Current Workload Recommendations in Baseball Pitchers

A Systematic Review

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Background: Several recommendations have been made regarding pitch counts and workload for baseball players of different levels, including Little League, high school, collegiate, and professional baseball. However, little consensus is found in the literature regarding the scientific basis for many of these recommendations.

Purpose: The primary purpose of this study was to summarize the evidence regarding immediate and long-term musculoskeletal responses to increasing pitching workload in baseball pitchers of all levels. A secondary purpose of this review was to evaluate the extent to which workload influences injury and/or performance in baseball pitchers.

Study Design: Systematic review.

Methods: We performed a systematic search in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for studies addressing physiologic and/or pathologic musculoskeletal changes in response to a quantifiable pitching workload. We included studies examining the effects of pitching workload on performance, injury rate, and musculoskeletal changes in Little League, high school, collegiate, and professional baseball players.

Results: We identified 28 studies that met our inclusion and exclusion criteria: 16 studies regarding Little League and high school pitchers and 12 studies regarding collegiate and professional pitchers. The current evidence presented suggests that increased pitching workload may be associated with an increased risk of pain, injury, and arm fatigue in Little League and high school pitchers. However, little consensus was found in the literature regarding the association between pitching workload and physiologic or pathologic changes in collegiate and professional pitchers.

Conclusion: Evidence, although limited, suggests the use of pitch counts to decrease injury rates and pain in Little League and high school baseball pitchers. However, further research must be performed to determine the appropriate number of pitches (or throws) for players of different ages. This systematic review reported conflicting evidence regarding the use of pitch counts in college and professional baseball. Future high-quality research is required to determine the role, if any, of pitch counts for collegiate and professional pitchers.

Keywords: pitch count; baseball; injury; performance; workload

A single high-velocity pitch in baseball can acutely disrupt normal musculoskeletal structures due to the extreme forces being experienced by the tissues.[1,2,4] The glenohumeral joint experiences up to 1090 N of compressive force at the moment of ball release, while the elbow is subject to almost 67 N·m of torque during the pitching motion.[14] Of particular importance, pitchers will repeat this strenuous motion over the course of a throwing session and season. As a result, the throwing extremity is subject to acute inflammation and microtrauma[34] as well as chronic physiologic or pathologic musculoskeletal adaptations,[7,20] which may predispose the pitcher to injury.[15,21,36,39] In light of this increased risk for injury, accurate monitoring of musculoskeletal load and identification of individualized injury thresholds are critical to maintaining safety and performance integrity for baseball pitchers of different ages and skill level.

Quantifiable markers of tissue load are often used to mitigate the risk of upper extremity injury in baseball pitchers. These markers are related to pitching workload and include pitches per game, innings per appearance, and days of rest between appearances. USA Baseball,[40] Baseball Canada,[3] and Little League Baseball[24] all use workload markers, with each organization using slightly different age-specific recommendations for Little League

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and adolescent athletes. Major League Baseball (MLB) does not have an official pitching workload recommendation; however, some teams attempt to quantify and limit the workload of their pitchers by tracking the aforementioned markers.

Although the relation between cumulative workload and risk of injury appears straightforward in theory, the evidence to support this logic is limited and conflicting,[13,15,18,19,33] particularly when comparing players across different ages and skill levels. For example, Lyman et al[25] examined youth baseball pitchers and reported an increased incidence of shoulder and elbow pain with an increasing number of pitches thrown per season. Similarly, Petty et al[33] examined high school baseball players who underwent ulnar collateral ligament (UCL) reconstruction and reported that 85% had a history of annual, seasonal, or single game overuse, as defined by the USA Baseball Medical & Safety Advisory Committee.[40] Whiteside et al[42] examined 104 MLB pitchers who underwent UCL reconstruction and reported that greater mean pitch counts and decreased rest were significantly associated with UCL injury.[42] Other studies, however, have not demonstrated increased pitching workload to be a predictor of injury or performance.[18,19] Furthermore, the heterogeneity of the metrics used (ie, pitch count, innings per appearance, appearances per season,[25] leagues per season, or days rest[6]) and outcome measures (ie, subjective fatigue,[32] physiologic fatigue, pain,[13] injury,[38] or time loss) makes comparison and interpretation across studies challenging. Therefore, the primary purpose of this study was to explore and summarize the evidence regarding immediate and long-term musculoskeletal responses to increasing pitching workload in baseball pitchers. A secondary purpose of this review was to evaluate the extent to which workload influences injury or performance in baseball pitchers.

METHODS

This review was conducted in accordance with PRISMA guidelines for systematic reviews. PubMed, EMBASE, MEDLINE, and Cochrane databases were queried on September 11, 2017, to identify potentially relevant articles for inclusion in this manuscript, using the search terms (1) "pitch count" and (2) "workload AND baseball" with results sorted by best match. No date range was specified for the manuscripts queried. Additional studies were located through the use of tangentially related systematic reviews, knowledge of previous manuscripts, and citations encountered during full-text review of manuscripts.

Two investigators (N.K.B., P.M.I.) independently conducted screens of titles and abstracts based on predetermined exclusion criteria: abstract-only sources, review articles, and articles unrelated to baseball or pitchers. Articles including nonbaseball overhead athletes (ie, cricket, tennis, and softball) were excluded, as overuse injuries in these studies may not be easily translated into applicable pitch count recommendations. When disagreement occurred, the senior author (M.T.F.) made the final determination.

Subsequently, the remaining full-text manuscripts were independently evaluated by the reviewers. The population of interest was baseball pitchers at the Little League, high school, college, and professional levels who are exposed to a quantifiable pitching workload (pitch count, innings/season, etc). Examining this population would allow for an improved understanding of the effect of pitch count on both skeletally mature and immature athletes. Athletes with a history of UCL reconstruction were excluded, as these throwers could be within an interval throwing program or at a lower workload depending on the duration of time from the procedure. The outcome of interest was physiologic or pathologic musculoskeletal changes related to increasing pitch counts. The study team assumed that pitching performance was a measurable consequence of physiologic performance and thus worthy of inclusion in the review. Case reports and opinion-based journal articles were removed in an effort to draw conclusions from an objective basis for expert opinion and guidelines. Only full-length manuscripts published in English-language journals were eligible for inclusion. Finally, given the main outcome of interest of physiologic or pathologic change in baseball pitchers, biomechanical or basic science studies insinuating the plausibility for injury were included in addition to clinical studies that objectively demonstrated the outcome of interest. Methodological quality assessment of all studies included in this review was completed by use of the Methodological Index for Nonrandomized Studies (MINORS).[37]

RESULTS

A total of 177 articles were identified through a query of the above-mentioned databases, while 5 additional articles were identified through the reference lists of other manuscripts. Duplicates were removed from the search results. The remaining 173 articles were independently screened for inclusion; 60 articles met selection criteria and received full-text review. During abstract review, the 2 independent authors agreed upon the inclusion or exclusion of 161 of the

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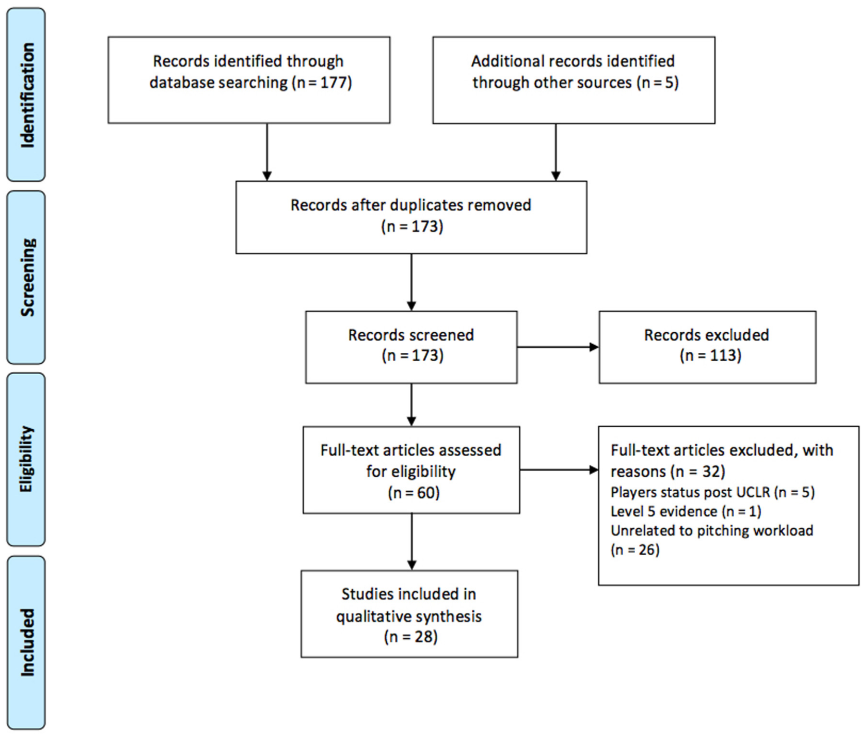

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart demonstrating the inclusion/exclusion process. UCLR, ulnar collateral ligament reconstruction.

TABLE 1
MINORS Scores for Included Manuscripts Regarding Little League and High School Baseball Players[a]

Lead Author	Clearly Stated Aim	Inclusion of Consecutive Patients	Prospective Collection of Data	Appropriate Endpoints	Unbiased Assessment of Endpoint	Appropriate Follow-up Period	Loss to Follow-up <5%	Prospective Calculation of Study Size	Adequate Control Group	Contemporary Study Groups	Baseline Equivalence of Groups	Adequate Statistical Analysis	Total Score
Oliver[29]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Popchak[34]	2	1	2	2	0	2	2	0	NA	NA	NA	NA	11
Kung[22]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Atanda[2]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
McHugh[27]	2	2	2	2	0	2	0	1	NA	NA	NA	NA	11
Oliver[30]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Pei-Hsi Chou[32]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Fleisig[13]	2	2	2	2	0	2	1	0	NA	NA	NA	NA	11
Olsen[31]	2	1	0	2	0	2	1	0	2	2	2	2	16
Lyman[25]	2	2	2	2	0	2	1	0	NA	NA	NA	NA	11
Erickson[10]	2	2	0	2	0	1	2	1	1	2	0	2	15
Sueyoshi[38]	2	0	2	2	0	2	2	0	2	2	1	2	17
Yukutake[43]	2	2	2	2	0	2	1	0	1	2	1	2	17
Lyman[26]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Gandhi[16]	2	2	2	2	0	2	1	0	NA	NA	NA	NA	11
Petty[33]	1	2	0	2	0	2	1	0	NA	NA	NA	NA	8

[a]MINORS, Methodological Index for Non-randomized Studies; NA, not applicable.

173 articles (93%), and the remaining 12 articles (7%) were reviewed together with the senior author to resolve discrepancies. Authors agreed upon 57 of the 60 (95%) manuscripts for inclusion or exclusion in this full-text review. Of these articles, 28 studies met inclusion criteria and are discussed below (Figure 1). MINORS scores are displayed for each manuscript (Tables 1 and 2).

Of the included papers, there was 1 level 1 study, 3 level 2 studies, 14 level 3 studies, 9 level 4 studies, and 1 basic science/laboratory study. As listed in Table 3, 16 studies focused on youth or high school pitchers and evaluated a total of 1673 pitchers; included in these were 1 level 1 study, 2 level 2 studies, 7 level 3 studies, 5 level 4 studies, and 1 basic science/laboratory study. As listed in Table 4, 12 studies focused on collegiate and professional pitchers and evaluated a total of 3443 pitchers; these included 1 level 2 study, 7 level 3 studies, and 4 level 4 studies.

TABLE 2
MINORS Scores for Included Manuscripts Regarding Collegiate and Professional Baseball Players[a]

Lead Author	Clearly Stated Aim	Inclusion of Consecutive Patients	Prospective Collection of Data	Appropriate Endpoints	Unbiased Assessment of Endpoint	Appropriate Follow-up Period	Loss to Follow-up <5%	Prospective Calculation of Study Size	Adequate Control Group	Contemporary Groups	Baselines Equivalence of Groups	Adequate Statistical Analysis	Total Score
Whiteside[42]	2	1	0	2	0	2	2	0	2	2	2	2	17
Chalmers[8]	2	1	0	2	0	2	1	0	2	2	2	2	16
Crotin[9]	2	2	0	2	0	2	2	0	NA	NA	NA	NA	9
Karakolis[18]	2	2	0	2	0	2	2	0	NA	NA	NA	NA	10
Bradbury[6]	2	1	0	2	0	2	0	0	NA	NA	NA	NA	7
Escamilla[11]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12
Zeppieri[45]	2	0	2	2	0	2	2	0	NA	NA	NA	NA	10
Grantham[17]	2	1	2	2	0	2	2	0	NA	NA	NA	NA	11
Freehill[15]	1	2	2	2	0	2	2	0	NA	NA	NA	NA	11
Bast[4]	2	0	2	2	0	2	2	0	1	2	0	2	15
Karakolis[19]	2	2	0	2	0	2	0	0	NA	NA	NA	NA	8
Murray[28]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	12

[a]MINORS, Methodological Index for Non-randomized Studies; NA, not applicable.

Effect of Acute Workload on Physiology

Youth pitchers (age 9-14 years) demonstrated increased width of both the long head of the biceps and the infraspinatus tendon after 50 pitches in a single simulated game session.[34] These changes in tendons measured via ultrasonography were not seen after 25 pitches. High school (age 14-19 years) pitchers demonstrated decreased voluntary activation of the infraspinatus muscle and decreased external rotational torque after 75 to 90 pitches in a simulated game session. Additionally, a decrease in pitch velocity was demonstrated during late inning (sixth inning) pitches.[16] Similarly, high school pitchers aged 16 to 18 years demonstrated an increase in shoulder flexion, extension, abduction, adduction, internal rotation, and external rotation weakness after a 100-pitch simulated bullpen session.[32] As seen in Tables 5 and 6, these changes can occur at pitch counts less than those recommended by baseball governing bodies.[3,24,40] Only 1 study was identified describing the acute physiologic changes associated with pitching workload in the professional athlete. MLB throwers demonstrated significant alterations in upper extremity arterial blood supply after a simulated game during a bullpen session (approximately 50 pitches). These arterial changes occurred only in pitchers without underlying anterior glenohumeral instability.[4]

Effect of Acute Workload on Biomechanics

Adolescent pitchers (age 12-16 years) demonstrated a decrease in both trailing leg hip extension and ankle plantarflexion during the stride phase, a decrease in hip flexion and hip abduction at foot contact, and a decrease in ball speed at release after a simulated game session (approximately 90 pitches).[22] Gluteal and scapular muscle activation did not significantly change during a bullpen session (approximately 75 pitches) in a similar patient population (age 11.2 ± 0.8 years).[30] Additionally, the same group of adolescent pitchers exposed to an 85-pitch workload simulated session of variable pitch type had no significant changes in pitching kinematics. Specifically, pelvic rotation, torso rotation, shoulder plane of elevation, and shoulder rotation, as well as muscle activation of bilateral pelvic and parascapular muscles, remained consistent across the throwing session.[29] In the collegiate pitchers, forward trunk tilt became increasingly close to vertical at the moment of ball release during a 7- to 9-inning (approximately 105-135 pitches) simulated game session.[11] In-game video recording of 11 collegiate pitchers found numerous kinematic changes over the course of a pitching outing (97.2 ± 16.1 pitches): decrease in maximum external rotation during late cocking phase, decrease in glove height during ball release, and decrease in glove height during follow-through. In the same population, throwers demonstrated additional kinematic changes during prolonged innings where they threw more than 15 pitches, including "increases in hip lean at hand separation, decreased stride length at foot contact, and increased hip flexion at maximum external rotation and ball release."[17] MLB pitchers demonstrated kinematic changes during a 5- or 6-inning spring training appearance, including decreases in maximum shoulder external rotation and knee angle at ball release. These changes were associated with a 5-mph decrease in velocity from the first inning (90 mph) to the fifth inning (85 mph).[28]

Effect of Chronic Workload on Physiologic Parameters

Physiologic adaptations of the UCL have been shown to be correlated with increasing pitching workload, where pitchers throwing more than 67 pitches per outing, playing more than 5 innings per appearance, and having more than 5.5 years of pitching experience demonstrated significantly thickened UCLs.[2] Furthermore, high school pitchers (age 16 ± 1 years; range, 14-18 years) throwing high volumes of pitches (>400 pitches per season or the highest volume tercile of pitchers) lost up to 13% of supraspinatus strength over the course of a single season.[27] Additionally, high- and medium-volume pitchers failed to gain strength season-to-season, whereas low-volume (<130 pitches per season or the lowest volume tercile of pitchers) high school pitchers increased strength by 24%.[27] Maintenance programs were not discussed in this study.

TABLE 3
Literature Pertaining to the Effect of Workload on the Little League and High School Pitcher[a]

Lead Author (MINORS Score)	Journal (Year)	Study Population	Study Design	Parameter Studied	Significant Findings
Atanda[2] (12/16)	*AJSM* (2016)	102 youth baseball pitchers (group 1, age 12-14 y; group 2, age 15-18 y)	Cross-sectional (stress ultrasonography of dominant and nondominant elbow)	UCL thickness	Increased UCL thickness identified in - Pitchers throwing >67 pitches per appearance (4.69 vs 4.14 cm, $P < .001$). - Pitchers throwing >5 innings per appearance (4.76 vs 4.11 cm, $P < .001$). - Pitchers with >5.5 y of throwing experience (4.71 vs 4.07 cm, $P < .001$).
Erickson[10] (15/24[b])	*Orthop J Sports Med*. (2017)	62 LLWS pitchers who progressed to play professional baseball	Retrospective cohort	Risk of UCLr as a professional	Of LLWS pitchers who went on to play professionally: - 1.7% (1/58) of pitchers who did not exceed pitch count recommendations as a Little Leaguer required UCLr as a professional. - 50% (2/4) of pitchers who exceeded pitch count recommendations as a Little Leaguer required UCLr as a professional.
Fleisig[13] (11/16)	*AJSM* (2011)	481 youth baseball pitchers (age 9-14 y)	Prospective cohort (10-year follow-up)	Risk of serious injury	- Participants throwing >100 innings per year faced a significantly higher risk of injury than those who did not (OR = 3.5, $P = .088$). - Injured pitchers threw more innings per year than all pitchers studied (48.9 vs 40.0 innings, $P < .05$).
Gandhi[16] (11/16)	*J Shoulder Elbow Surg*. (2012)	21 uninjured, high school–aged pitchers (mean age 14 y)	Descriptive laboratory study (75- to 90-pitch simulated game)	Infraspinatus strength, subjective fatigue, and pitching velocity	Before simulated game: - No difference in throwing vs nonthrowing shoulder ER strength (27.3 ft/lb dominant vs 28.8 ft/lb nondominant). - No difference in voluntary infraspinatus activation (96% dominant vs 93% nondominant). After throwing session, players demonstrated - Decrease in shoulder ER strength compared with pregame levels (27.3 ft/lb before game vs 25.6 ft/lb after game, $P = .06$). - Decrease in voluntary infraspinatus activation compared with pregame levels (96% before game vs 89% after game, $P = .01$). Pitch velocity decreased over the course of the simulated game (65 mph first inning vs 63 mph last inning, $P = .01$), while subjective fatigue increased (mean, <1 before game vs 6 after game, $P < .01$).
Kung[22] (12/16)	*AJSM* (2017)	12 youth baseball pitchers (age 12-16 y)	Descriptive laboratory study (6 sets of 15 fastballs in bullpen session)	Lower extremity kinematic variables	Extended play resulted in - Decreased maximum angular excursion for hip extension during stride phase (14.7° first set vs 11.6° final set, $P < .05$). - Decreased maximum angular excursion for ankle plantarflexion during stride phase (30.2° vs 24.2°, $P < .05$). - Decreased angular velocity of knee extension (114.9 deg/s vs 121.7 deg/s) during the stride phase. - Decreased hip flexion (69.5° vs 66.5°, $P < .05$) at foot contact. - Increased hip abduction (20.7° vs 25.4°) in the lead leg at foot contact. Ball speed decreased during the bullpen session (29.5 ± 2.5 m/s first set vs 28.3 ± 2.5 m/s final set).
Lyman[26] (12/16)	*Med Sci Sports Exerc*. (2001)	298 youth baseball pitchers (age 10.8 ± 2.1 y)	Prospective cohort (2-year follow-up)	Risk of shoulder and/or elbow pain	Pitchers experienced an increased risk of - Elbow (OR = 1.06, $P = .06$) and shoulder (OR = 1.15, $P < .01$) pain per 10 pitches thrown during a game. - Elbow pain when playing baseball outside of a single league (OR = 2.35, $P = .01$). - Shoulder pain when throwing >75 pitches (OR = 3.2, $P < .01$). Pitching >300 pitches during a season appeared to reduce risk of pain, while throwing >600 pitches appeared to confer increased risk.

(continued)

TABLE 3
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Lead Author (MINORS Score)	Journal (Year)	Study Population	Study Design	Parameter Studied	Significant Findings
Lyman[25] (11/16)	*AJSM* (2002)	476 youth baseball pitchers (age 9-14 y)	Prospective cohort (single-season follow-up)	Risk of shoulder and/or elbow pain	- Pitchers throwing >100 pitches experienced increased odds of elbow (OR = 1.44, *P* = .07) and shoulder (OR = 1.77, *P* < .01) pain compared with those throwing <24 pitches. - Pitchers with season pitch counts >800 experienced increased odds of elbow (OR = 2.61, *P* < .01) and shoulder (OR = 3.29, *P* < .01) pain.
McHugh[27] (11/16)	*AJSM* (2016)	69 high-volume youth baseball pitchers (566 ± 153 pitches), moderate-volume pitchers (288 ± 71 pitches), and low-volume pitchers (105 ± 45 pitches) (age 16 ± 1 y)	Prospective cohort (pre- and postseason ROM and strength measurements)	Shoulder strength and ROM	Over the course of a season: - Supraspinatus strength decreased, with high-volume (–13%) pitchers losing more strength than moderate (–6%) or low-volume (–2%) pitchers. - ROM did not change and was unaffected by pitch volume. Year to year: - Supraspinatus strength increased in low-volume pitchers (+24%). - Supraspinatus strength remained unchanged in high-volume pitchers.
Oliver[30] (12/16)	*J Strength Cond Res.* (2016)	23 youth baseball pitchers (age 11.2 ± 0.8 y)	Descriptive laboratory study (simulated game of <75 pitches)	Gluteal and upper extremity muscle activation	No change in muscle activation was seen in scapular gluteal muscle activation during simulated games.
Oliver[29] (12/16)	*J Pediatr Orthop.* (2017)	14 youth baseball pitchers (age 12.4 ± 1.1 y)	Descriptive laboratory study (simulated game of <85 pitches)	Muscle activation and pitching mechanics	Neither pitch type nor simulated game resulted in change to pitching mechanics.
Olsen[31] (16/24[b])	*AJSM* (2006)	95 adolescent pitchers requiring shoulder or elbow surgery and 45 healthy controls (case group age 18.3 ± 1.5 y)	Case-control	Risk of pitching-related injury	Compared with healthy controls, injured pitchers - Pitched more months per year (7.9 ± 2.5 vs 5.5 ± 2.3 months, *P* < .001). - Pitched more appearances per year (28.8 ± 14.7 vs 18.6 ± 13.0, *P* < .001). - Pitched more innings per appearance (5.6 ± 1.4 vs 4.3 ± 1.7, *P* < .001). - Pitched more pitches per appearance (87.8 ± 21.8 vs 66.6 ± 25.3, *P* < .001). - Pitched more pitches per year (2562 ± 1505 vs 1268 ± 1039, *P* < .001). Pitching >8 months per year increased risk of injury (OR = 5.05, CI = 1.39-18.32), as did pitching >80 pitches per appearance (OR = 3.83, CI = 0.94-7.02).
Pei-Hsi Chou[32] (12/16)	*J Strength Cond Res.* (2015)	16 high school baseball pitchers (age 16-18 y)	Descriptive laboratory study (100-pitch bullpen session)	Muscle strength, pitching mechanics, and subjective fatigue	Numerous kinematic changes were noted in pre- and postsession comparisons, including - Shoulder horizontal abduction (21.1° vs 18.7°) at foot contact. - Maximum shoulder horizontal adduction (13.4° vs 15.3°), maximum elbow flexion (126° vs 125°), and maximum pelvis angular velocity (734 vs 765 deg/s) during arm cocking. - Shoulder horizontal adduction (13.1° vs 15.3°) and upper torso forward tilt (12.6° vs 14.8°) during maximum ER. - Maximum forearm pronation (27.4° vs 22.4°) during arm acceleration phase. - Shoulder horizontal adduction (11.9° vs 14.8°), elbow valgus (8.8° vs 6.9°), forearm pronation (24.9° vs 20.1°), knee flexion (53.6° vs 56.1°), and upper torso forward tilt (21.4° vs 24.2°) at the instant of ball release. Ball velocity decreased from pre- to postsession (117 vs 112 km/h). Shoulder strength decreased for shoulder extension, flexion, abduction, IR, and ER after session.
Petty[33] (8/16)	*AJSM* (2004)	27 high school baseball pitchers with UCL injury (mean age 17.4 y)	Retrospective cohort	Risk of UCLr	85% of injured pitchers were involved in at least 1 overuse category (as defined by USA Baseball recommendations): - 69% of injured pitchers threw year-round. - 62% of pitchers were involved in seasonal overuse. 42% of pitchers were involved in event overuse.

(continued)

TABLE 3
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Lead Author (MINORS Score)	Journal (Year)	Study Population	Study Design	Parameter Studied	Significant Findings
Popchak[34] (11/16)	*Med Sci Sports Exerc.* (2017)	50 youth baseball pitchers (age 9-14 y)	Descriptive laboratory study (50-pitch simulated game)	Tendon width of infraspinatus and long head of biceps	After 50-pitch throwing session, pitchers demonstrated - Increased width of infraspinatus tendon (+0.21 mm, P = .03). - Increased width of the long head of the biceps tendon (+0.18 mm, P = .03). Similar changes were not observed after 25 pitches.
Sueyoshi[38] (17/24[b])	*Orthop J Sports Med.* (2017)	41 Little League to college-level baseball pitchers (mean age 14.9 y)	Cross-sectional study	Risk of injury	Compared with healthy controls, injured pitchers threw - More games per season (29.0 ± 17.1 vs 18.1 ± 12.2, P = .02). - More innings per game (5.5 ± 1.8 vs 3.5 ± 1.8, P = .002). - More pitches per game (74.2 ± 25.5 vs 56.6 ± 32.9, P = .05).
Yukutake[43] (17/24[b])	*Orthop J Sports Med.* (2015)	336 uninjured (age 10.4 y) and 53 injured (age 10.0 y) Japanese Little League Baseball players	Case-control	Risk of elbow injury requiring medical treatment	Compared with healthy controls, injured pitchers were - More likely to "often throw more than 100 pitches/week" (24.5% vs 11.0%, P = .01). - Not more likely to have "a period when [they] do not throw anything for at least 1 month" (96.2% vs 95.8%, $P > .99$).

[a]ER, external rotation; IR, internal rotation; LLWS, Little League World Series; MINORS, Methodological Index for Non-randomized Studies; OR, odds ratio; ROM, range of motion; UCL, ulnar collateral ligament; UCLr, ulnar collateral ligament reconstruction.
[b]Comparative study criteria used when assigning MINORS score.

Range of motion (ROM) measurements in the above subset of high school pitchers were unaffected by high pitch volume.[27] Freehill and colleagues[15] demonstrated similar findings in 6 collegiate pitchers (age 21.7 ± 0.7 years), with no association identified between single game and changes over the course of a season in upper extremity ROM changes and innings pitched, pitch count, or types of pitches thrown. In the lower extremity, no association was identified between cumulative pitching workload and hip ROM changes over the course of a collegiate baseball season in 12 college baseball pitchers (age 19.35 ± 1.4 years).[45]

Effect of Chronic Workload on Biomechanics

No studies were found that examined the influence of chronic workload (eg, over the course of a season or seasons) on pitching biomechanics.

Effect of Chronic Workload on Upper Extremity Pain

Two large, prospective cohort studies were identified regarding the association between pitching workload and shoulder and elbow pain in adolescent athletes (age 8-12 years). In the first study, Lyman and colleagues[26] demonstrated increased odds of shoulder pain when athletes pitched more than 75 pitches in an outing, when compared with throwing fewer than 24 pitches (odds ratio [OR] = 3.22, $P < .01$). Additionally, increasing workload was associated with an increased risk of elbow pain, but results did not reach statistical significance. Finally, throwing more than 300 pitches in competition before a pitching outing was protective against elbow pain, whereas throwing more than 600 pitches was associated with an increased risk of pain.

In the second study, Lyman and colleagues[25] reported similar findings between shoulder and elbow pain with increased pitch counts in youth baseball pitchers ranging from age 9 to 14 years, where throwing more than 100 pitches in an appearance increased risk of both elbow (OR = 1.44, P = .07) and shoulder (OR = 1.77, $P < .01$) pain.

Effect of Chronic Workload on Pitching Performance

Two studies attempted to associate exposure to a defined pitching workload and subsequent pitching performance at the professional level. Crotin et al[9] demonstrated that neither days of rest nor the ratio of pitching work to rest affected fastball velocity of young professionals. However, Bradbury and Forman[6] reported that earned run average (ERA) was adversely associated with increased pitches thrown in prior games. Those investigators demonstrated that a pitcher's ERA increased with more pitches thrown in the prior appearance (0.007 earned runs per pitch) and with average workload in the prior 10 appearances (0.022 earned runs per pitch).[6]

Effect of Chronic Workload on Injury Risk

In the adolescent population (age 9-14 years), injured pitchers (players with elbow or shoulder surgery or ending their career due to throwing injury) are more likely to cross the 100 innings per year threshold than their uninjured counterparts.[13] Pitchers requiring operative intervention

TABLE 4
Literature Pertaining to the Effect of Workload on the Collegiate and Professional Pitcher[a]

Lead Author (MINORS Score)	Journal (Year)	Study Population	Study Design	Parameter Studied	Significant Findings
Bast[4] (15/24[b])	*J Shoulder Elbow Surg*. (2011)	18 professional male pitchers with and without shoulder laxity on examination	Descriptive laboratory study (50-pitch workout)	Upper extremity arterial blood flow before and after workout	After 50-pitch workload: - Pitchers demonstrated increase of arterial blood volume (from 234 mL/min before pitching to 397 mL/min after pitching). - Pitchers with laxity or shoulder instability experienced less increase in arterial blood flow than pitchers without shoulder laxity (35% vs 115%, $P < .05$).
Bradbury[6] (7/16)	*J Strength Cond Res*. (2012)	1058 MLB starting pitchers 1988-2009 after <15 days of rest	Retrospective cohort	Subsequent game ERA	A pitcher's predicted ERA increased by - 0.007 runs/pitch thrown in the proceeding game. - 0.014 runs/average pitches thrown in the proceeding 5 games. - 0.022 runs/average pitches thrown in the proceeding 10 games. Pitchers >34 y of age were more sensitive to the effect of increased 10-game workloads.
Chalmers[8] (16/24[b])	*AJSM* (2016)	1327 pitchers, of whom 309 MLB required UCLr from 2007 to 2015	Case-control	Risk of requiring UCLr	No significance difference noted between pitch counts of throwers requiring UCLr (annual pitch count 2804 pitches) and healthy controls (2823 pitches).
Crotin[9] (9/16)	*J Strength Cond Res*. (2013)	12 Minor League pitchers in 2009 Class A short season (both starts and relievers)	Retrospective cohort	Changes in fastball velocity over 8-game short season	Over 8-game short season: - A pitcher's fastball velocity increased 0.25 m/s, in a linear fashion (R^2 = 0.91). - Days rest and pitching work/days rest did not affect fastball velocity.
Escamilla[11] (12/16)	*AJSM* (2007)	10 collegiate baseball pitchers (age 20.0 ± 1.4 y)	Descriptive laboratory study (7- to 9-inning simulated game)	Ball velocity and kinematic variable changes over simulated game	Compared with the first 2 innings: - Ball velocity decreased in the last 2 innings (34.7 ± 1.8 m/s vs 33.7 ± 1.5 m/s). - Trunk position at ball release was closer to vertical in the last 2 innings (34° ± 12° to 29° ± 11°). - No significant difference was found between 10 other kinematic variables tested.
Freehill[15] (11/16)	*Phys Sportsmed.* (2014)	6 NCAA Division III starting pitchers (age 21.7 ± 0.7 y)	Prospective cohort	Glenohumeral ROM	No statistically significant relationship exists between changes in ROM throughout a season and number of innings pitched, pitch count, or pitch type.
Grantham[17] (11/16)	*Orthop J Sports Med*. (2014)	11 NCAA Division I collegiate baseball pitchers	Descriptive laboratory study	Ball velocity and kinematic variable changes over the course of an inning, appearance, and season	During long innings (>15 pitches), pitchers displayed - Increased hip lean at hand separation, elbow height at foot contact, and hip flexion and shoulder tilt at maximum ER. Throughout an appearance: - Pitchers always reported they could continue pitching, regardless of pitch count, and velocity remained consistent (38.6 m/s vs 38.4 m/s) throughout an appearance. - Elbow height at foot contact decreased. As subjective fatigue increased, there was a negative correlation with stride knee flexion at maximum ER and glove height at follow-through. Over the course of a season, increasing pitch count correlated with - Increased stride knee flexion at foot contact; increased maximum shoulder ER, shoulder alignment, and stride knee flexion at maximum ER; increased shoulder abduction and stride knee flexion at ball release.

(continued)

TABLE 4
(continued)

Lead Author (MINORS Score)	Journal (Year)	Study Population	Study Design	Parameter Studied	Significant Findings
Karakolis[18] (10/16)	*J Strength Cond Res.* (2013)	Every MLB pitcher throwing a pitch from 2002 to 2007, including 1031 pitchers placed on disabled list	Retrospective cohort	Risk of placement on disabled list	Injury rates for pitchers compared for those pitching 1801 to greater than 3300 pitches per season: - Pitchers throwing 2710-3300 pitches/year had similar rates of injury the subsequent year (40%-43%). - Pitchers throwing >3300 pitches/year had a lower rate of injury. Additional findings included: - Injury rates were highest in pitchers throwing between 6 and 7 innings per appearance (37%). - Pitchers throwing 2 or 3 innings demonstrated the lowest rate of injury (21%). - Pitchers faced a steadily increasing risk of injury when increasing from 41-50 pitches/outing to 90-100 pitches/outing. - This increasing risk of injury plateaued after 100 pitches. No single metric was found to be statistically significant in predicting injury.
Karakolis[19] (8/16)	*J Sports Med Phys Fitness* (2016)	All pitchers <25 years of age throwing at least one-third of an MLB inning (761 pitcher-seasons from 2002 to 2007)	Retrospective cohort	Time spent on disabled list	No significant relationship was found between innings pitched and risk of future injury.
Murray[28] (12/16)	*AJSM* (2001)	7 MLB pitchers	Cohort study	Ball velocity and kinematic changes over the course of a single game	Over the course of an outing: - Fastball velocity decreased (90 mph first inning vs 85 mph late inning). Kinematic variable changes included: - Maximum ER of the shoulder (181° vs 172°, P = .007). - Knee angle at ball release (140° vs 132, P = .024). - Maximum shoulder distraction force (97% vs 88% WGT, P = .018). - Maximum elbow distraction force (85% vs 72% WGT, P = .030). - Horizontal abduction force at ball release (5% vs 4% WGT × HGT, P = .005). - Maximum horizontal abduction torque (11% vs 8% WGT × HGT, P = .018).
Whiteside[42] (17/24[b])	*AJSM* (2016)	104 MLB pitchers who underwent UCLr and 104 age- and position-matched controls	Case-control	Likelihood of UCLr	A 1-pitch increase in mean pitches/game results in 2% increase in likelihood of requiring UCLr (OR = 1.020, CI = 1.007-1.033).
Zeppieri[45] (10/16)	*Int J Sports Phys Ther.* (2015)	12 college baseball pitchers (age 19.35 ± 1.4 y)	Prospective cohort	Lower extremity ROM	No correlation was found between in-season pitches thrown and hip range of motion or hip strength.

[a]ER, external rotation; ERA, earned run average; HGT, height; MINORS, Methodological Index for Non-randomized Studies; MLB, Major League Baseball; NCAA, National Collegiate Athletic Association; OR, odds ratio; ROM, range of motion; UCLr, ulnar collateral ligament reconstruction; WGT, weight.
[b]Comparative study criteria used when assigning MINORS score.

on the shoulder or elbow threw more warm-up pitches (21 pitches control vs 34.1 injured, $P < .01$), more months per year (5.5 control vs 7.9 injured), more innings per appearance (4.3 control vs 5.6 injured), more pitches per appearance (66.2 control vs 87.8 injured), and more pitches per year than uninjured controls (1268 control vs 2562 injured).[31] Sueyoshi and colleagues[38] demonstrated similar findings, with injured throwers again throwing more games per season, innings per game, and pitches per game than healthy throwers. Among Japanese Little League pitchers, injured pitchers were more likely to throw more than 100 pitches per week (24.5% injured vs 11.0% healthy).[43] Finally, 85% of high school baseball athletes requiring UCL reconstruction exhibited increased or high-volume load in at least 1 of 3 categories: year-round throwing, seasonal overuse, and event overuse.[33]

A single study, performed by Erickson and colleagues,[10] examined the association between youth exposure to pitching workload and injury risk as a professional. The investigators found that players who had violated Little League pitch count recommendations of fewer than 85 pitches for players age 11 to 12 and fewer than 96 pitches for players age 13 to 16 were more likely to require UCL reconstruction during their professional career compared with professional throwers who adhered to pitch count recommendations as Little Leaguers (50% vs 1.7%, P = .009).

TABLE 5
Current Single-Outing Pitch Count Recommendations by Organization

Age, y	Little League Baseball[a]	USA Baseball[a]	Baseball Canada[a]
7	50	50	No recommendation
8			No recommendation
9	75	75	75
10			
11	85	85	
12			85
13	95	95	
14			95
15			
16			105
17		105	
18			
<21		120	115

[a]Values are pitch counts.

In professional pitchers, Whiteside et al[42] demonstrated that higher pitch counts per game and fewer days of rest between appearances increased the risk of UCL injury in professional pitchers. Conversely, Chalmers et al[8] reported that pitch counts per year were not statistically different between controls (2826 pitches) and throwers who required subsequent UCL reconstruction (2804 pitches). When broadening beyond UCL injuries, 2 studies from Karakolis and colleagues[18,19] demonstrated that no cumulative workload metric was a significant predictor for future injury including innings per season or year-to-year increases in innings pitched in professional baseball.

DISCUSSION

The purpose of this study was to evaluate the association between pitching workload and acute or chronic musculoskeletal changes in the baseball pitcher. We also aimed to evaluate for any relationship between increased pitching workload and injury risk or decreased performance. A total of 28 articles were included in this review, with 16 regarding youth and high school pitchers and 12 regarding college and professional baseball pitchers. The current evidence presented suggests that increased pitching workload may be associated with an increased risk of pain, injury, and arm fatigue in Little League and high school pitchers. However, little consensus was found in the literature regarding the association between pitching workload and physiologic or pathologic changes in collegiate and professional pitchers.

Youth/High School Pitchers

Eight studies[10,13,27,31,33,34,38,43] reported on Little League and high school pitchers and demonstrated an association between increased pitch counts and shoulder or elbow pain and injury. Furthermore, Erickson et al[10] reported that increased in-game pitch counts as a Little Leaguer can also predispose to future UCL injury as a professional athlete. These results support the implementation of pitch count and rest recommendations by the USA Baseball Medical and Safety Advisory Committee[40] to decrease the risk of injury. However, Olsen et al[31] found that the USA Baseball guidelines may be far too liberal. Those investigators reported that adolescent pitchers (age 14-20 years) who threw more than 80 pitches per game were at nearly 4 times increased risk of injury that would require surgery. The current USA Baseball recommendations suggest pitch count limits that significantly exceed this number,[40] with pitchers who are 14 and 20 years of age being limited to a maximum of 95 and 120 game pitches per appearance, respectively. In addition, Popchak et al[34] demonstrated acute physiologic alterations at the 50-pitch threshold in the youth (age 9-14 years) shoulder, demonstrating the potential for pathologic changes and injury to occur at a workload significantly below pitch count recommendations (Tables 5 and 6). Furthermore, McHugh et al[27] reported decreased rotator cuff strength and muscular fatigue in 14- to 18-year-old pitchers throwing more than 400 pitches per season, a number attained by the majority of high school starting pitchers. This suggests that cumulative pitches over a season can have detrimental effects on a pitcher and should be included in pitch count recommendations as a result. Although these results demonstrate an association between pitch count and risk of shoulder and elbow pain and injury, several methodologic flaws limit the use of these conclusions. These studies were retrospective in nature and had significant recall bias and confounding variables present. As a result, high-level prospective studies are needed to demonstrate a causal relationship between pitch count and injury risk and to determine appropriate pitch count recommendations for Little League and high school baseball organizations.

Multiple studies also reported that pitching with arm fatigue is a significant factor associated with shoulder or elbow pain and injury, regardless of pitch count in youth players.[26,31] These results suggest that a player should be removed from a game or prevented from pitching, regardless of pitch count, if he or she complains of arm fatigue. This increased risk of injury is likely related to muscle fatigue, resulting in decreased dynamic stability provided by the arm and forearm musculature with excessive pitching. The dynamic stabilizers of the shoulder and elbow have been shown to weaken at the 75-pitch threshold in high school pitchers,[32] but dynamic stability is typically physiologically undetectable to the parent or the coach. As a result, the shoulder and elbow of the adolescent pitcher may be vulnerable to microtrauma and fatigue, which has been hypothesized to predispose to injury. For example, the flexor and pronator forearm muscles function as the primary dynamic stabilizers of the medial aspect of the elbow and decrease the forces placed on the UCL with excessive valgus force during pitching.[23] However, with arm fatigue, the stabilizing effect of the flexor-pronator mass is likely decreased, resulting in increased tensile stress throughout the UCL. These studies demonstrate

TABLE 6
Current Recommendations for Days of Rest by Organization and Age Group[a]

	USA Baseball[b]							Little League[b]		Baseball Canada[b]				
Days of Rest	7-8 y	9-10 y	11-12 y	13-14 y	15-16 y	17-18 y	19-22 y	<14 y	15-16 y	<11 y	<13 y	<15 y	<18 y	<21 y
0	1-20	1-20	1-20	1-20	1-30	1-30	1-30	1-20	1-30	1-25	1-30	1-35	1-40	1-45
1	21-35	21-35	21-35	21-35	31-45	31-45	31-45	21-35	31-45	26-40	31-45	36-50	41-55	46-60
2	36-50	36-50	36-50	36-50	46-60	46-60	46-60	36-50	46-60	41-55	46-60	51-65	56-70	61-75
3	NA	51-65	51-65	51-65	61-75	61-80	61-80	51-65	61-75	56-65	61-75	66-80	71-85	76-90
4	NA	≥66	≥66	≥66	≥76	≥81	80-105	≥66	≥76	66-75	76-85	81-95	86-105	91-115
5							≥106							

[a]NA, not applicable.
[b]Values are pitch counts.

the limited utility of pitch count, as it is an absolute measure of workload that does not account for subjective feelings of arm fatigue or individual endurance levels. Future research is required to better understand the physiologic mechanisms (ie vascular, neuromotor, structural) that underlie this muscular fatigue and the resultant clinical effects.

A primary limitation on the use of baseball pitch counts for youth and high school players is the adherence of coaches, players, and parents to these recommendations. Several studies have obtained surveys of players and coaches and have demonstrated poor knowledge of and compliance with pitching guidelines.[1,5,12,35,41,44] These surveys reported that the majority of youth players and coaches had little understanding of the USA Baseball pitch count and rest recommendations.[5,12] Furthermore, players and coaches also had opinions and actions regarding pitch counts and pitching injuries that were contradictory to the published literature.[1,5,12,35,41] These results suggest the importance of educating players, coaches, and parents about recommended pitch counts and rest days. Involved parties should also be aware of the injury implications associated with exceeding these pitching workload guidelines. Finally, players, coaches, and parents should be counseled regarding the increased injury risk when pitching with arm fatigue and pain. This awareness and compliance by athletes, coaches, and parents is critical to maintaining the health and performance of youth and adolescent pitchers.

College/Professional Pitchers

Overall, mixed results regarding pitch counts at the college and professional levels have been reported. Although Bradbury and Forman[6] and Whiteside et al[42] reported increased injury risk and worse performance with increasing pitches thrown compared with controls, Karakolis et al[18,19] and Chalmers et al[8] produced conflicting evidence. Furthermore, all of the evidence regarding college and professional pitchers, with the exception of 1 study, was level of evidence 3 and 4, with the majority of studies involving small cohorts of pitchers. This demonstrates the need for higher level prospective studies that can elucidate any deleterious effects of cumulative pitching workload in elite pitchers. Studies of this nature could further examine the benefit of pitch counts and cumulative workload on injury rates and performance in college and professional pitchers. Ultimately, higher quality research in this level of baseball pitcher will help to maintain the health, performance, and longevity of college and professional pitchers.

Although this conflicting evidence may suggest that developing athletes (Little League and high school) respond differently to musculoskeletal loads compared with elite athletes (college and professional), it may also be related to a survival bias. It is possible that the pitchers who attain collegiate and professional levels represent a cohort of players who have minimized physiologic and pathologic and performance changes with increasing pitching workload. These pitchers may have achieved their elite level of play due to an ability to avoid decreases in performance and injury with increasing stress and workload. Furthermore, these pitchers may have been able to train more and spend extra hours pitching as Little League and high school athletes without sustaining the detrimental effects often seen with high pitching volume. This training and durability advantage, compared with their teammates, could have allowed these pitchers to rise to the collegiate and professional ranks.

Another possible explanation for the difficulty in defining the relationship between workload and injury in the professional pitcher may be found in the work by Erickson and colleagues,[10] who demonstrate a correlation between Little League workload and professional UCL injury risk. Although this study had a significant risk of recall bias, it along with other physiologic studies demonstrated an association between long-term (>5.5 years of pitching experience)[2] exposure to pitching workload and UCL thickening in younger populations. This may indicate that a professional pitcher's risk of injury is likely a product of not only professional workload but also the cumulative, long-term stress imparted on the extremity over an athletic life time.

Interestingly, pitch counts in the acute settings noted above quantify only live, in-game (or simulated in-game) throws. Yet the upper extremity responds in a manner indifferent to the situation in which a force is applied: bullpen warm-up, between innings, or during a game. Consequently, the throw count (including bullpen warm-up, between-inning, and in-game pitches) experienced by the shoulder and elbow may be significantly distorted when quantified as only an in-game "pitch count." Rather, the throw count, inclusive of bullpen warm-up and between-inning pitches, may better capture the cumulative workload imparted on the thrower. Furthermore, this suggests that bullpen warm-up and between-inning pitches should be included in the pitch count limits determined by baseball organizing bodies. This suggestion is supported by Crotin and colleagues,[9] who reported that injured professional baseball pitchers threw significantly more warm-up pitches than uninjured athletes.

Limitations

The studies that met our inclusion and exclusion criteria had significant limitations. Methodological designs were different in all studies with respect to data collection, limiting the comparison between studies and the ability to make conclusions regarding the results. Additionally, the majority of studies were level 3 and level 4 evidence, including case-control and/or retrospective studies, limiting the ability to demonstrate a causal relationship and questioning the overall quality of evidence summarized in this systematic review. Our review included a limited number of publications (n = 28), particularly at the college and professional levels (n = 12). Furthermore, given the age ranges for the players in the included studies, we combined Little League and high school players into a single cohort and combined collegiate and professional pitchers into a second cohort. However, this was a comprehensive review, and the limited quality of evidence points to the need for higher level prospective studies regarding safe and effective pitch counts at all levels of baseball. Multiple studies demonstrated kinematic and ROM changes with increasing pitch count.[11,17,22,28,29,30] Although these changes may be significant, no existing literature suggests that these changes are injurious or detrimental to the pitcher. For example, Grantham et al[17] reported numerous kinematic changes over the course of a pitching outing, including decreased maximal external rotation during late cocking and decreased glove height during ball release and follow-through. Although these changes were significant, there is no reported literature to indicate that these kinematic changes will lead to pain, injury, or upper extremity abnormality. Furthermore, several different methods were used to collect and calculate pitch count and workload, with varying levels of accuracy. A prime example, as discussed above, is reporting only "in-game" pitches in a player's final pitch count. As a result, the pitch count is an incomplete representation of the pitcher's cumulative workload, as the pitcher will have thrown several warm-up pitches (on the field and in the bullpen) before an appearance and between innings. Finally, a few studies that discussed the injury or performance implications of pitch count monitoring were not found in our initial search results. These studies broached the subject of pitch counts but primarily addressed other related topics. Although the majority of these publications were found through "other sources," as per the PRISMA guidelines, it is possible that a few publications were not included that met our criteria.

CONCLUSION

Evidence, although limited, suggests the use of pitch counts to decrease injury rates and pain in Little League and high school baseball pitchers. However, further research must be performed to determine the appropriate number of pitches (or throws) for players of different ages. This systematic review reported conflicting evidence regarding the use of pitch counts in college and professional baseball. Future, high-quality research is required to determine the role, if any, of pitch counts for elite pitchers.

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