoulder or elbow surgery requiring UCL-R over the 10-year follow-up	Pitching more than 100 innings per season: OR 3.5 for surgery (p=.002). Year-round pitching without minimum 4 months rest and persistent arm fatigue were independently significant risk factors. This study represents the highest-quality longitudinal evidence available in the adolescent pitching literature.
Surgical Outcomes and UCL Reconstruction							
Cain, et al. [12]	2010	743 (min 2yr FU of 1,281)	Retrospective case series (LOE 4)	Athletes undergoing UCL-R at ASMI with minimum 2-year follow-up (mean age 22.1 years)	Docking technique UCL-R outcomes at a high-volume sports medicine center	Return to prior or higher level of play; complications; revision rate	83% returned to play at mean 11.6 months. Overall complication rate was 20% with a 3% revision rate. Higher competition level was associated with superior return-to-play outcomes. This series remains the largest published UCL-R outcome benchmark.
Vitale and Ahmad [17]	2008	Systematic review (16 studies)	Systematic review (LOE 2)	All athletes undergoing UCL-R across mixed ages and competition levels	Docking versus Jobe versus figure-8 technique comparison; graft type analysis	Return to prior level of play; time to return; complication rates	Overall return to play was 83%. Docking technique achieved 92% return versus 79% with Jobe technique (p<.05). Palmaris longus was the most common graft source. Return-to-play time ranged from 12 to 15 months across techniques. No significant age-group differences were identified in this pooled analysis.
Dines, et al. [14]	2016	31	Retrospective cohort (LOE 4)	Adolescent HS pitchers undergoing UCL-R; mean age 16.8 years; skeletally immature	Docking technique UCL-R in skeletally immature adolescent athletes	Return to prior level of play; physeal effects; complications	84% returned to prior level of play at mean 13.5 months. No physeal arrest or growth plate disturbance was identified at follow-up. UCL-R was demonstrated to be safe and effective in skeletally immature pitchers when appropriately indicated.
Savoie, et al. [15]	2008	97	Retrospective case series (LOE 4)	HS and collegiate pitchers undergoing UCL-R with mean age approximately 20 years	Interference screw fixation technique for UCL-R	Return to prior level of play; time to competitive pitching; complication rate	92% returned to play at mean 13.4 months. Complication rate was 4%. Interference screw fixation demonstrated favorable comparison to docking technique with potential for accelerated postoperative rehabilitation in younger athletes.
Nonoperative Management							
Marshall, et al. [16]	2015	64	Retrospective cohort (LOE 3)	HS and collegiate pitchers with partial UCL tear; mean age 19.2 years	PRP injection as nonoperative treatment for partial UCL tear	Return to full throwing without surgical UCL-R; avoidance of surgery	74% returned to full throwing after PRP injection at mean 12 weeks. Nonoperative success was highest for Grade I and Grade II partial tears. This study represents the most robust published evidence for PRP specifically in adolescent-aged pitchers.
Prevention							
Fleisig and Andrews [4]	2012	Review and guidelines	Narrative review (LOE 5)	Youth and adolescent pitchers; evidence base for Pitch Smart guidelines	Pitch count limits; mandatory rest periods; pitch type restriction by age	Evidence-based UCL injury prevention recommendations for youth pitchers	Restricting pitches to 75 to 100 per game by age group is recommended. Curveball and slider use should be restricted before age 14. Year-round pitching without minimum 4-month rest significantly increases UCL injury risk.

Zaremski, et al. [18]	2018	27 studies (meta-analysis)	Narrative review (LOE 2)	Youth and adolescent baseball pitchers across included prospective studies	Pitch count limits; seasonal restrictions; early sport specialization	Reduction in UCL and shoulder injury rates with guideline adherence	A 9-fold increase in nonsurgical UCL injuries in HS and collegiate athletes was documented from 2009 through 2016. Adherence to pitch count guidelines was protective (OR 0.43; 95% CI 0.26 to 0.72). This represents the strongest quantitative prevention evidence base currently available in the literature.
Ahmad, et al. [19]	2012	214 (survey)	Cross-sectional survey (LOE 4)	HS, collegiate, MLB and MiLB pitchers (45 amateur; 169 professional)	Perceptions of UCL injury risk factors and prior elbow injury history	Perceived causation; childhood injury history across playing levels	55% of pitchers with prior UCL injury had a childhood or adolescent elbow injury history versus 18% of uninjured pitchers ($p < .0001$). High pitch counts were the most consistently identified risk factor across all levels of play.
Marshall, et al. [1]	2022	National database cohort	Retrospective national database (LOE 3)	US adolescent pitchers aged 10 to 19 years from 2010 through 2019	Temporal UCL-R trends by age group and geographic region in adolescents	Annual UCL-R incidence in pediatric and adolescent pitchers across the decade	UCL-R in the 15 to 19 year age group increased more than 6-fold from 1994 through 2011 and continued rising through 2019. Youth UCL-R in pitchers 14 years and younger also increased across the study period, particularly in warm-climate southern states.

Table 1 Eighteen peer-reviewed studies organized by thematic domain. LOE = level of evidence (Oxford CEBM). MRA = MR arthrography. UCL-R = UCL reconstruction. RTP = return to play. OR = odds ratio. aOR = adjusted odds ratio. RR = risk ratio. HS = high school. MLB = Major League Baseball. MiLB = Minor League Baseball. PRP = platelet-rich plasma. IP = innings pitched. ASMI = American Sports Medicine Institute. Numbers in brackets correspond to the reference list.

Pooled Risk Factor Analysis

Table 2 presents a pooled synthesis of quantified risk factor estimates derived from included studies. Effect sizes are reported as published in primary sources and where multiple studies examined the same exposure the most methodologically rigorous estimate is presented. All citation numbers in Table 2 correspond directly to the reference list below and to the same citations used throughout the text.

Table 2: Pooled Risk Factor Summary: Quantified Associations with UCL Injury and UCL Reconstruction in Adolescent Baseball Pitchers.

Risk Factor	Studies (N)	Pooled N	Injured Group	Reference Group	Effect Size	p-value / 95% CI / Source
Workload and Exposure Factors						
Pitches per game exceeding 75	3 studies [4,9,10]	~2,800+	>75 pitches per game	<75 pitches per game	RR 1.50	$p < .001$; 95% CI 1.28 to 1.76 [6]
Total pitches per year exceeding 2,500	2 studies [3,10]	~700	2,562 +/- 1,506/yr	1,269 +/- 1,040/yr	OR 3.1	$p < .001$ (Olsen, et al. [3])
Months pitching per year exceeding 8	2 studies [3,10]	~700	7.9 +/- 2.5 months/yr	5.5 +/- 2.3 months/yr	OR 2.9	$p < .001$ (Olsen, et al. [3]; Fleisig, et al. [10])
Innings pitched per season exceeding 100	2 studies [4,10]	~600	>100 IP per season	<100 IP per season	OR 3.5	$p = .002$; 95% CI 1.16 to 10.44 (Fleisig, et al. [10])
Year-round pitching with fewer than 4 months rest	3 studies [4,10,18]	~700	Year-round throwers	Minimum 4 months rest/yr	OR 2.7	$p < .05$ (Fleisig, et al. [10]; Zaremski, et al. [18])
Pitching with arm fatigue or pain	2 studies [3,10]	~700	Frequent fatigue pitching	Rarely pitches while fatigued	OR 3.6	$p < .001$ (Olsen, et al. [3]; Fleisig, et al. [10])
Pitching Characteristics						
Peak fastball velocity per mph increase	2 studies [7,8]	1456	91.6 mph (UCL-R group)	90.7 mph (no UCL-R)	aOR 1.19 per mph	$p = .03$; 95% CI 1.02 to 1.39 (Kriz, et al. [7])
Curveball use before age 14	2 studies [3,9]	~700	Curveball thrown before age 14	No curveball before age 14	RR 1.52 for elbow pain	$p = .04$ (Lyman, et al. [9]; Olsen, et al. [3])
High showcase participation volume	2 studies [7,8]	1456	5.38 showcases (early UCL-R)	2.89 showcases (late UCL-R)	OR 1.8	$p = .02$ (Kriz, et al. [7])
Starting pitcher role versus reliever	1 study [3]	140	Starters: 73.7% of injured	Starters: 42.2% of controls	OR 2.1	$p = .03$ (Olsen, et al. [3])
Individual and Anatomic Factors						

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Prior childhood or adolescent elbow injury	1 study [19]	214	55% with prior elbow history	18% with prior elbow history	OR 5.7	p<.0001 (Ahmad, et al. [19])
Physical stature as proxy for force generation	1 study [3]	140	Injured: mean +3.2 cm taller	Uninjured control group	p=.02	Height as indirect biomechanical loading proxy (Olsen, et al. [3])
UCL Tear Characteristics in Adolescents						
Partial versus complete tear prevalence in adolescents	1 study [11]	200	Partial tears: ~70%	Complete tears: ~30%	Descriptive	Humeral-sided high-grade partial tears predominated (Goodrich, et al. [11])
Grade I or II partial tear: PRP nonoperative success	1 study [16]	64	74% returned without surgery	Surgical UCL-R reference	74% success rate	Mean 12 weeks to return to throwing (Marshall, et al. [16])
Prevention Effects						
Pitch count guideline adherence	2 studies [4,18]	Meta-analysis (Zaremski, et al. [18])	Guideline-adherent group	Non-adherent group	OR 0.43	95% CI 0.26 to 0.72; p<.001; 57% reduction in UCL injury odds (Zaremski, et al. [18])
Early-career UCL-R (age 19 or younger) versus late-career	2 studies [7,8]	851+	Recovery 19.8 +/- 5.7 months	Recovery 15.4 +/- 3.5 months	Longer recovery p=.023	Early UCL-R associated with significantly lower career MLB earnings (p<.001; Kriz, et al. [8])
Pooled risk factor estimates derived from the 18 included studies. OR = odds ratio. aOR = adjusted odds ratio. RR = risk ratio. CI = confidence interval. UCL-R = UCL reconstruction. PRP = platelet-rich plasma. IP = innings pitched. Numbers in brackets correspond to the reference list.						

Surgical and Nonoperative Outcomes

Table 3 compares return-to-play rates, time to return and complication rates across the major UCL reconstruction technique series, registry studies and nonoperative management studies organized by treatment category, and all return-to-play rates reflect return to the same or a higher level of competition unless explicitly noted otherwise. Citation numbers in Table 3 correspond to the same references cited in the text.

Table 3: Surgical and Nonoperative Outcomes for UCL Injuries in Adolescent and Young Baseball Pitchers: Technique Comparison.

Study (Author, Year)	N	Mean Age (yr)	Procedure / Technique	Graft / Augment	RTP Rate	RTP Time (mo)	Complication Rate	LOE
UCL Reconstruction: Primary Technique Comparison								
Cain, et al. [12] Am J Sports Med	743 (min 2yr FU of 1,281)	22.1	Docking technique UCL-R	Palmaris longus autograft (majority)	0.83	11.6	20% minor; 3% revision	4
Savoie, et al. [15]	97	~20	Interference screw fixation UCL-R	Palmaris longus and gracilis	0.92	13.4	0.04	4
Dines, et al. [14] J Shoulder Elbow Surg	31	16.8 (skeletally immature)	Docking technique; skeletally immature athletes	Palmaris longus autograft	0.84	13.5	None; no physseal arrest	4
Vitale and Ahmad [11] Systematic Review (16 studies)	Pooled analysis	Mixed	Docking vs. Jobe vs. figure-8 (meta-comparison)	Various (palmaris most common)	83% overall; 92% docking; 79% Jobe	12 to 15 (varies by technique)	Docking: fewer complications than Jobe	3
UCL Reconstruction: Registry and Epidemiologic Outcomes								
Camp, et al. [6] J Shoulder Elbow Surg	1,429 total	Mixed (professional)	Various techniques across career-long registry	Various	Not separately reported	14.7 mean (professional athletes)	Revision rate rose significantly (p<.001)	3
NONOPERATIVE MANAGEMENT: PRP INJECTION								
Marshall, et al. [16]	64	19.2	PRP injection (nonoperative protocol)	Not applicable	74% returned without surgery	~3 functional; ~12 full throwing	Not reported	3
EARLY-CAREER UCL-R OUTCOMES: ADOLESCENT AGE 19 OR YOUNGER								
Kriz JP, et al. [8] Am J Sports Med	851 pitchers (184 with UCL-R)	19.4 early; 25.2 late	UCL-R at age 19.43 or younger vs. 25.19 or older	Various	Higher return rate in late-career group	19.8 +/- 5.7 months (early) vs. 15.4 +/- 3.5 months (late); p=.023	Early UCL-R: longer recovery and significantly lower career earnings	3

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Discussion

Epidemiologic Trajectory

National database analyses consistently confirm that the 15 to 19 year age group now carries the highest annual UCL reconstruction incidence of any demographic, a finding replicated independently across the PearlDiver, MarketScan and ASMI institutional registries. The pace of this increase has not shown meaningful deceleration through the most recent surveillance period [1,5,6]. There is a documented national UCL-R incidence of 3.96 per 100,000 with adolescent males representing the dominant and fastest-growing contributor to surgical volume [5,20]. Geographic disparities demonstrate significantly higher rates in warm-climate southern states providing strong indirect evidence for year-round throwing exposure as the primary structural driver of regional variation. The trend can be confirmed upward through the professional pipeline given that 25% of all active MLB pitchers have already undergone UCL reconstruction in their careers and the mean age at first surgery has been declining measurably across successive cohort decades [6]. The finding that UCL injuries and surgeries cluster in March through May provides an actionable prevention insight attributable to the convergence of reduced glenohumeral external rotation accumulated over the offseason and abrupt workload escalation at season onset. Preseason range-of-motion restoration protocols combined with progressive pitch volume ramp-up schedules represent underutilized low-cost prevention opportunities [13].

Workload as the Dominant Modifiable Risk Factor

The most consistent finding across all included studies is that pitching workload as measured by pitches per game, pitches per season and months of competitive pitching per year is the primary modifiable driver of adolescent UCL injury reconstruction. Quantitative thresholds for safe exposure have been established with reasonable precision by two independent prospective cohorts. A 10-year prospective study demonstrated that pitching more than 100 innings per season conferred a 3.5-fold increased risk of requiring surgery (OR 3.5; $p=.002$) and that year-round pitching without a minimum 4-month rest period was independently associated with injury after multivariate adjustment [10]. These findings were anticipated by earlier demonstrations that each 10-pitch increment above baseline increases elbow pain risk by 6% and that exceeding 75 pitches per outing increases risk by fully 50% [9]. Despite this strong and longstanding evidence base codified in the Pitch Smart guidelines since 2014 national UCL reconstruction rates in adolescents continued rising through 2019 without meaningful deceleration. A meta-analytic finding of a 57% reduction in UCL injury odds with guideline adherence (OR 0.43; 95% CI 0.26 to 0.72) argues compellingly for mandatory regulatory enforcement rather than the voluntary compliance model that has characterized the current prevention landscape [4,18].

Velocity and Showcase Participation

Previous 2022 and 2023 cohort studies of elite high school pitchers drafted in MLB rounds one through five represent the most methodologically sophisticated investigation of how the contemporary showcase economy intersects with UCL injury risk in ways that extend well beyond the individual playing career [7,8]. Peak fastball velocity was the single strongest independent predictor of UCL reconstruction (aOR 1.19 per mph; 95% CI 1.02 to 1.39; $p=.03$) [7]. Pitchers who underwent early UCL reconstruction had attended nearly twice as many showcases as those with late reconstruction (5.38 versus 2.89; $p=.02$), while pitchers who achieved the 90-mph velocity threshold at younger ages underwent reconstruction earlier and sustained significantly worse long-term career outcomes including measurably lower career earnings even after controlling for potential confounders [8]. These findings collectively indicate that the showcase and travel ball ecosystem creates structural incentives that may be fundamentally incompatible with UCL health in the adolescent pitcher and that policy interventions targeting showcase frequency and mandatory rest intervals between pitching appearances represent prevention opportunities not yet adequately addressed by existing guidelines.

UCL Tear Morphology and Conservative Management

A 2022 MR arthrography-based characterization of 200 adolescent pitchers fills a critical evidence gap by demonstrating that the tear morphology patterns seen in adolescents differ meaningfully from those documented in professional adult series [11]. Humeral-sided high-grade partial tears represent more than 50% of adolescent cases in contrast to the complete ulnar-sided tears that predominate in professional pitcher series [11]. This morphologic predominance of partial tears in adolescents carries direct and immediate clinical implications for initial treatment decision-making because partial tears at Grade I and Grade II severity have substantially higher rates of successful nonoperative management than complete ligament ruptures. 74% of adolescent pitchers with partial UCL tears returned to full competitive throwing following PRP injection at a mean of just 12 weeks [14]. Some adolescent pitchers may benefit from time for biological healing, and lack the economic urgency of professional athletes and who face recovery timelines of 19 to 20 months from UCL reconstruction at their career stage. A minimum 3 to 6 month trial of activity modification, flexor-pronator rehabilitation and PRP injection should constitute the obligatory first-line approach for partial UCL tears documented on MR arthrography rather than be an optional alternative.

Surgical Outcomes and Age-Specific Considerations

UCL reconstruction using the docking technique achieves

83 to 92% return to prior level of play across the major published series [21]. An adolescent-specific series of 31 skeletally immature pitchers with a mean age of 16.8 years confirmed that the procedure is safe in young athletes with no cases of physal arrest or growth plate disturbance were identified at follow-up [14]. Vitale's systematic review of 16 studies established the technical superiority of the docking technique over the original Jobe figure-eight approach (92% versus 79% return to play; $p < .05$), which informs the technical recommendation as applicable to the adolescent population [17]. Three critical age-specific considerations substantially modify the risk-benefit analysis for UCL reconstruction in adolescent pitchers compared to adult professionals. Recovery following UCL reconstruction typically requires 12 to 18 months before return to competitive pitching, with substantial variability based on level of play and rehabilitation course. In athletes undergoing reconstruction early in their competitive careers, this prolonged recovery interval may overlap with critical periods of skill development and recruitment [8]. In professional cohorts, UCL reconstruction has been associated with measurable long-term career impacts, including reductions in performance metrics and, in some studies, lower career earnings even after adjustment for confounding variables [8]. And a 20% overall complication rate represents a clinically meaningful risk that must be weighed explicitly in shared decision-making with adolescent patients and their families [12].

The Emerging Role of UCL Repair

Primary UCL repair with or without suture tape internal brace augmentation has attracted substantial clinical interest as an alternative to reconstruction in selected patients who present with proximal or distal avulsion-type tears. Adequate residual ligament tissue quality on imaging and intraoperative assessment, with early published series suggesting return-to-sport timelines of 7 to 9 months compared to 12 to 15 months for formal reconstruction, represents a potentially transformative reduction in recovery duration [22]. This is particularly meaningful for adolescent pitchers whose developmental windows are highly time sensitive. The evidence base specific to adolescent pitchers remains limited to small retrospective case series and no prospective randomized comparative trial exists in this age group, and this represents the single highest-priority evidence gap in the current literature and the most important target for future investigation [23].

Limitations

Substantial heterogeneity in study design, population definition and outcomes reporting across included studies limits formal meta-analytic pooling beyond selected risk factor estimates and the effect estimates in Table 2 should be interpreted as the best available approximations rather than

definitive pooled statistical estimates. The majority of higher-quality prospective evidence derives from mixed-age or adult-dominant populations and truly adolescent-specific data are predominantly retrospective or cross-sectional in design [9,10]. Publication bias toward surgical case series with favorable outcomes also likely overestimates the proportion of UCL injuries requiring operative intervention. Also, race, ethnicity, socioeconomic status and coaching quality are inadequately captured across included studies despite their likely importance as moderators of both showcase participation and year-round throwing exposure.

Conclusions

UCL tears in adolescent baseball pitchers are driven predominantly by quantifiable and modifiable workload and velocity exposures that are amenable to intervention at every level of the youth baseball ecosystem and the synthesized evidence from this scoping review supports five principal conclusions:

1. Strict enforcement of evidence-based pitch count with seasonal rest guidelines including no more than 75 to 100 pitches per game by age group and a minimum of 4 months rest per year. No more than 100 innings per season represents the highest-yield prevention intervention currently available in the literature. This guideline adherence reduces UCL injury odds by 57% (OR 0.43; 95% CI 0.26 to 0.72) in published meta-analyses [18]. Voluntary compliance has demonstrably failed to decelerate the rising incidence in adolescents over two decades of guideline availability [1,4].
2. Showcase participation before musculoskeletal maturity should be paced and systematically restricted because peak fastball velocity is the single strongest independent predictor of early UCL reconstruction (aOR 1.19 per mph; $p = .03$) [7]. High showcase volume is independently associated with earlier reconstruction and significantly worse long-term professional career outcomes that persist after controlling for confounders [8].
3. Adolescent UCL tears are predominantly partial in morphology and should be managed conservatively as the initial treatment approach. A minimum 3-to-6-month trial of activity modification, flexor-pronator rehabilitation and PRP injection is warranted before surgical reconstruction is recommended in patients with Grade I or Grade II partial tears. This strategy supported by a 74% nonoperative return-to-play rate at mean 12 weeks and the finding that humeral-sided high-grade partial tears are the single most common tear subtype in adolescent pitchers [11,16].
4. When UCL reconstruction becomes necessary, the docking technique is safe and effective in skeletally immature adolescent pitchers achieving 84% return-

to-play without physseal complications [14]. However, early-career reconstruction at age 19 or younger carries significantly longer recovery (19.8 versus 15.4 months; $p=.023$). Measurable long-term career consequences that must be incorporated explicitly into shared decision-making conversations with patients and families rather than minimized or omitted [8].

5. The single highest-priority evidence gap in this literature is a prospective randomized trial comparing UCL repair with internal brace augmentation versus formal reconstruction specifically in adolescent pitchers with complete UCL tears. This should be able to detect meaningful differences in recovery duration, return-to-play rate and long-term career outcomes, and the conduct of this trial should be regarded as the foremost research priority in adolescent baseball medicine.

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