

Longitudinal study of elbow and shoulder pain in youth baseball pitchers

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ABSTRACT

LYMAN, S., G. S. FLEISIG, J. W. WATERBOR, E. M. FUNKHOUSER, L. PULLEY, J. R. ANDREWS, E. D. OSINSKI, and J. M. ROSEMAN. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med. Sci. Sports Exerc.*, Vol. 33, No. 11, 2001, pp. 1803–1810. **Purpose:** Previous studies among young pitchers have focused on the frequency and description of elbow injuries. The purpose of this study was to evaluate the frequency of elbow and shoulder complaints in young pitchers and to identify the associations between pitch types, pitch volume, and other risk factors for these conditions. **Methods:** A prospective cohort study of 298 youth pitchers was conducted over two seasons. Each participant was contacted via telephone after each game pitched to identify arm complaints. Generalized estimating equations were used to assess associations between arm complaints and independent variables. **Results:** The frequency of elbow pain was 26%; that of shoulder pain, 32%. Risk factors for elbow pain were increased age, increased weight, decreased height, lifting weights during the season, playing baseball outside the league, decreased self-satisfaction, arm fatigue during the game pitched, and throwing fewer than 300 or more than 600 pitches during the season. Risk factors for shoulder pain included decreased satisfaction, arm fatigue during the game pitched, throwing more than 75 pitches in a game, and throwing fewer than 300 pitches during the season. **Conclusion:** Arm complaints are common, with nearly half of the subjects reporting pain. The factors associated with elbow and shoulder pain were different, suggesting differing etiologies. Developmental factors may be important in both. To lower the risk of pain at both locations, young pitchers probably should not throw more than 75 pitches in a game. Other recommendations are to remove pitchers from a game if they demonstrate arm fatigue and limit pitching in nonleague games. **Key Words:** EPIDEMIOLOGY, COHORT STUDY, ARM INJURIES

Baseball is generally a safe and enjoyable sport in which millions of Americans participate (3); however, injuries do occur. One of the most common is overuse injury to the throwing arms of pitchers, believed to be a result of cumulative microtrauma from the repetitive, dynamic overhand throwing motion used to pitch a baseball (3,11). Although the most common age to participate in baseball pitching is from 9 to 18 yr, the determinants of arm injury among these pitchers are not well understood (5). Number of pitches thrown in a single game and types of pitches thrown have been suggested as determinants, though this has not been demonstrated empirically (3,4). Despite this lack of evidence, most youth leagues limit the number of innings that a pitcher throws per week. Nonetheless, arm complaints persist despite these regulations. Anecdotal evidence, corroborated by biomechanical research, has suggested that certain types of pitches (e.g., curveball, slider) are more stressful on the shoulder and elbow joints than others (e.g., change-up) (9,10). It has been recommended that these potentially harmful pitches should be reserved for older ages when the arm is more developed (4). Previous studies have demonstrated that arm injury risk among pitch-

ers increases with age (11,12,14), and it is possible that other developmental factors contribute to this increase.

The present research addresses the hypotheses that throwing breaking pitches (e.g., curveball, slider) and increased pitch volume (i.e., number of pitches thrown in a game or season) are associated with an increased risk of arm-related complaints in youth baseball pitchers, whereas throwing the change-up pitch is associated with a decreased risk. Other factors were measured, such as physical development, experience, skill, and frequency of participation. The study was conducted to address repeated requests for information from parents and coaches involved in youth baseball throughout the United States.

METHODS

This study used a prospective cohort design with follow-up consisting of two consecutive spring baseball seasons (1997 and 1998). Teams from two large youth baseball parks in the Birmingham, Alabama, metropolitan area were recruited. Each park had two pitching leagues: 9- and 10-yr-olds and 11- and 12-yr-olds.

The park directors provided the names and telephone numbers for all participating coaches and players. Introductory telephone contacts were made with all coaches to encourage participation, to identify probable pitchers for their teams, and to conduct a baseline interview. For the 336 potential pitchers identified for follow-up, parents of each

were contacted for their informed consent before recruitment. Once parental consent was obtained, the pitchers were invited to participate, and a baseline pitching interview was administered. Two parents refused participation, citing lack of interest and language barrier, respectively, as reasons for denial. Four pitchers declined the invitation to participate, all citing lack of interest. An additional 32 subjects were not included in the analyses because they did not make at least one pitching appearance.

Data on 298 pitchers were analyzed, 180 pitchers during the first season and 218 pitchers during the second season. One hundred of the 298 pitchers were followed for both seasons, resulting in a total of 398 pitcher seasons. The reasons for dropout between season one and two were graduation to 13- to 14 yr-old league ($N = 31$), coach during second season refused to participate ($N = 19$), moved to another park ($N = 11$), did not pitch during second season ($N = 10$), and did not play baseball during second season ($N = 9$).

Before the start of the season, coaches were given a pitch count book developed for this study. Explicit instructions for its use were included in the book. Interrater reliability testing revealed perfect correlation (Pearson's $= 1.00$) between team bookkeepers and random park visits by study personnel.

Once the follow-up period began, coaches were contacted after each game to identify the pitchers for that game. These pitchers were then contacted for a postgame telephone interview to collect information on the game in question and the occurrence of any pitching-related arm complaints. At the end of each season, pitchers were contacted to complete a follow-up pitching interview to identify any changes in characteristics collected at the beginning of the season.

Data collected with these interviews and the pitch count books included demographic characteristics (e.g., age, height, weight), baseball participation (e.g., years played, primary position played, baseball camp attendance), pitching history (e.g., seasons pitched, pitching practice frequency, pitch types used), and game characteristics (e.g., pitch count, self-satisfaction with performance, arm-related complaints). Inter- and intra-rater reliability testing of questionnaire responses revealed kappa coefficients consistently over 0.80, and data ranges suggested the young population largely understood the questions asked.

The outcomes of interest in this study were arm-related complaints, specifically pain or soreness in the elbow or shoulder joints during or after pitching in a league baseball game. This definition was restricted to the elbow and shoulder joints to limit the likelihood that the complaint of pain was muscle soreness of the upper arm, which commonly occurs with overhand throwing. Arm complaints in locations other than the elbow or shoulder were counted to gain perspective on their frequency. Pain severity was evaluated in order to differentiate between mild, minor, moderate, and serious elbow and shoulder-related complaints, and to better understand the nature of these complaints. Mild complaints were defined as pain in the elbow or shoulder joint without loss of league-sanctioned game or practice time. Minor

complaints were defined as pain in the elbow or shoulder joint with loss of time pitching in the game in which the pain occurred. Moderate complaints were defined as pain in the elbow or shoulder joint with loss of time in a subsequent league-sanctioned game or practice session, visiting a physician for evaluation, or stopping pitching for 2 wk or more during the season. Serious complaints were defined as cessation of pitching for the remainder of the season accompanied by physician evaluation and treatment. No serious complaints occurred during the study period. The questions used to categorize these complaints were taken directly from the history and physical exam protocol used to evaluate pitchers in the orthopaedic clinic of a senior author (JRA).

This study was approved by the Institutional Review Committee at the HEALTHSOUTH Medical Center in Birmingham, Alabama, and complied with the ethical guidelines outlined by the Declaration of Helsinki. All parents and children consented to study enrollment and any request to terminate involvement was honored without question.

Statistical Analyses

Statistical analyses were divided into two components, descriptive and inferential. To describe personal, behavioral, and baseball-related factors, standard statistical parameters were used, such as means and medians for continuous variables and frequency distributions for categorical variables. Responses that changed between the baseline and follow-up interviews were coded as the follow-up value (e.g., pitchers who learned the curveball during the season). A complaint rate was calculated by dividing the number of complaints by the number of pitching appearances $\times 100$. A period prevalence was calculated by dividing the number of pitchers experiencing pain by the total number of pitchers $\times 100$. Complaint rates and prevalences were calculated separately for elbow and shoulder pain.

Longitudinal analysis using a generalized estimating equation (GEE) was performed to allow for multiple events at different time intervals (e.g., game pitched) and for adjustment of game-specific covariates (e.g., pitches thrown per game) (8). The GEE allows for the possibility of dependence between events, and manipulation of the covariance structure allows for adjustment of the degree of dependence between time intervals. For the purpose of this analysis the covariance matrix was left unstructured to accommodate the lack of *a priori* understanding of the dependence between outcomes over time. The GEE remains robust even when the selected covariance structure is suboptimal (8). Simple GEE models were used to determine the bivariate relationship between suspected risk factors and elbow or shoulder pain. To evaluate the independent relationships between suspected risk factors and elbow or shoulder pain, stepwise GEE models were developed. Age, height, weight, game pitches, and cumulative pitches were forced into each model. All other variables thought to be significantly associated with elbow or shoulder pain were included in a full model. The least significant variables were then dropped one at a time. This procedure stopped when all

TABLE 1. Description of the study population.

Characteristics	Mean ± SD	Min-Max	N (%)
Individual characteristics			
Population size			298 (100)
Age in years	10.8 ± 1.2	8.1–12.4	
Height in inches	57.2 ± 3.9	46–68	
Weight in pounds	86.7 ± 20.4	50–179	
Right-handed thrower			
Pitch types used			
Change-up			188 (63.1)
Curve			99 (33.2)
Slider			16 (5.5)
Sinker			24 (8.2)
Knuckle			13 (4.4)
Game characteristics			
Pitching appearances			2,699 (100)
Innings pitched	2.4 ± 1.3	0–7	
Pitches thrown	42.7 ± 24.6	1–154	
Self-satisfaction			
Excellent			494 (18.4)
Good			1,414 (52.7)
Average			502 (18.7)
Fair			162 (6.0)
Poor			110 (4.1)

eligible variables remaining in the model had a *P*-value of <0.10. This was repeated using forward stepwise GEE modeling and identical models were identified, suggesting the modeling technique is appropriate.

Odds ratios (OR) and 95% confidence intervals (95% CI) were obtained through the GEE for all potential determinants of either elbow or shoulder pain. *P*-values were considered statistically significant if less than 0.05. All analyses were performed using the SAS System for Windows version 6.12 (The SAS Institute, Cary, NC).

RESULTS

Population Characteristics

As seen in Table 1, the average age, height, and weight were 10.8 yr (range 8.1–12.4), 4'9" (range 3'10" to 5'8"), and 87 pounds (range 50–179). Nearly 94% of the pitchers were right handed. A majority threw change-up pitches, and about one third threw curveballs. Sinker, slider, and knuckle ball pitches were much less common (<10%). During follow-up, the 298 pitchers made 2699 pitching appearances, appearing in an average of 9 games (range 1–30) each. Each appearance averaged 2.4 innings (range 0–7) and 43 pitches (range 1–154). After each game pitched, study participants were asked to rate their pitching performance using a 5-point Likert scale (1=poor; 5=excellent). Pitchers classified more than 70% of their pitching appearances as either good or excellent performances.

Complaint Frequency

The most commonly reported complaint was pain in the shoulder, reported by 32% of pitchers in 7% of pitching appearances (Table 2). Elbow pain was reported by 25.5% of the pitchers in 4.5% of their pitching appearances. Elbow or shoulder pain was reported in 47% of the pitchers over the course of the study. Pain was reported in other arm locations by 28% of pitchers in more than 5% of all pitching appearances.

TABLE 2. Location of pain in elbow, shoulder, and other arm complaints.

Variable	Pitchers (%)	Appearances (%)	Complaints (%) ^a
Elbow pain			
Medial	76 (25.5)	123 (4.6)	65 (52.9)
Lateral			33 (26.8)
Medial and lateral			19 (15.5)
Internal			3 (2.4)
Posterior			3 (2.4)
Shoulder pain			
Anterior	95 (31.9)	191 (7.1)	4423.0
Posterior			3417.8
Superior			5528.8
Lateral			3819.9
Multiple			2010.5
Other arm pain			
Upper arm	83 (27.9)	141 (5.2)	127 (88.2)
Forearm			11 (7.6)
Wrist			4 (2.8)
Finger			2 (1.4)

^a Among those reporting pain.

Pain Location

More than 68% of elbow pain occurred on the medial side of the elbow with or without lateral involvement (Table 2). An additional 27% of elbow pain occurred on the lateral side without medial involvement. Nearly 29% of shoulder pain was located in the superior aspect of the shoulder, whereas approximately 20% of shoulder pain was located in each of the anterior, posterior, and lateral aspects. The remaining 10% reported shoulder pain in more than one location. The primary location for other arm pain was the upper arm (88%). Other, infrequent, pain locations were the forearm, wrist, and finger.

Pain Severity

A majority of all pain complaints were mild in nature, with 70% or more being classified as such (data not shown). Eight pitchers who reported moderate elbow or shoulder pain had an additional complaint of arm pain; six different pitchers reported moderate arm pain in another location with no elbow or shoulder involvement. A total of 13 arm-related physician visits were reported. Three pitchers visited a physician for elbow pain: all were diagnosed with medial epicondylitis. Two pitchers visited a physician for shoulder pain. One was diagnosed with a muscle strain and the other with an inflamed rotator cuff. Physicians diagnosed four other pitchers with arm complaints. Two were diagnosed with fractured fingers, one with a collarbone injury (not otherwise specified), and one with arm weakness.

Elbow Pain

Pitches, innings, games, and pitch types. There was a 6% increase in the odds of elbow pain per 10 pitches thrown in a given game (Table 3); over 75 pitches, odds of elbow pain increased over 50%. Cumulative pitches thrown before the game in which pain occurred had a protective effect (OR = 0.54, *P* = 0.02) when comparing the 300–599 pitch category with the <300 pitch category; however, when the ≥ 600 pitch category is compared to the <300 pitch category, the opposite effect is observed (OR = 2.07,

TABLE 3. Association between pitches, innings, games, and pitch types with elbow and shoulder pain.

Variable	Elbow Pain OR (95% CI)	P	Shoulder Pain OR (95% CI)	P
Game pitches, per 10 pitches	1.06 (1.00,1.12)	0.06	1.15 (1.08,1.23)	<0.01
Pitches in game				
1–24	Referent	0.21 ^a	Referent	<0.01 ^a
25–49	1.26 (0.78,2.03)		1.27 (0.88,1.83)	
50–74	1.10 (0.67,1.80)		1.61 (1.04,2.49)	
≥75	1.56 (0.89,2.75)		3.22 (1.84,5.61)	
Cumulative pitches				
<300	Referent	— ^b	Referent	<0.01 ^a
300–599	0.54 (0.32,0.92)	0.02	0.40 (0.24,0.65)	
≥600	2.07 (0.68,6.26)	0.20	0.13 (0.01,1.10)	
Innings in game	1.07 (0.96,1.20)	0.23	1.21 (1.07,1.36)	<0.01
Total innings, per 10 innings	0.92 (0.80,1.06)	0.30	0.54 (0.42,0.69)	<0.01
Games pitched	0.94 (0.87,1.02)	0.15	0.85 (0.80,0.91)	<0.01
Pitch types				
Fastball only	Referent	—	Referent	—
Change-up	1.06 (0.59,1.90)	0.85	0.74 (0.45,1.21)	0.23
Curve	1.11 (0.66,1.85)	0.70	1.39 (0.83,2.33)	0.22
Slider	1.17 (0.66,2.08)	0.58	0.44 (0.05,3.59)	0.44
Sinker	1.70 (0.99,2.93)	0.06	1.08 (0.47,2.52)	0.85

^a Test for trend.

^b Linear trend test not calculated because assumptions were violated.

$P = 0.20$). Innings and games pitched were not associated with elbow pain.

The use of a split-finger pitch (e.g., forkball, sinker, splitter) resulted in an increased odds of having elbow pain (OR = 1.70, $P = 0.06$). When pitch types were stratified by age group, it was found that older pitchers (11- and 12-yr-olds) who threw a change-up had a significantly decreased odds of elbow pain (OR = 0.27, $P = 0.01$). This association was not found for younger pitchers (9- and 10-yr-olds). There was no indication of other pitch types being associated with elbow pain.

Multivariable analysis. Multivariable analysis was conducted to identify independent relationships between

elbow pain and suspected risk factors. Age, height, weight, game pitches, and cumulative pitches were forced into the model. Increased age, increased weight, and lower height were found to be significant independent risk factors for elbow pain. (Table 4). Cumulative pitches thrown before the game of interest maintained a significant J-shaped relationship with 300–599 pitches thrown resulting in a decreased risk, and throwing ≥ 600 pitches resulting in increased risk of elbow pain compared with <300 cumulative pitches thrown. Other significant risk factors included reporting fatigue during the game, decreased self-satisfaction with performance, weight lifting, and playing baseball outside the league. Pitches thrown in the game was not a significant

TABLE 4. Multivariable models for elbow and shoulder pain.

Factor	Elbow Pain OR (95% CI)	P	Shoulder Pain OR (95% CI)	P
Age (mean = 10.8 years)				
<10 yr	Referent	0.02 ^a	Referent	0.13 ^a
10 yr	1.66 (0.71,3.88)		0.55 (0.29,1.03)	
11 yr	2.60 (0.99,6.81)		0.68 (0.28,1.65)	
≥12 yr	2.91 (1.14,7.41)		0.41 (0.14,1.15)	
Weight (mean = 86.7 lbs)				
<71 lbs	Referent	<0.01 ^a	Referent	0.87 ^a
71–85 lbs	1.31 (0.57,3.01)		1.30 (0.63,2.66)	
86–100 lbs	4.11 (1.71,9.86)		1.18 (0.54,2.57)	
≥101 lbs	5.39 (1.74,16.70)		0.94 (0.33,2.70)	
Height (mean = 57.2 inches)				
<55 inches	Referent	0.04 ^a	Referent	0.07 ^a
55–58 inches	0.79 (0.35,1.82)		1.15 (0.52,2.52)	
59–60 inches	0.45 (0.17,1.19)		2.26 (0.83,6.15)	
≥61 inches	0.35 (0.12,0.99)		3.59 (1.10,11.69)	
Pitches in game				
1–24	Referent	— ^b	Referent	0.01 ^a
25–49	0.99 (0.46,2.15)	0.98	1.19 (0.80,1.76)	
50–74	0.82 (0.43,1.55)	0.53	1.48 (0.89,2.45)	
≥75	1.16 (0.68,1.98)	0.59	2.48 (1.33,4.60)	
Cumulative pitches				
<300	Referent	— ^b	Referent	<0.01 ^a
300–599	0.47 (0.24,0.92)	0.03	0.51 (0.33,0.80)	
≥600	3.44 (0.84,14.12)	0.09	0.19 (0.05,0.68)	
Arm fatigue during outing	5.94 (3.48,10.14)	<0.01	4.14 (2.76,6.22)	<0.01
Self-perceived performance	0.83 (0.70,0.99)	0.04	0.75 (0.65,0.86)	<0.01
Weight-lifting	1.99 (1.07,3.70)	0.03	—	—
Baseball outside league	2.35 (1.26,4.38)	0.01	—	—

^a Linear trend test.

^b Linear trend test not calculated because assumptions were violated.

risk factor for elbow pain after adjustment for the other factors.

Shoulder Pain

Pitches, innings, games, and pitch types. Every 10 pitches thrown resulted in significantly increased odds ($P < 0.01$) of shoulder pain (Table 3). This trend was also seen when the game pitches were categorized into 25 pitch increments, with pitchers in the highest category (≥ 75 pitches) being 3.2 times more likely to experience shoulder pain ($P < 0.01$) than those in the lowest category (< 25 pitches). However, for cumulative pitches before the game in which pain occurred, risk decreased significantly ($P < 0.01$). Each inning pitched in a specific game was associated with an increased risk of shoulder pain. However, every 10 cumulative innings pitched during the season and each additional game pitched during the season resulted in a decreased risk of shoulder pain. When pitches thrown in a game and innings pitched in the game were adjusted for one another, the effect of pitches remained nearly constant (13% per 10 pitches), but the effect of innings disappeared.

There was no significant association of any pitch type with shoulder pain.

Multivariable analysis. Fewer independent risk factors were identified for shoulder pain than for elbow pain. Increased pitches per game, decreased cumulative pitch total, arm fatigue, and lack of self-satisfaction with performance were identified as risk factors for shoulder pain (Table 4).

DISCUSSION

Overall, young pitchers appeared to frequently suffer from elbow or shoulder pain. The associated factors appeared to be different for each, suggesting diverse etiologies. Elbow pain was associated with increased age, decreased height, increased weight, cumulative pitch counts, arm fatigue, self-perceived performance, weight-lifting, and playing baseball outside of the league. Shoulder pain was associated with increased game pitches, decreased cumulative pitch counts, arm fatigue, and decreased self-perceived performance.

The total number of pitchers ($N = 298$) and the two season follow-up represent the second largest study group of its kind and matches the longest follow-up period for a study of young pitchers. This is the first study of its kind in which arm pain was evaluated after each game pitched rather than through a cross-sectional survey or at the end of a season. This allowed for evaluation of injury per appearance, which should be more reliable than postseason recollections. With the exception of a study looking at pitching mechanics (16), this is the first study to evaluate a variety of risk factors for arm pain in young pitchers, to separately evaluate risk factors for elbow and shoulder pain, and to do multivariable analyses.

In general, ages, definitions of pain, percentage of pitchers reporting pain, and locations of pain in the present study

are very similar to that found in prior studies. Pitchers in previous studies may have been more experienced because 9- and 10-yr-olds either were not included or were included in very small numbers (1,2,12–14,17). Pitchers in the present study averaged 2.4 innings and 43 pitches per appearance (18 pitches per inning), consistent with a previous report looking at pitch counts in these ages (12).

Identification of pitchers with pain is likely more accurate in the current study than in previous studies because the pitcher was contacted after each game pitched rather than at the beginning or end of a season. No x-rays were performed for this evaluation. This should not be considered a limitation of the present study because no previous study has demonstrated an association between arm pain and radiographic changes (1,12–14,17).

Two previous studies of American youth league pitchers found that elbow pain was present in 18% of pitchers aged 11 and 12 yr (12,14), similar to the current study (22% per season). Only one study has examined the prevalence of shoulder pain among young pitchers, and they found that 26.5% had had shoulder pain by the end of a youth league season (17), similarly 29% of pitchers reported shoulder pain per season in the current study.

As was found with previous studies of elbow pain, the medial aspect of the elbow was the most common site affected (1,12,13). Medial epicondylitis in young pitchers has been referred to as Little League elbow (7), though this is an unfair implication of Little League, Inc., which has done much to further the understanding of arm pain in youth pitchers.

Little League shoulder has also been identified in the literature, but the location of the pain is not specifically defined (17). A study of symptomatic adult athletes receiving treatment found that the most common locations for pain were the anterior and posterior shoulder (6). In the current study, however, a substantial number of pitchers reported superior (28.8%) and lateral pain (19.9%). This difference is possibly because pitchers in the current study rarely sought professional treatment; therefore, their pain profile differed from a population of pitchers seeking medical care. Superior or lateral pain is likely to involve muscle soreness of the deltoid, whereas anterior or posterior pain may represent a more serious injury to the shoulder capsule or rotator cuff, thus prompting medical evaluation.

Elbow Pain Risk Factors

Age and weight appear to be the primary developmental risk factors for elbow pain, with the highest two quartiles for each resulting in significantly increased odds. The association with age has been well established. Older ages consistently have higher rates of elbow pain than younger ages (11,12,14). That this increase was found within only 2–3 yr in age, between ages 9 and 12, may have important implications. One hypothesis focuses on the secondary ossification centers (16). These centers begin to ossify between the ages of 2 and 11 and do not fuse to the long bones until as late as age 17 (16). It is possible for there to be as many as

six secondary ossification centers present in the elbows of 11- to 12-yr-old boys. These centers are the most vulnerable points in the young elbow and can become inflamed and irritated by the throwing motion. The finding that the 11- and 12-yr-olds in this study had higher rates of elbow pain than the 9-yr olds is consistent with this hypothesis. The finding that increased weight, independent of age, is a risk factor for elbow pain may have a similar explanation. Heavier pitchers may be putting more of a burden onto their immature skeletons, thereby exacerbating elbow weakness, resulting in an increased likelihood of elbow pain.

Pitchers who played recreational baseball not sanctioned by their league had a significantly increased likelihood of elbow pain. It is likely that these pitchers were not only playing outside their league games and practices but may also have been pitching in these games. This would greatly increase their pitch volume if they were playing consistently. It is also possible that these pitchers were throwing at or near maximum effort in these games in order to succeed among their peers. This was not evaluated in this study and may be an interesting topic for future research. One possible recommendation is to limit or discourage pitching in these unsanctioned contests and to encourage playing other positions instead.

Involvement in physical activities beyond baseball was evaluated because muscular fitness may play a role in arm pain in children. Also, some sports or activities may increase or decrease the odds of pain if played during the baseball season. Participation in other sports or activities during the baseball season has not previously been considered as risk factors for elbow pain in young pitchers. This study found that pitchers who lifted weights were at increased risk of elbow pain; however, this is a tenuous association because of the broadness of the question. The current study simply asked, "Did you lift weights during the baseball season?" No questions were posed concerning the frequency or type of weight lifting done or the presence of adult supervision.

Arm fatigue while pitching was strongly associated with increased elbow pain. This may be the most useful finding for both parents and coaches with regard to preventing elbow pain in these children. If pitchers complain of or demonstrate signs (e.g., increased inaccuracy of pitches) of arm fatigue while pitching in a game, that may be a sign that it is time to remove them from the contest to avoid injury. Arm stiffness in the previous game pitched was also associated with an increased risk of elbow pain (data not shown). This finding may be used to encourage coaches to decrease use of pitchers who experience stiffness after pitching to prevent elbow pain.

Pitchers who were less satisfied with their pitching were more likely to report elbow pain; this was also true for shoulder pain. A lower self-rating may be consequent to poor performance brought on by arm pain or a result of poor performance for which arm pain is being used as an explanation.

A study conducted by Little League, Inc., found no relationship between average number of pitches thrown per inning and elbow pain (12) as was found in the current study. However, every 10 pitches thrown in a game resulted in a 6% increased odds of elbow pain in the current study. Although this does not

appear to be a strong relationship, there are serious implications for pitchers throwing a large number of pitches in a game. In the course of the follow-up period, there was one pitcher who threw 154 pitches in a single outing, more than three times the average number of pitches (43 pitches).

No previous study has considered cumulative pitches up to the game of interest as a risk factor for elbow pain in youth pitchers. A J-shaped relationship was apparent for cumulative pitches, with pitchers being more likely to have elbow pain during their first 300 pitches than during their second 300 pitches. This may be because pitchers who had elbow pain early in the season were less likely to throw more than 300 pitches because of the pain. Another possible explanation is that early elbow pain was a result of a lack of arm conditioning, whereas late (≥ 600 pitches) elbow pain was as result of overuse of the elbow. This would suggest that cumulative pitches thrown during a season is an important risk factor for elbow pain.

No other studies have considered the impact of pitch types with regard to elbow pain in this age group. Only use of the sinker pitch was found to be a potential risk factor for elbow pain; however, this association disappeared after adjustment for other factors. It is unlikely that most pitchers of these ages are properly throwing sophisticated pitches such as the sinker or slider, but attempting to throw these pitches or throwing them incorrectly may be harmful to the elbow or shoulder. As hypothesized, pitchers who threw a change-up were at a decreased risk of elbow pain; however, this was apparent only after adjustment for age and predominantly in 11- and 12-yr-old pitchers. This suggests that pitchers should be encouraged to learn the change-up to improve pitching performance and decrease the risk of elbow pain.

Shoulder Pain Risk Factors

We found that developmental measures such as age and weight did not appear to be as important to the risk of shoulder pain as they were with elbow pain. However, increased height, after age-adjustment, demonstrated a nonsignificant increased risk of shoulder pain. Taller pitchers likely have longer arms, and these arms likely weigh more than shorter arms, resulting in more weight being maintained by the shoulder joint during pitching. This creates a greater moment of inertia, resulting in higher torque on the shoulder joint.

As was seen for elbow pain, arm fatigue while pitching was a strong risk factor for shoulder pain. Again, it may be important for coaches and parents to watch for early signs of problems in order to intervene before the onset of pain. Stiffness in the prior pitching appearance does not appear to be a risk factor for shoulder pain. This is likely due to the increased musculature stability of the shoulder compared to the elbow.

Game pitches were a significant risk factor for shoulder pain, with each pitch resulting in a 1.5% increased risk of shoulder pain and a significant trend per 25 pitches thrown. This was especially apparent when more than 75 pitches had been thrown in a game. This would suggest that a pitch limit of 75 pitches might be instituted in these age groups. It

appears that pitches thrown are a more precise measure of risk than innings pitched; therefore, any recommendations should focus on pitches rather than innings. Young, inexperienced pitchers tend to throw more pitches per inning than older, experienced pitchers, so an innings limit may be allowing younger, less developed arms to throw more pitches than older, developed arms in the same league.

Cumulative pitches thrown appeared to have a protective effect on the shoulder, supporting the hypothesis that shoulder pain is often a result of a lack of strength or conditioning early in the season, resulting in protection as the arm strengthens over the course of the season. Because the shoulder relies more on musculature for stability than does the elbow, it is possible that pitchers reduce shoulder pain risk as they develop muscle. However, once the pitcher ages and cumulative use reaches a certain level, there is apparently a higher risk of serious shoulder injury, resulting from accumulated microtrauma to the rotator cuff (15), though this was not seen in this young cohort.

The use of a change-up and slider were associated with a decreased risk of shoulder pain. Baseball experts suggest that the slider be learned after the fastball, change-up, and curveball (4). As mentioned previously, young pitchers who reported throwing sophisticated pitches may not be throwing them correctly. However, if they are throwing a slider correctly, they may have better mechanics or overall pitching skills than other young pitchers. As hypothesized, the curveball resulted in an increased risk of shoulder pain, though this was not significant.

CONCLUSION

The elbow and shoulder pain evaluated in this study are common injuries experienced among youth baseball pitchers (17). Although these conditions are prevalent in youth baseball, we found that a surprisingly small number of studies had been conducted to identify risk factors for these problems. The primary finding in this study is that the etiologies of elbow and shoulder pain are different from one another, and, therefore, any recommendations should be made only if the prevention of pain in one location does not increase the risk of pain in the other location. Little or no reduction in the frequency of elbow pain was found when comparing the current study with

studies conducted before initiation of the current pitching regulations (1,17). More stringent limitations may be needed to reduce the frequency of elbow pain in these young players. No previous study has been conducted for shoulder pain in a similar population; therefore, it is difficult to make this same inference about the adequacy of current regulations.

The suggestion from the pitch count findings from this study is that pitchers in this age group should not throw more than 75 pitches in a single game to limit the risk of shoulder, and possibly elbow, pain. Therefore, an answer may be a pitch count regulation rather than current weekly innings limits. Although the cumulative pitches issue is less clear, it appears that throwing more than 600 game pitches in a single season is a risk factor for elbow pain. Thus, a season-long pitch limit might be considered, though further research of cumulative pitches may be necessary.

From the age-adjusted results regarding pitch types, pitchers of all ages should be encouraged to learn the change-up as opposed to other off-speed or breaking pitches, not because the other pitches are necessarily harmful but because the change-up is safer. The findings also suggest that pitchers who use the sinker might consider discontinuing or limiting use of that pitch to reduce the risk of elbow pain. As mentioned previously, pitchers who report arm fatigue while pitching are at vastly increased odds of elbow and shoulder pain. Therefore, pitchers with complaints of arm fatigue should perhaps be removed from pitching in the game. Other recommendations supported by these results include education for pitchers and coaches concerning proper strength and conditioning programs (5) and reducing the pitching done in nonleague games.

With the paucity of information available in the medical literature regarding arm pain in youth baseball, it is hoped that this study will improve the abilities of parents, coaches, and health professionals to oversee the activities of young pitchers to keep them free from pain. It is also hoped that this research will provide direction for future studies to explore and confirm these findings.

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