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Arm complaints in youth baseball pitchers: Frequency and associations with pitch volume, pitch type, and other factors.

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ARM COMPLAINTS IN YOUTH BASEBALL PITCHERS: FREQUENCY AND ASSOCIATIONS WITH PITCH VOLUME, PITCH TYPE, AND OTHER FACTORS

by

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A DISSERTATION

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ABSTRACT OF DISSERTATION
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Title Arm Complaints in Youth Baseball Pitchers: Frequency and Associations with Pitch Volume, Pitch Type, and Other Factors

Baseball is one of the most popular sports for children to play, and pitching remains the most glamorous position. It also remains the most common fielding position in which players experience arm problems. Previous studies of arm complaints 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 pain in young pitchers and to identify risk factors for these conditions, specifically the role of pitch counts and pitch types used.

A prospective cohort study of 298 9- to 12-year-old pitchers was conducted over two spring baseball seasons. Each participant was contacted via telephone after each game pitched to identify arm complaints. Hypotheses were tested using a generalized estimating equation. The generalized estimating equation provides a new method of analysis for the sports medicine researcher, accommodating repeated measurements of outcome and exposure while controlling for the dependence between observations within subjects.

The frequency of elbow pain was 26%, and the frequency of shoulder pain was 32%. The factors associated with elbow and shoulder pain were different, suggesting

separate etiologies for each condition. Independent risk factors for elbow pain were increased age, increased weight, private pitching instruction, weight lifting, playing baseball outside the league, arm fatigue, and throwing fewer than 300 or more than 600 pitches during the season. Risk factors for shoulder pain included increased height, arm fatigue, increasing pitches thrown in the game of interest, and having thrown fewer than 300 pitches during the season.

Elbow and shoulder in young pitchers are common. The risk of shoulder pain can be lowered among young pitchers by not allowing them to throw more than 75 pitches in a game. Other recommendations would be to remove pitchers from a game if they report arm fatigue and to limit pitching done in nonleague games. Future studies should focus on the impacts of skeletal development and the pitching motion on these complaints. It is hoped that these recommendations will reduce the frequency of these complaints and make baseball a safer game for young pitchers.

DEDICATION

To my God, who gave me life. To my parents, who put up with me for years 0-26. To my wife, Jacquelyn, who has taken over the duties. To Coach Terry Hahn, who never knew his right fielder would grow up to *play* baseball. To every little boy and girl who might be protected as a result. I dedicate this to you.

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INTRODUCTION

In the United States, over 19 million people play organized baseball each year, a vast majority of whom are children and teenagers [1]. Approximately 25% of these young athletes participate in pitching. Pitching is the primary defensive activity in the sport of baseball, and it requires the repetition of a dynamic arm motion during which the pitcher delivers the ball to the batter. Rates of serious or traumatic injury in youth baseball are very low [2-4]. However, several studies have found high rates of mild-to-moderate elbow and shoulder pain in youth and adolescent pitchers [5-14]. These injuries are believed to be a result of overuse of the affected joints. Furthermore, continued overuse is believed to eventually result in serious injury in some pitchers [15].

Frequency

Table 1 summarizes the findings of studies conducted between 1965 and 1994. In 1965, Adams conducted the seminal epidemiologic study on this issue. This study identified injuries as pitcher self-report of elbow soreness while pitching [5]. Adams compared three groups of male children: pitchers, baseball players who did not pitch, and healthy boys who did not play baseball. The frequency of arm pain was higher in the group of young pitchers than in the other groups.

Table 1. Previous Studies of Elbow and Shoulder Injury in Youth Pitchers

Study (year)	Level, Location	*N*	Age (years)	Joint	Measure	%	%[a]
Adams [5] (1965)	Various, California	80	9-14	Elbow	Prevalence	45	95
Torg et al. [6] (1972)	Boys' Club, Pennsylvania	49	9-18	Elbow Shoulder	Prevalence	29 29	4 n.a.
Gugenheim et al. [7] (1976)	Little League, Texas	595	11-12	Elbow	Prevalence	18	28
Larson et al. [8] (1976)	Little League, Oregon	120	11-12	Elbow	Prevalence	18	95
Albright et al. [9] (1978)	Little League, Connecticut	54	11-12	Both	Incidence	44	n.a.
Grana & Rashkin [10] (1980)	High School, USA	73	15-18	Elbow	Incidence	58	56
Hang [12] (1983)	Little League, Taiwan	112	11-12	Elbow	Incidence	69	62
Ochi et al. [14] (1994)	High School, Japan	130	15-18	Elbow Shoulder	Prevalence	38 38	43 n.a.

[a] Percentage with radiographically defined abnormalities of the elbow joint

A study among Boys' Club baseball league players in Philadelphia, Pennsylvania revealed that an identical number of pitchers had elbow and shoulder pain (29%) [6]. This study included pitchers ages 9 to 18.

Two U.S. Little League studies, conducted in Houston, Texas and Eugene, Oregon, inquired about prior elbow injury, as well as past and present elbow symptoms, to identify injuries. These studies used identical surveys to conduct personal interviews and found identical frequency of elbow pain (18%) [7,8].

A two-season study of 54 Little League pitchers in New Haven, Connecticut revealed that 44% of youth pitchers reported elbow or shoulder pain during the follow-up period. This study did not separate the conditions, treating them as a single arm problem [9].

A one-season study of 130 U.S. high school pitchers identified injuries as self-reported elbow pain resulting from pitching during a preseason or regular season game [10]. Six of these pitchers experienced an acute episode of pain that inhibited performance, and four of the six missed at least one pitching turn. Ten pitchers had a previous history of elbow injury and had residual pain during the season studied, and 26 pitchers reported pain in the elbow without a previous history. No pitcher missed game time during the season as a result of elbow discomfort [10].

A Taiwan Little League study evaluated all pitchers participating in the 1980 Taiwan Little League championship tournament. Injury was defined as a complaint of elbow soreness during the tournament. This study evaluated a specific location of elbow injury and found that 41% of the pitchers experienced tenderness over the medial epicondylar region of the elbow during the tournament [12]. Another Asian study among Japanese High School pitchers was conducted during the Japanese High School Baseball Association national championship. Injury was defined as a self-reported history of shoulder or elbow pain, and a frequency of 38% was found for each [14].

All of the above studies used radiographic comparison of pitchers' throwing elbows to their nonthrowing elbows. The initial study in 1965 identified radiographic changes in the arms of 95% of the pitchers, compared with 11% in the group of non-pitching baseball players [5]. The Pennsylvania study found that only 4% of pitchers had radiographic changes that could be attributed to pitching [6]. The Houston study found that 95% of the pitchers had radiographic changes in their throwing elbows, compared with 28% in the Eugene study [7,8]. The U.S. high school study found that 56% of the pitchers had radiographic changes [10]. Among the Taiwanese Little League pitchers, 62% had radiographic changes [12]. In the study of Japanese high school pitchers, radiographic evaluation revealed elbow changes in 43% of the pitchers [14]. In no study was the radiographic identification of elbow abnormality correlated with elbow pain. Individual interpretation of the radiographs may explain part of the differences identified. The studies also used inconsistent definitions of *abnormal* when reviewing radiographs. No study examined the shoulders of these pitchers with radiographs.

Francis, Bunch, and Chandler reported that 15% of a sample of 398 male college students who pitched in youth baseball felt their ability to throw in college was hindered or hampered by pain, tenderness, or limitation of movement as a result of their youth baseball pitching. Also, 58% reported having experienced arm pain at some point during their youth league years. Radiographic evaluation found no differences between those who reported pain and those who did not [16]. This is not surprising since none of the studies that evaluated radiographic changes have linked these changes to injury [5-14]. Nevertheless, this study suggests a potential for sports-related disability that is associated with youth baseball pitching and continues into adulthood.

Determinants

Relatively little research has been published concerning determinants of arm injury in youth league baseball pitchers. The Little League surveys from Houston and Eugene found that the effect of number of years pitching did not significantly influence the likelihood of arm injury [7,8]. Furthermore, the study of American high school pitchers found no relationship between number of years playing baseball and arm injury [10].

The Houston study calculated the average pitches per inning for approximately 25% of the pitchers. No association was found between average pitches per inning and self-reported elbow pain. The authors stated that this was probably because those pitchers who threw more pitchers per inning were not used as often as those with better control. No further statement was made concerning this issue [7].

The U.S. high school study attempted to qualify the pitching motion using three separate indices: orientation of the hand to the shoulder, velocity, and pitching style. Orientation of the hand to the shoulder was described as tight or loose and was based upon the distance between the hand and the shoulder during the acceleration phase of the pitching motion. Velocity was described as hard or moderate ball speed. Pitching style was defined as overhand, three-quarters, or sidearm and was determined by the position of the extremity in relation to the trunk during delivery. All three indices were determined jointly by the team coach and one of the authors viewing the pitcher throwing from a pitcher's mound. None of these indices were associated with current elbow pain except among those pitchers with previous injury, who were more likely to have a loose orientation and moderate velocity. The investigators concluded that this association was likely a result of compensation for the previous injury rather than a cause of the current injury [10].

A study by Albright found that pitchers who threw with a sidearm motion rather than overhand motion were at increased risk of elbow pain [9]. Other aspects of the pitching motion were evaluated, but none were found to be significant.

The study among high school pitchers stated that approximately 80% of the pitches thrown were breaking pitches (i.e., pitches that are thrown with the intention of deceiving the hitter through downward or horizontal movement of the ball during flight). No attempt was made to examine the relationship between these pitches and risk of elbow pain [10].

Biomechanics

Although the epidemiological literature is sparse on the subject of determinants of arm injury in youth baseball pitchers, biomechanists have not ignored this issue. Research conducted at the American Sports Medicine Institute (ASMI) in Birmingham, Alabama has quantified shoulder and elbow kinetics (i.e., forces and torques) with implications for injury mechanisms [17,18]. Proper pitching kinematics (i.e., motions) have also been quantified [19,20], and a relationship between improper kinematics and increased kinetics has been demonstrated [21]. A recent study found that there are few differences between youth and adult pitching kinematics, implying that a youth pitcher may be able to learn proper mechanics at a young age [22]. Research has also been conducted to compare the biomechanics of the fastball and the two most common breaking pitches, the curveball and the slider. The results indicate that the curveball may be the most difficult and dangerous pitch to learn, as it is thrown hard like a fastball and slider, but with significantly different mechanics [22-24].

Regulations

Youth baseball leagues regulate pitchers, but the current standards may be inadequate to prevent arm injuries. The leagues currently have limits on the number of innings pitched (e.g., six innings pitched per week) and required rest periods (e.g., minimum of 48 hours rest after at least two innings pitched). These regulations apply to all pitchers within a youth league organization [25]. The difficulty with this regulatory system is that younger pitchers tend to throw more pitches per inning than older pitchers because they have less control over their pitches because of lack of experience, greater musculoskeletal immaturity, or both [26]. Therefore, with innings limits, those with potentially weaker and less developed arms are throwing more pitches than those with stronger arms. It is possible that these youth league organizations could more effectively prevent these injuries in pitchers with pitch limits or batter limits.

Significance

With so many athletes participating in pitching, there are ample opportunities for arm injury. Although baseball is one of the safest team sports in which athletes participate [2-4], the sheer number of players makes any relatively frequent injuries important to prevent. Among pitchers, the repetitive nature of the activity places these athletes at high risk for overuse injuries and long-term sports-related disability. The facts that mild to moderate elbow and shoulder injury occurs at very high rates among youth league pitchers [5-14] and sports-related disability has been associated with youth baseball pitching [16] make these injuries especially important to prevent.

The purpose of this study was to elucidate the effect of pitch type and pitch volume on risk of self-reported arm pain among youth league baseball pitchers and to evaluate other potential determinants of these complaints. It is anticipated that youth league organizations, coaches, and pitchers will use the results of this research to help prevent these injuries in the future.

Goals and Objectives

The goals of this research were to reduce the pain and discomfort experienced by youth league baseball pitchers, evaluate the effectiveness of current youth league safety regulations for pitchers, and provide USA Baseball with information that may be used to institute revised safety recommendations. USA Baseball is the national governing body for amateur baseball in the United States and is in a position to influence the pitching regulations in youth leagues across the country. The goals were accomplished primarily through the main objective of this research: to examine the relationship between pitch types and pitch volume, and the risk of arm-related complaints. An additional objective was to identify other potential risk factors for these arm-related complaints.

Accomplishing the objectives may help define the relationship between arm injury in youth baseball pitchers and pitching patterns, especially pitch volume and pitch type. Dr. James Andrews, who sits on the Medical and Safety Advisory Committee of USA Baseball, will present the findings of this study to USA Baseball. USA Baseball will use this information to educate youth baseball organizations about the risk factors for arm-related complaints among youth baseball pitchers. The study findings will also be presented at the annual ASMI Injuries in Baseball course and at community meetings at each of the participating parks. The annual ASMI Injuries in Baseball course is a meeting for physicians, physical therapists, athletic trainers, coaches, and others who are involved in the prevention, treatment, and rehabilitation of baseball injuries. In addition, the recommendations may assist in determining pitch limits and minimum ages at which certain pitch types can be learned safely.

LONGITUDINAL STUDY OF ELBOW AND SHOULDER PAIN IN YOUTH BASEBALL PITCHERS

by

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ABSTRACT

Baseball remains one of the most popular sports for children to play, and pitching remains the most glamorous position. It also remains the single most common position in which players experience arm problems. Previous studies of arm complaints 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 pain in young pitchers and to identify risk factors for these conditions, specifically the role of pitch counts and pitch types used.

A prospective cohort study of 298 9- to 12-year-old pitchers was conducted over two spring baseball seasons. Each participant was contacted via telephone after each game pitched to identify arm complaints. Hypotheses were tested using a generalized estimating equation, which provided estimates of the risk ratio for game-specific associations.

The frequency of elbow pain was 26%, and the frequency of shoulder pain was 32%. The factors associated with elbow and shoulder pain were different, suggesting separate etiologies for each condition. Independent risk factors for elbow pain were increased age, increased weight, private pitching instruction, lifting weights during the season, playing baseball outside the league, 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 increased height, arm fatigue during the game pitched, an increasing number of pitches thrown in the game, and having thrown more than 300 pitches during the season.

The frequency of arm complaints is unacceptably high. To lower the risk of shoulder pain, pitchers of this age should not throw more than 75 pitches in a single game. Other recommendations are to remove pitchers from a game if they report arm fatigue and to limit pitching done in nonleague games. Future studies should focus on the impact of the pitching motion on these complaints and on the association between skeletal development and these complaints. Adherence to these recommendations should reduce the frequency of these complaints and make baseball a safer game for young pitchers.

INTRODUCTION

Baseball is generally a safe and enjoyable sport in which millions of Americans participate every year [1]. However, some injuries do occur. One of the most common baseball injuries is chronic injury to the throwing arms of pitchers, believed to be a result of the repetitive, dynamic overhand throwing motion used to pitch a baseball [1,2]. Although the most common time of life to participate in baseball pitching is from age 9 to 18, the determinants of arm injury among these pitchers are not well understood [1]. Number of pitches thrown in a single game and types of pitches thrown have often been suggested as determinants, though this has not been demonstrated empirically [1,3]. Despite this lack of evidence, most leagues have limited the number of innings that a pitcher may pitch per week. Nonetheless, arm complaints continue despite these regulations. Anecdotal evidence, corroborated by biomechanical research, has suggested that certain types of pitches (e.g., fastball, curveball, slider) are more stressful on the shoulder and elbow joints than others (e.g., change-up) [4,5]. It has been suggested that these strenuous pitches should be reserved for older ages when the arm is more developed [3]. Previous studies have demonstrated that arm injury risk among pitchers increases with age [2,6,7], and it is possible that other developmental factors account for this increase.

The present research addressed the hypotheses that use of 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 use of the change-up pitch is associated with a decreased risk of these complaints. Other factors were also evaluated, such as physical development, experience, skill, and frequency of participation. The study was conducted because of repeated requests for such 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 was divided into two pitch leagues: 9- and 10-year-olds, and 11- and 12-year-olds. The 9- and 10-year-old leagues included a few 8-year-olds as a result of the birth date cutoffs used by the parks. The park directors provided the names and telephone numbers for coaches and players in the 9- to 12-year age leagues.

Introductory telephone contacts were made with all coaches to encourage participation, to identify probable pitchers for their teams, and to conduct a baseline coaching interview (Appendix A). As a result of these coaching contacts, 336 potential pitchers were identified for follow-up. The parents of each were contacted for parental consent prior to recruitment (Appendix B). Once parental consent was obtained, the pitchers were invited to participate, and a baseline pitching interview was administered (Appendix C). Two parents denied participation (citing lack of interest and language barrier as reasons for denial), and four subjects declined the invitation to participate (all citing lack of interest). Subjects were not included in the analyses unless they had at least one pitching appearance in a league game (32 excluded). Data on a total of 298 pitchers were analyzed, 180 pitchers during the first season and 118 additional pitchers during the second season. One hundred pitchers were followed for both seasons. The reasons for dropout were graduation to an older league (n = 31), coach during second season refused to participate (n = 19), did not pitch during second season (n = 10), moved to another park (n = 11), and did not play baseball during second season (n = 9).

Prior to the start of the season, coaches were given a pitch count book developed for the purpose of this study (Appendix D). Explicit instructions detailed the proper use of the pitch count book, and interrater reliability testing revealed perfect correlation (Pearson's = 1.00) between team bookkeepers and random checks by study personnel who visited parks to count pitches.

Once the follow-up period began, coaches were contacted after each game to identify the pitchers for that game. Pitchers were then contacted for a post-game telephone interview (Appendix E) to collect information on the game in question and the presence 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 during the season (Appendix F).

Data were collected using the pitch count book, baseline interviews, post-game interviews, and follow-up interviews. Data collected included demographic characteristics (e.g., age, height, weight), baseball characteristics (e.g., years played, primary position played, baseball camp attendance), pitching characteristics (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 0.82, 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. Other outcomes considered were complaints of arm fatigue, arm stiffness, and arm pain in locations other than the elbow or shoulder. 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 in youth league pitchers. 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 weeks 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; however, none of these serious complaints occurred during the study. These self-reported complaints have been used as measures of injury based upon previous studies. The questions developed to identify these complaints were taken directly from the history and physical used to evaluate pitchers in the clinic of Dr. James Andrews.

The study was approved by the Institutional Review Committee at the HealthSouth Medical Center in Birmingham, Alabama (Appendix G) and complied with the ethics of human experimentation as outlined by the Declaration of Helsinki.

Statistical Analyses

Statistical analyses were divided into two components, descriptive and inferential. A complaint rate was calculated by dividing the number of complaints by the number of pitching appearances x 100 for elbow and shoulder pain. A period prevalence was calculated by dividing the number of pitchers experiencing pain by the total number of pitchers x 100 for elbow and shoulder complaints. To describe personal, behavioral, and baseball-related factors, standard statistical parameters were used, such as means and medians for continuous variables and frequency distributions and proportions for categorical variables. Continuous variables were also categorized into frequency quartiles for ease of interpretation unless prior research had established other category bounds.

Responses that changed between the baseline and follow-up interviews were coded as the follow-up value (e.g., pitchers who learned the curve ball during the season).

Inferential analyses included both univariate and multivariable techniques. Univariate analyses consisted of the calculation of odds ratios (OR) and 95% confidence intervals (95% CI). ORs were calculated for all potential determinants of both elbow and shoulder pain. *P* values were considered statistically significant if <0.05.

Longitudinal analysis using a generalized estimating equation (GEE) was performed [8]. The GEE allowed for multiple events at different time intervals (e.g., game pitched) and allowed for adjustment of game-specific covariates (e.g., pitches thrown per game). The GEE allowed for the possibility of dependence between events, and manipulation of the covariance structure allowed 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]. To evaluate the independent relationships between suspected risk factors and elbow and shoulder pain, stepwise GEE models were developed. Age, height, weight, pitch types, 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 variables that were not forced into each model had a *p* value of <0.10.

All analyses were performed using the SAS System for Windows version 6.12 (The SAS Institute, Cary, NC).

RESULTS

Population Characteristics

Tables 1 and 2 present baseline characteristics of the pitchers, who were an average of 10.8 years of age, 4'9" tall, and weighed 87 pounds. Pitchers were primarily right handed, had played baseball for an average of 6 years, played organized baseball for an average of 5 years, and pitched in organized baseball for nearly 2 years. Nearly two thirds of the pitchers had attended baseball camps in the past, and over 40% had received some sort of private pitching instruction (i.e., pitching lessons from someone other than a coach or parent). Over 30% of the pitchers had previously pitched on the league all-star team. A majority threw change-up pitches, and more than 27% threw curve balls. Sinker, slider, and knuckle ball pitches were much less common (<12%). Relatively few of the pitchers (15.5%) had previous arm injuries or complaints. During the follow-up, pitchers appeared in an average of 9 games (range 1-30) and averaged 2.4 innings and 43 pitches per appearance. Pitchers classified more than 70% of their pitching appearances as either good or excellent performances.

Table 1. Continuous Characteristics of the Study Population

Category	Variable	Mean ± S.D.	Min – Max
Physical characteristics	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
Baseball characteristics	Years played	6.5 ± 1.6	2 – 11
	Seasons played	5.4 ± 1.6	1 – 9
	Frequency of play (days/week)	2.4 ± 1.7	0 – 7
Pitching characteristics	Seasons pitched	1.7 ± 1.2	0 – 5
	Days/week practice pitching	2.5 ± 1.4	1 – 7
	Minutes per practice session	28.6 ± 16.5	7 – 120
Game characteristics	Innings pitched	2.4 ± 1.3	0 – 7
	Pitches thrown	42.7 ± 24.6	1 – 154

Table 2. Discrete Characteristics of the Study Population

Category	Variable	Value	*n* (%)
Physical characteristics	Hand	Left	18 (6.1)
		Right	278 (93.9)
	Previous arm injury	Yes	46 (15.5)
		No	250 (84.5)
Baseball characteristics	Baseball camp	Yes	191 (64.3)
		No	106 (35.7)
	Previous baseball injury	Yes	98 (33.1)
		No	198 (66.9)
	Primary position played	Pitcher	46 (15.8)
		Catcher	46 (15.8)
		1st base	42 (14.4)
		2nd base	33 (11.3)
		3rd base	39 (13.4)
		Shortstop	68 (23.4)
		Outfield	17 (5.9)
Pitching characteristics	Private instruction	Yes	127 (43.1)
		No	168 (56.9)
	Previous pitching complaint	Yes	67 (22.6)
		No	229 (77.4)
	All-star pitcher	Yes	61 (32.4)
		No	127 (67.6)
	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	Self satisfaction with pitching	Excellent	494 (18.4)
		Good	1414 (52.7)
		Average	502 (18.7)
		Fair	162 (6.0)
		Poor	110 (4.1)

Complaint Frequency

Table 3 presents the arm complaints reported by pitchers as both the number of pitchers who reported the complaint at least once and the total number of complaints reported. Arm fatigue while pitching was reported by 42% of pitchers and in nearly 9% of pitching appearances (maximum = 10). Arm stiffness after pitching was reported by 35% of pitchers and in nearly 8% of pitching appearances (maximum = 10). The most

Table 3. Reported Complaints by Study Participants and Pitching Appearances

	298 subjects		2699 pitching appearances	
Complaint	*n*	% of subjects	*n*	Rate/100 appearances
Fatigue	125	41.9	237	8.78
Stiffness	105	35.2	208	7.71
Elbow pain	76	25.5	123	4.56
Shoulder pain	95	31.9	191	7.08
Other pain	83	27.9	141	5.22

commonly reported complaint was pain in the shoulder, reported by 32% of pitchers in 7% of pitching appearances (maximum = 7). Elbow pain was reported in 25.5% of the pitchers and in 4.5% of the pitching appearances (maximum = 6). Pain was reported in other arm locations by 28% of pitchers in more than 5% of all pitching appearances (maximum = 10).

Pain Location

Table 4 presents the location of elbow and shoulder pain as reported by the pitchers as well as the anatomical site of other arm pain (i.e., arm pain in a location other than the elbow or shoulder). More than 68% of elbow pain occurred on the medial side of the elbow with or without lateral involvement. An additional 27% of elbow pain occurred on the lateral side without medial involvement. This accounted for more than 95% of the elbow pain reported in this population. Nearly 29% of shoulder pain was located in the superior aspect of the shoulder (i.e., top of the shoulder), whereas approximately 20% of shoulder pain was located in the anterior, posterior, or lateral aspects of the shoulder. The primary location for other arm pain was the upper arm (88%). Other, infrequent, pain locations were the forearm, wrist, and finger.

Table 4. Location of Pain in Elbow, Shoulder and Other Arm Complaints

Variable	Value	*n*	%
Location of elbow pain	Medial	65	52.9
	Lateral	33	26.8
	Medial & lateral	19	15.5
	Internal	3	2.4
	Posterior	3	2.4
Location of shoulder pain	Anterior	44	23.0
	Posterior	34	17.8
	Superior	55	28.8
	Lateral	38	19.9
	Multiple	20	10.5
Location of other arm pain	Upper arm	127	88.2
	Forearm	11	7.6
	Wrist	4	2.8
	Finger	2	1.4

Pain Severity

Table 5 presents the frequency of various pain severity levels in the pitchers. A majority of all pain complaints were mild in nature, with 70% or more of complaints being classified as such. Elbow pain not classified as mild was split between minor and moderate severity. The preponderance of shoulder pain was mild, and minor complaints were more frequent than moderate complaints. Pain in other arm locations appeared to be more moderate than minor. In fact, although 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 12 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. The pitcher with the inflamed rotator cuff did not complain of pain during the follow-up period. Five other pitchers visited a physician for other arm

Table 5. Severity of Arm Complaints in Study Population

Severity	Elbow Pain *n* (%)	Shoulder Pain *n* (%)	Other Arm Pain *n* (%)
Mild	53 (69.7)	74 (77.9)	63 (75.9)
Minor	11 (14.5)	12 (12.6)	6 (7.2)
Moderate	12 (15.8)	9 (9.5)	14 (16.9)

complaints. Two were diagnosed with fractured fingers, one with a collarbone injury (not otherwise specified), one with weakness, and the remaining pitcher with a "bad release point." Two pitchers visited a chiropractor during the follow-up period to relieve arm pain in multiple locations.

Elbow Pain

Baseline characteristics. Table 6 presents the results of variables thought to be potentially important risk factors for elbow pain in young pitchers. As chronological age increased, so did the pitcher's odds of reporting elbow pain. Pitchers ages 11 and 12 years had a 2.5 and 3.4 times increased odds of experiencing elbow pain, respectively, compared with pitchers under age 10. Also, as body weight increased, so did the odds of elbow pain, with pitchers weighing 86-100 lb and ≥101 lb being 2.8 and 3.9 times more likely, respectively, to experience elbow pain than pitchers weighing <71 lb. After adjustment for age, the effect of weight is slightly muted. A similar trend to that with weight was demonstrated with height. However, age adjustment reversed the direction of the trend. When height and weight was combined into body mass index (g/m^2), a significant increasing trend was demonstrated (results not shown).

Table 6. Crude and Age-Adjusted Associations Between Selected Variables and Elbow Pain

Factor		Crude OR (95% CI)	*P*	Age-Adjusted OR (95% CI)	*P*
Age	<10 years	Referent	<0.01[a]	-	-
	10 years	1.17 (0.54,2.54)		-	
	11 years	2.47 (1.15,5.28)		-	
	≥12 years	3.36 (1.68,6.72)		-	
Weight	<71 lb	Referent	<0.01[a]	Referent	<0.01[a]
	71-85 lb	1.11 (0.50,2.44)		1.12 (0.52,2.44)	
	86-100 lb	2.82 (1.41,5.64)		1.79 (0.82,3.93)	
	≥101 lb	3.91 (2.01,7.60)		2.15 (1.01,4.55)	
Height	<55 in.	Referent	0.19[a]	Referent	0.57[a]
	55-58 in.	1.08 (0.51,2.32)		0.81 (0.31,2.13)	
	59-60 in.	1.33 (0.62,2.86)		0.77 (0.29,2.07)	
	≥61 in.	1.73 (0.73,4.11)		0.80 (0.27,2.36)	
Years playing baseball		1.16 (1.02,1.32)	0.02	0.97 (0.86,1.10)	0.66
Seasons playing baseball		1.36 (1.14,1.61)	<0.01	1.10 (0.92,1.32)	0.30
Spring seasons pitched		1.31 (1.16,1.49)	<0.01	0.88 (0.71,1.09)	0.24
Private instructor		1.49 (0.95,2.36)	0.08	1.39 (0.87,2.21)	0.17
Number of camps attended		1.22 (1.05,1.42)	<0.01	1.08 (0.93,1.26)	0.33
Weight-lifting		2.30 (1.36,3.91)	<0.01	2.04 (1.19,3.51)	<0.01
Sit-ups		0.47 (0.16,1.34)	0.16	0.54 (0.19,1.51)	0.24
Basketball		0.58 (0.34,1.01)	0.05	0.57 (0.33,0.98)	0.04
Tennis		0.42 (0.22,0.81)	0.01	0.44 (0.23,0.85)	0.01
Baseball outside of league		1.90 (1.12,3.24)	0.02	2.14 (1.21,3.81)	<0.01
Arm injury, nonbaseball		1.59 (0.87,2.90)	0.13	1.30 (0.72,2.33)	0.38
Previous pitching injury		1.22 (0.74,2.01)	0.44	1.01 (0.59,1.72)	0.97
All star pitcher		1.33 (0.73,2.42)	0.35	0.90 (0.50,1.62)	0.73
Arm fatigue during outing		6.27 (3.99,9.85)	<0.01	6.28 (3.91,10.09)	<0.01
Arm stiffness in previous game		1.59 (0.79,3.22)	0.20	1.57 (0.80,3.07)	0.19
Self-satisfaction		0.77 (0.66,0.88)	<0.01	0.79 (0.68,0.91)	<0.01
Primary Position	Pitcher	0.70 (0.38,1.28)	0.25	0.69 (0.37,1.26)	0.23
	Catcher	1.30 (0.64,2.63)	0.47	1.67 (0.84,3.32)	0.14
	1st base	1.67 (0.83,3.39)	0.15	1.73 (0.92,3.23)	0.09
	2nd base	0.37 (0.15,0.87)	0.02	0.44 (0.19,1.05)	0.06
	3rd base	0.98 (0.41,2.30)	0.96	0.84 (0.35,2.01)	0.69
	Shortstop	1.24 (0.70,2.19)	0.46	1.18 (0.68,2.03)	0.56
	Outfield	0.87 (0.38,1.98)	0.74	0.68 (0.29,1.63)	0.39

[a] Linear trend test.

Each year of previous baseball play, each season of organized baseball play, number of baseball camps attended, and each season pitched were all associated with significantly increased risk of elbow pain. After age adjustment, the results were no longer significant. Private pitching instruction was associated with increased odds of elbow pain (OR = 1.49, $P = 0.08$). Age-adjustment muted this effect (OR = 1.33, $P = 0.24$).

Among physical activities done outside of baseball during the season, pitchers who lifted weights during the baseball season were 2.3 times more likely to experience elbow pain compared with pitchers who did not lift weights. Elbow pain was decreased among pitchers who did sit-ups (OR = 0.47, $P = 0.16$), played basketball (OR = 0.58, $P = 0.05$), or played tennis (OR = 0.42, $P = 0.01$). Age adjustment did little to change these estimates.

Pitchers who played baseball outside of their league games and practices had a 1.90 times increased odds of experiencing elbow pain ($P = 0.02$) compared with pitchers who did not play baseball outside of their league. Adjustment for age or cumulative pitches had no effect on this association.

Previous all-star selection as a pitcher was used as a crude estimate of ability; no association was found with elbow pain.

Previous nonbaseball arm injury (e.g., fracture, sprain) and previous pitching-related arm complaint prior to study enrollment both resulted in elevated odds of elbow pain (OR = 1.59 and 1.22 respectively, neither significant, with the latter null after age adjustment).

Game characteristics. Complaints of arm fatigue while pitching in game of interest (OR = 6.27, $P < 0.01$) was significantly associated with an increased likelihood of elbow pain. Experiencing arm stiffness in prior game was associated with an increased risk of elbow pain (OR = 1.59, $P = 0.20$), though not significantly. Experiencing shoulder pain in a previous game was not associated with elbow pain (results not shown).

After each game pitched, study participants were asked to rate their pitching performance using a 5-point Likert scale (1 = *poor*, 5 = *excellent*). Each level of increase in self-satisfaction resulted in a 23% decrease in odds of elbow pain ($P < 0.01$).

Players who primarily played second base were 63% less likely to experience elbow pain than players who played other positions ($P = 0.02$). No other position was significantly associated with increased or decreased risk of elbow pain.

Pitches, innings, and games pitched. Table 7 presents the associations between pitches, innings, and games, and elbow pain. There was a 6% increase in the odds of elbow pain per 10 pitches thrown in a given game ($P = 0.06$). Cumulative pitches thrown prior to 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 was observed (OR = 2.07, $P = 0.20$). The effects of innings and games pitched were not associated with elbow pain.

Table 7. Association Between Pitches, Innings and Games and Elbow Pain

Variable		Elbow pain OR (95% CI)	*P*
Game pitches, per 10		1.06 (1.00,1.12)	0.06
Pitches in game	1-24	Referent	0.21[a]
	25-49	1.26 (0.78,2.03)	
	50-74	1.10 (0.67,1.80)	
	≥75	1.56 (0.89,2.75)	
Cumulative pitches	<300	Referent	-
	300-599	0.54 (0.32,0.92)	0.02[b]
	≥600	2.07 (0.68,6.26)	0.20[b]
Innings in game		1.07 (0.96,1.20)	0.23
Total innings, per 10		0.92 (0.80,1.06)	0.30
Games pitched		0.94 (0.87,1.02)	0.15

[a] Linear trend test.
[b] Linear trend test monotonic assumption violated.

Pitch types. Table 8 presents the results of analyses of the association between elbow pain and type of pitch used. 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). Age-adjustment for pitch types resulted in a decreased odds of elbow pain with change-up use (OR = 0.74, *P* = 0.39) and slider use (OR = 0.77, P = 0.43). No other pitch types were associated with elbow pain. When pitch types were stratified by age group, it was found that older pitchers (11- and 12-year-olds) who threw a change-up had a significantly decreased odds of elbow pain (OR = 0.27, *P* = 0.01).

Table 8. Association Between Pitch Types and Elbow Pain

Pitch type	Crude OR (95% CI)	*P*	Age-adjusted OR (95% CI)	*P*
Fastball only	Referent	-	Referent	-
Change-up	1.06 (0.59,1.90)	0.85	0.74 (0.37,1.48)	0.39
Curve	1.11 (0.66,1.85)	0.70	0.80 (0.48,1.35)	0.41
Slider	1.17 (0.66,2.08)	0.58	0.77 (0.41,1.46)	0.43
Sinker	1.70 (0.99,2.93)	0.06	1.62 (0.95,2.75)	0.07

Shoulder Pain

Baseline characteristics. The results of analysis of factors thought to potentially be important determinants of shoulder pain in young pitchers are presented in Table 9. Increasing age appeared to be minimally protective, although the OR did not decline consistently and the trend test was not significant. Increased height resulted in increasing odds of shoulder pain, with a significant trend after age adjustment. There were similar results with respect to increased weight, although the associations were weaker. Adjustment for one another suggested that both age and height were independent risk factors for shoulder pain, but that weight was not (results not shown). Combination of height and weight into a body mass index did not yield significant results (not shown).

Measures of experience demonstrated that although years playing baseball, seasons playing baseball, and seasons pitched all resulted in slightly decreased odds of shoulder pain, none were significant decreases. Each additional baseball camp attended was associated with a significant decrease in risk of shoulder pain. Private pitching instruction had no association. Age adjustment of these experience measures resulted in no appreciable changes.

No sport or physical activity was significantly associated with shoulder pain. However, weight-lifting resulted in 38% decreased odds (P = 0.07), and sit-ups resulted in 25% decreased odds (P = 0.46). A weak protective association was found between shoulder pain and playing baseball outside of the league (OR = 0.80, P = 0.45). Age adjustment did not appreciably change these findings.

Table 9. Crude and Age-Adjusted Associations Between Selected Variables and Shoulder Pain

Factor		Crude OR (95% CI)	*P*	Age-adjusted OR (95% CI)	*P*
Age	<10 years	Referent	0.56[a]	-	-
	10 years	0.77 (0.45,1.32)		-	
	11 years	0.98 (0.41,2.33)		-	
	≥12 years	0.70 (0.28,1.76)		-	
Weight	<71 lb	Referent	0.44[a]	Referent	0.18[a]
	71-85 lb	1.17 (0.64,2.15)		1.24 (0.67,2.33)	
	86-100 lb	1.28 (0.69,2.37)		1.46 (0.74,2.90)	
	≥101 lb	1.31 (0.66,2.61)		1.63 (0.69,3.86)	
Height	<55 in.	Referent	0.09[a]	Referent	0.04[a]
	55-58 in.	1.21 (0.58,2.56)		1.28 (0.58,2.81)	
	59-60 in.	1.87 (0.85,4.14)		2.59 (0.99,6.78)	
	≥61 in.	1.91 (0.84,4.35)		2.82 (0.91,8.73)	
Years playing baseball		0.88 (0.74,1.04)	0.12	0.85 (0.70,1.05)	0.13
Seasons playing baseball		0.91 (0.75,1.12)	0.39	0.94 (0.74,1.19)	0.60
Spring seasons pitched		0.84 (0.62,1.14)	0.27	0.94 (0.59,1.52)	0.81
Private pitching instructor		1.00 (0.52,1.92)	0.99	1.07 (0.55,2.11)	0.84
Number of camps attended		0.76 (0.57,1.00)	0.05	0.73 (0.54,0.98)	0.04
Weight-lifting		0.62 (0.37,1.04)	0.07	0.64 (0.37,1.10)	0.11
Sit-ups		0.75 (0.35,1.60)	0.46	0.72 (0.34,1.51)	0.39
Basketball		1.23 (0.72,2.12)	0.45	1.22 (0.71,2.11)	0.47
Tennis		1.17 (0.66,2.09)	0.59	1.16 (0.65,2.07)	0.62
Baseball outside of league		0.80 (0.46,1.41)	0.45	0.79 (0.45,1.38)	0.40
Arm injury, nonbaseball		1.15 (0.43,3.09)	0.78	1.26 (0.44,3.62)	0.67
Previous pitching injury		0.80 (0.39,1.64)	0.54	0.79 (0.38,1.62)	0.52
All star pitcher		0.95 (0.46,1.96)	0.88	1.01 (0.48,2.16)	0.97
Arm fatigue during outing		5.16 (3.50,7.62)	<0.01	5.07 (3.42,7.52)	<0.01
Arm stiffness in previous game		0.86 (0.41,1.81)	0.69	0.85 (0.40,1.79)	0.66
Self-satisfaction		0.74 (0.65,0.84)	<0.01	0.73 (0.64,0.84)	<0.01
Primary Position	Pitcher	0.86 (0.51,1.45)	0.56	0.89 (0.52,1.51)	0.66
	Catcher	0.59 (0.29,1.20)	0.14	0.56 (0.27,1.15)	0.11
	1st base	1.05 (0.50,2.22)	0.89	1.07 (0.51,2.27)	0.85
	2nd base	1.00 (0.34,2.92)	0.99	0.96 (0.32,2.86)	0.94
	3rd base	2.13 (1.03,4.41)	0.04	2.16 (1.03,4.52)	0.04
	Shortstop	0.95 (0.53,1.72)	0.87	0.94 (0.51,1.72)	0.84
	Outfield	1.07 (0.43,2.64)	0.89	1.10 (0.43,2.86)	0.84

[a] Linear trend test.

Pitchers who had previously experienced a pitching injury were 34% less likely to have shoulder pain during the follow-up period ($P = 0.22$). Previous nonbaseball arm injuries were not associated with shoulder pain.

No association was found between previous all-star pitching and shoulder pain.

Game factors. As seen for elbow pain, arm fatigue while pitching was strongly associated with shoulder pain, with pitchers reporting fatigue having a more than fivefold increased odds of shoulder pain ($P < 0.01$). No association was found for stiffness after the previous game pitched. Experiencing elbow pain in a previous game did not increase the risk of shoulder pain (results not shown).

Self-perceived performance was associated with 26% decreased odds of shoulder pain per increase in performance category ($P < 0.01$). Pitchers who primarily played third base were 2.6 times more likely to have shoulder pain than pitchers who primarily played other positions ($P < 0.01$). No other significant relationship was demonstrated for positions played, although catcher was associated with a 41% reduction in the odds of shoulder pain.

Pitches, innings, and games pitched. Table 10 presents associations between pitches, innings, and games pitched with shoulder pain. Every 10 pitches thrown resulted in significantly increased odds ($P < 0.01$) of shoulder pain. This trend was also seen when the game pitches were categorized into 25 pitch increments, with pitchers in the highest category ($\geq$75 pitches) 3.2 times more likely to experience shoulder pain

Table 10. Association Between Pitches, Innings and Games and Shoulder Pain

Variable		Shoulder pain OR (95% CI)	*P*
Game pitches, per 10		1.15 (1.08,1.23)	<0.01
Pitches in game	1-24	Referent	<0.01[a]
	25-49	1.27 (0.88,1.83)	
	50-74	1.61 (1.04,2.49)	
	≥75	3.22 (1.84,5.61)	
Cumulative pitches	<300	Referent	<0.01[a]
	300-599	0.40 (0.24,0.65)	
	≥600	0.13 (0.01,1.10)	
Innings in game		1.21 (1.07,1.36)	<0.01
Total innings, per 10		0.54 (0.42,0.69)	<0.01
Games pitched		0.85 (0.80,0.91)	<0.01

[a] Linear trend test.

($P < 0.01$) than those in the lowest category (<25 pitches). However, for cumulative pitches prior to 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 pitch), but the effect of innings completely disappeared.

Pitch types. Table 11 presents the results of analyses of the association between shoulder pain and pitch types used. The use of a change-up (OR = 0.74, P = 0.23) or slider (OR = 0.44, P = 0.44) was associated with a decreased odds of having shoulder pain. The use of a curveball was associated with an increased odds of shoulder pain (OR = 1.39, P = 0.22). Age-adjustment did little to modify these effects.

Table 11. Association Between Pitch Types and Shoulder Pain

Pitch type	Crude OR (95% CI)	*P*	Age-adjusted OR (95% CI)	*P*
Fastball only	Referent	-	Referent	-
Change-up	0.74 (0.45,1.21)	0.23	0.74 (0.44,1.23)	0.25
Curve	1.39 (0.83,2.33)	0.22	1.41 (0.84,2.36)	0.19
Slider	0.44 (0.05,3.59)	0.44	0.44 (0.05,3.73)	0.46
Sinker	1.08 (0.47,2.52)	0.85	1.07 (0.45,2.56)	0.88

Multivariable Analysis

Table 12 presents the results of multivariable analysis for both elbow and shoulder pain. These models were obtained through both forward and backward stepwise procedures. All variables in the table were included in a GEE model to determine the independent effects of all risk factors identified in crude and age-adjusted analyses.

Several independent risk factors were identified for elbow pain. The previously found significant relationship between increased age and elbow pain was maintained. Increased weight was associated with a very high increased risk of elbow pain in pitchers weighing more than 85 lb. Conversely, pitchers taller than 58 inches were at greatly decreased risk for elbow pain.

Pitches thrown in the game was no longer a significant risk factor for elbow pain after adjustment for other factors, including cumulative pitches thrown. Cumulative pitches thrown up to the game of interest remained an intriguing risk factor, with 300 to 599 pitches thrown resulting in a 52% decreased risk of elbow pain compared with 1 to 299 pitches thrown. However, throwing 600 or more pitches resulted in a 3.79 times increased odds of elbow pain compared with 1 to 299 cumulative pitches thrown.

Table 12. Multivariable Models for Elbow and Shoulder Pain

Factor		Elbow pain OR (95% CI)	P	Shoulder pain OR (95% CI)	P
Age	<10 years	Referent	0.03[a]	Referent	0.17[a]
	10 years	1.80 (0.70,4.61)		0.58 (0.27,1.26)	
	11 years	3.20 (1.03,9.91)		0.85 (0.35,2.05)	
	≥12 years	3.46 (1.17,10.28)		0.43 (0.27,1.20)	
Weight	<71 lbs	Referent	<0.01[a]	Referent	0.87[a]
	71-85 lbs	1.40 (0.60,3.27)		1.30 (0.63,2.68)	
	86-100 lbs	4.27 (1.73,10.51)		1.12 (0.50,2.50)	
	≥101 lbs	5.94 (1.82,19.38)		0.91 (0.31,2.67)	
Height	<55 in.	Referent	0.06[a]	Referent	0.07[a]
	55-58 in.	0.86 (0.39,1.89)		1.15 (0.52,2.52)	
	59-60 in.	0.48 (0.19,1.20)		2.26 (0.83,6.15)	
	≥61 in.	0.37 (0.13,1.05)		3.59 (1.10,11.69)	
Pitches in game	1-24	Referent	-	Referent	0.01[a]
	25-49	1.11 (0.64,1.91)	0.71[b]	1.17 (0.78,1.77)	
	50-74	0.83 (0.44,1.57)	0.56[b]	1.61 (0.94,2.76)	
	≥75	1.01 (0.46,2.21)	0.97[b]	2.57 (1.29,5.10)	
Cumulative pitches	<300	Referent	-	Referent	<0.01[a]
	300-599	0.48 (0.24,0.94)	0.03[b]	0.41 (0.28,0.61)[c]	
	≥600	3.79 (0.91,15.77)	0.07[b]	0.19 (0.09,0.40)[c]	
Change-up		0.81 (0.41,1.63)	0.56	0.82 (0.45,1.49)	0.51
Curve		0.86 (0.50,1.48)	0.59	1.19 (0.62,2.28)	0.60
Slider		0.71 (0.34,1.47)	0.35	0.61 (0.17,2.25)	0.46
Sinker		1.25 (0.73,2.15)	0.42	1.24 (0.39,3.91)	0.72
Arm fatigue during outing		5.69 (3.29,9.85)	<0.01	3.81 (2.52,5.75)	<0.01
Self-perceived performance		0.84 (0.71,1.00)	0.05	0.74 (0.64,0.85)	<0.01
Weight-lifting		2.14 (1.10,4.18)	0.03	-	-
Baseball outside		2.42 (1.29,4.55)	0.01	-	-

[a] Linear trend test.
[b] Linear trend test montonic assumption violated.
[c] Derived from continuous cumulative pitches GEE parameter estimate.

No associations were evident between pitch types used and elbow pain, though all pitches other than the sinker pitch demonstrated nonsignificant decreased risks.

Arm fatigue during the game in which pain occurred continued to be a risk factor for elbow pain. though the effect was muted from 6.28 in crude analysis to 5.69 in the multivariable model. Increasing self-satisfaction with pitching the performance remained a protective factor for elbow pain.

Weight lifting (OR = 2.14) and playing baseball outside of league games and practices (OR = 2.42) were independently associated with an increased risk of elbow pain in multivariable analysis.

Fewer independent risk factors were identified for shoulder pain. Increased height remained a risk factor, with all pitchers over 58 inches tall at greatly increased risk of shoulder pain. Increased pitches thrown per game remained a significant risk factor for shoulder pain, whereas increased cumulative pitch total remained a protective factor for shoulder pain. Pitch types used were not significantly associated with shoulder pain. The protective effect demonstrated for the slider in crude analysis was still apparent, though muted.

Arm fatigue remained a significant risk factor for shoulder pain, though it was also muted from a crude effect of 5.16 to an adjusted effect of 4.28. Self-satisfaction with pitching performance remained a significant protective factor for shoulder pain as well. Weight lifting and playing baseball outside of league games and practices, which were significantly associated with elbow pain, were not associated with shoulder pain and were not included in the model.

DISCUSSION

The number of pitchers ($N = 298$) followed for two spring baseball seasons ($N = 100$) represents the second largest study group of its kind and matched 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 was probably more reliable than a postseason recollections. With the exception of a study looking at pitching mechanics [11], this is the first study to make a concerted effort to identify risk factors for arm pain in young pitchers.

Baseline Characteristics

As far as can be determined, the ages of these pitchers are consistent with the ages of pitchers in other studies. However, the pitchers in previous studies have been more experienced on average because 9- and 10-year-olds either have not been included or have been included in very small numbers [6,7,9,10,11,12]. Pitchers in this study averaged 2.4 innings and 43 pitches per appearance (18 pitches per inning), which is consistent with previous studies looking at pitch counts in these ages [6].

Pain Frequency

The definitions of elbow pain used for this study are consistent with the definitions used in previous evaluations. However, the identification of pitchers with pain is likely more accurate here 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 because no previous study has associated radiographic changes with arm pain [6,7,9,10,12].

Two previous studies of American youth league pitchers found that elbow pain was present in 18% of pitchers aged 11 and 12 years [6,7], similar to the current study (22% per season). A study of Taiwanese youth league pitchers found that elbow pain occurred in 69% of pitchers of these same ages [12]. That study is likely not comparable with the current study because the data collection methods are inconsistent, and with children of these ages, it is possible that there is a culturally based interpretation of arm pain. Furthermore, at the time of the previous study, Taiwan and other Asian countries used a unique pitcher training philosophy, having pitchers throw daily [13].

One previous study examined the prevalence of shoulder pain among young pitchers, finding that 26.5% had shoulder pain at the end of a youth league season [10]. In the current study, shoulder pain occurred in 29% of the pitchers per season.

Pain Location

As was found with previous studies of elbow pain, the medial side of the elbow was the most common site affected [6,9,12]. Medial epicondylitis in young pitchers has been referred to as Little League elbow [14], 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, though the location of the pain is less clear [10]. A study of symptomatic athletes receiving treatment found that the most common locations for pain were the anterior and posterior shoulder [15]. However, in this study, a fair number of pitchers reported pain superiorly (28.8%) and laterally (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. This is likely because superior or lateral pain is likely to involve muscle soreness of the deltoid, while anterior or posterior pain may represent a more serious injury to the shoulder capsule or rotator cuff.

Elbow Pain Risk Factors

Few previous studies have attempted to identify risk factors for elbow pain in young pitchers. The previous studies that did attempt to identify risk factors met with little success. The current study not only attempted to identify risk factors, but was successful in doing so.

Baseline characteristics. 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 of elbow pain. The association with age has been well established. Older ages consistently have higher rates of elbow pain than younger ages [2,6,7]. The fact that this increase was found within only 2 to 3 years 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-year-old males. These centers are the weakest points in the young elbow and can become inflamed and irritated by the throwing motion. The finding that the 11- and 12-year-olds in this study had higher rates of elbow pain than the 9-year olds is consistent with this hypothesis concerning secondary ossification centers.

The finding that increased weight, independent of age, is a risk factor for elbow pain may have a similar explanation. Heavier boys may be putting more of a burden onto their skeletons, or they may be more developed, resulting in higher pitch speeds and more force on the elbow per pitch thrown. Either of these may exacerbate the elbow weakness, resulting in an increased likelihood of elbow pain.

It has long been held that elbow pain in baseball pitchers is a result of overuse of the elbow joint [10,11]. However, no studies have been able to confirm this association. Little League surveys in Houston, Texas and Eugene, Oregon found no significant relationship between the number of years pitching and the risk of elbow pain [6,7]. The study among American high school pitchers found no association between years playing baseball and elbow pain [2]. The current study found an increased likelihood of elbow pain with each year playing both recreational and organized baseball. Likewise, each season pitched was found to have an increased likelihood of elbow pain. However, all of these associations disappeared after adjusting for age, suggesting that age, rather than the duration of exposure, was responsible for the increased odds of elbow pain.

Private pitching instruction is a factor not previously addressed in the literature. This was analyzed because coaches and parents appear to believe that these lessons are beneficial for their children. Although there appeared to be an increased risk of elbow pain among pitchers who had been taught privately, this association disappeared after age adjustment. It is possible that lessons given by certain organizations are protective, but this investigation did not have adequate power to evaluate specific private instructors.

Involvement in physical activities beyond baseball was recorded 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 jointly with baseball. Participation in other sports or activities during the baseball season has not previously been considered as a risk factor for elbow pain in young pitchers. This study found that pitchers who lifted weights were at increased risk of elbow pain. This suggests that some types of weight-lifting may contribute to elbow pain among pitchers. Perhaps pitchers at this age should not lift weights to improve their fitness or should strengthen their arms in other ways. This association should be explored further because 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. The decreased likelihood of elbow pain among pitchers who did sit-ups during the season, although not significant, is supportive of previous research. Strengthening of the torso might allow pitchers to use more of their body and less of their arm to generate velocity. Previous biomechanics research has demonstrated that torso mechanics influence pitch velocity [17]. This should theoretically decrease the forces on the elbow joint. Perhaps pitchers should be encouraged to do sit-ups in order to develop and maintain their torso strength.

The relationship between playing basketball and tennis and a reduction in elbow pain is less clear. In Alabama, the youth basketball season occurs just before spring baseball. Therefore, the preventive effect may represent a general overall level of fitness: that is, the children playing basketball during the season might be more likely to have played organized basketball prior to the baseball season. The protective effect, however, was absent for pain in the shoulder, which relies more on musculature for stability. The finding that tennis is protective is especially interesting, as tennis elbow is a relatively common condition in adults. This may represent a selection bias, with pitchers who have elbow problems not playing tennis because of pain.

Previous arm injuries suffered would be expected to increase the likelihood of elbow and shoulder pain in the young pitcher because the integrity of the joint may have been compromised with residual effects or persistence of the original injury. A slightly increased likelihood of elbow pain was found for both previous arm injury not related to baseball and previous arm pain as a result of baseball pitching. Neither of these findings was significant. This may be because the location of the previous injury was not considered when evaluating this association, due to small numbers of previously injured children.

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 of their league games and practices, but may also have been pitching in these games. This would increase their pitch volume significantly if they were playing this way 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 for testing this hypothesis is to limit or stop pitching in these unsanctioned contests and to play other positions instead.

An interesting finding was the lack of an association between previous all-star selection and elbow pain. This may reflect two issues canceling each other out. First, it would stand to reason that all-star pitchers have better pitching mechanics, which have been shown to affect injury risk [18-20]. These pitchers with better mechanics would be expected to have lower injury rates than pitchers who are not all-stars. Second, the pitchers who are all-stars usually are the most often used pitchers in the league; therefore, they may have had higher pitch counts than other pitchers during their all-star seasons.

This increased exposure may be canceling out the beneficial effect of improved pitching mechanics. This same lack of association was found for shoulder pain.

Game factors. Arm fatigue while pitching was highly 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 a pitcher complains of or demonstrates arm fatigue while pitching in a game, that may be a sign that it is time to remove him or her from the contest to avoid injury. Arm stiffness in the previous game pitched was also associated with an increased risk of elbow pain. 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 found for shoulder pain. This may reflect that a lower self-rating may be a result of poor performance brought on by arm pain or a result of poor performance for which arm pain is being used as an excuse.

The primary position played by each pitcher during the season was considered because players making frequent or long, forceful throws may be increasing their risk of arm pain if they also pitch. In today's youth baseball leagues, a vast majority (100% in this study) of pitchers play other positions when they are not pitching. The position that the pitcher spends a majority of his or her game time playing is potentially important with regard to elbow pain. It is possible that positions that involve repeated long or maximum force throwing would increase a pitcher's risk of arm pain. Conversely, throwing from other positions may be effective exercise for strengthening a pitcher's arm.

Biomechanical data indicate that flat-ground throwing has few mechanical differences from pitching from a mound and that shoulder and elbow forces between pitching and flat-ground throwing are similar [21]. Besides pitcher, the positions with the most demanding throws are third base, which has the longest infield throw; shortstop, which involves the most infield throwing; and catcher, which involves as much throwing as the pitcher. Conversely, positions that do not require repeated long or forceful throwing are first base, which does very little forceful throwing, and second base, which has the shortest throw to first base in the infield. None of these positions were significantly associated with risk of elbow pain except for second base, where there was a significantly decreased risk. First base resulted in a nonsignificantly increased risk of elbow pain. This may be because players with elbow pain migrate to first base to limit their throwing, but may still be willing to pitch because of the status that pitching affords in the youth baseball environment. A possible explanation for the lack of other findings related to primary position played may be that at these ages, the players are still playing a number of positions, so a primary position may still consist of less than half of the player's field time.

Pitches thrown. A study conducted by Little League, Inc. found no relationship between average pitches thrown per inning and elbow pain [6]. This same result was found in the current study: pitches thrown per inning was not a risk factor for elbow pain. However, every 10 pitches thrown in a game resulted in a 6% increased odds of elbow pain. 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 ($\geq$600 pitches) elbow pain was a result of overuse of the elbow. This would suggest that cumulative pitches thrown during a season is an important risk factor for elbow pain.

Pitch types. No other studies have considered the impact of pitch types with regard to elbow pain in this age group. Only the use of the sinker pitch was found to be a significant risk factor for elbow pain. 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-year-old pitchers. This would suggest that use of the sinker pitch should be discouraged in these ages and that pitchers should be encouraged to learn the change-up to improve pitching ability and decrease the risk of elbow pain.

Shoulder Pain Risk Factors

No previous study has attempted to identify factors associated with shoulder pain in young pitchers. This study attempted to demonstrate the relationship between several factors and shoulder pain.

Baseline characteristics. The 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, height, after adjustment for age, demonstrated a significantly increased risk of shoulder pain among taller pitchers. 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. For readers with a physics background, this would be a greater moment of inertia, resulting in higher torque on the shoulder joint.

Experience measures such as years playing baseball, seasons playing baseball, and seasons pitching in organized baseball were not important risk factors of shoulder pain, though all appeared to result in a slightly decreased risk. Because the shoulder relies more on musculature for stability than the elbow, it is possible that pitchers reduce shoulder pain risk as they develop muscle. New or inexperienced pitchers may be at increased risk of shoulder pain because their shoulder joints are not as strong or stabilized as those of more experienced pitchers. However, once the cumulative use reaches a certain level, there is apparently a higher risk of serious shoulder injury, resulting from accumulated microtrauma to the rotator cuff [22]. This eventually increased risk is outside of the scope of this study.

Exercise using weights appears to lower the likelihood of shoulder pain in young pitchers. A training regimen that isolates the shoulder may be beneficial to pitchers this age. Many coaches and athletic trainers advocate an interval throwing program to strengthen a pitcher's arm before the season or while recovering from injury [23]. This typically involves throwing from flat ground and gradually increasing the throwing distance to as far as 200 feet.

Previous arm injury (baseball or nonbaseball) did not appear to have an impact on the likelihood of shoulder pain, though pitchers with a previous pitching injury did appear to have a slightly decreased likelihood than those without previous pitching injury. As mentioned earlier, the type of injury previously sustained was not analyzed because of insufficient sample size. Therefore, it is possible that the pitchers who were previously injured were primarily elbow-injured pitchers. It appears that elbow and shoulder pain have different etiologies, which would explain why pitchers with a previous elbow injury would not necessarily increase their risk of shoulder pain. However, there could be a compensation mechanism in some pitchers with pain in one location, leading to adjustment of the pitching motion and resulting in pain in the other location.

Game factors. As was seen for elbow pain, arm fatigue while pitching was a strong risk factor for shoulder 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. Again, it may be wise for coaches and parents to watch for early signs of problems in order to intervene before the onset of pain.

For primary position played, only playing third base demonstrated an increased risk of shoulder pain. This supports the hypothesis that repeated, long, forceful throwing may increase the risk of elbow or shoulder pain, but does not support the hypothesis of a decreased risk at positions not requiring this kind of throwing.

Pitches thrown. With regard to shoulder pain, game pitches were a significant risk factor, with each pitch resulting in a 15% 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 should be instituted in these age groups.

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.

Pitch types. The use of a change-up and the use of a slider were associated with a decreased risk of shoulder pain. Baseball experts consider the slider to be a pitch learned after the fastball, change-up, and curve ball [3]. Therefore, young pitchers who throw a slider may have better mechanics or overall pitching skills than young pitchers who do not throw a slider. As expected, the curve ball resulted in an increased risk of shoulder pain, though this was not significant.

Multivariable Analysis

The results of multivariable modeling identify the factors in which improvement will most likely make an impact on the risk of elbow and shoulder pain in young pitchers. Age, height, and weight are largely nonmodifiable risk factors for these children. so attention should focus on modifiable factors such as weight lifting, baseball play outside of the league, arm fatigue, and pitches thrown per game and season.

Conclusion

The elbow and shoulder pain evaluated in this study are the most common problems experienced among youth baseball pitchers [10]. 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 or modifications should be made only if the prevention of one pain location does not increase the risk of pain in the other location.

Little or no reduction was found in the frequency of elbow pain when comparing the current study with studies conducted prior to the initiation of the current pitching regulations [9,10]. Therefore, we may infer that more stringent limitations should be placed upon pitchers in this age group. Since no previous study has been conducted for shoulder pain in a similar population, it is difficult to make this same inference.

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 lower the risk of shoulder, and possibly elbow, pain. Therefore, an answer may be a pitch count regulation rather than current weekly innings limits. It is possible that more stringent innings limits, batter limits, or appearance limits for the season would better retain the integrity of the game. The concern with pitch limits is that savvy coaches might do their best to use up the pitches for an opposing team's star pitcher so that his team has a better chance of success against another young arm. If an inning or batter limit was used, that same coaches know that he or she will see that pitcher for those innings or batters, making him or her less likely to alter game strategy. Although the cumulative pitches issue is less clear, it appears that throwing more than 600 game pitches in a single season may be a risk factor for elbow pain.

From the age-adjusted results regarding pitch types, it appears that pitchers at 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 harmful, but because the change-up is safer. The findings also suggest that pitchers who use the sinker ball 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 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 for pitchers [23] and reducing the pitching done in nonleague games.

With a paucity of information available in the medical literature regarding arm pain in youth baseball, it is hoped that this study will contribute to the existing body of knowledge and improve the abilities of parents, coaches, and health professionals to keep young pitchers free from pain. It is also hoped that this research will assist future studies in the directions that still might be explored and confirm many of the new findings of this study. The next primary advancement in the understanding of arm pain in youth baseball pitchers should be in the area of the pitching motion. Although overuse and other factors contribute significantly to arm pain in this population, it is possible that no other single factor has as great an impact as pitching mechanics.

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AN EXAMPLE OF LONGITUDINAL ANALYSIS FOR THE SPORTS MEDICINE RESEARCHER

by

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ABSTRACT

Many early epidemiologic studies in sports medicine focused on understanding the frequency and descriptive characteristics of sports injuries. Recently, much more emphasis has been placed upon identifying risk factors that can be modified to prevent sports injuries. However, the epidemiological methods available to accomplish this goal have not been fully recognized or utilized.

The opportunity for multiple injuries over time and the discrete time intervals in which sports injuries may occur make traditional analytic techniques suboptimal for use in sports medicine epidemiology. The present effort represents an attempt to expose sports medicine researchers to a relatively new analytic technique, longitudinal analysis. For the purposes of this paper, a marginal model, specifically a generalized estimating equation, has been used to demonstrate the utility of longitudinal analysis with regard to sports medicine data.

Longitudinal analyses such as the marginal model allow for multiple measures of exposure and outcome over the course of a study period, multiple injuries in a single subject, and account for the dependence between observations in a single subject over the course of the study. These benefits are compared with two logistic regression models: First, a cumulative risk model, which represents the cumulative exposure and outcome information from a study will be presented. Second, a game-specific risk model is shown, which represents the game-specific exposure and outcome information from the same study. Finally, a generalized estimating equation is used to analyze the game-specific risk, controlling for potential dependence between games and using the same data.

Comparison of the results of these various modeling techniques demonstrated wide variation in the point estimates because of either game-specific effects or the effects of dependence between observations in a single subject. These variations could have a significant impact on the interpretation of the results and subsequent preventive efforts.

INTRODUCTION

Epidemiology has long been referred to as the cornerstone of public health because it provides the scientific basis for disease prevention efforts. To this end, epidemiologists have adopted new methods to tackle problems as they arise. The epidemiology of sports injuries has been recently described as being in its adolescent phase as a discipline [1]. Great strides have been made in a relatively short period of time to incorporate the tools provided by epidemiology with the challenges presented by sports medicine; however, maturity is still ahead. A recent article by Meeuwisse encouraged sports medicine epidemiologists to adopt a multifactorial model when assessing causality [2]. It is hoped that the present contribution will demonstrate the utility of this recommendation.

Meeuwisse suggested the use of multivariable statistical techniques but did not explicitly identify which techniques to use [2]. The classic techniques used by epidemiologists to evaluate the multifactorial relationships between the outcome and potential risk factors have been multiple regression models such as linear regression for continuous outcomes (e.g., heart rate) and logistic regression for categorical variables (e.g., injury: yes or no). Survival analysis techniques have also been used to evaluate data in which person-time of follow-up is known. These techniques are quite useful in the analysis of relationships between risk factors and injuries or diseases that are measured at one point in time or that are chronic in nature (e.g., spinal cord injuries). Sports injuries, although they may be measured at a single point in time, are infrequently chronic, in the sense that once an injury occurs, it is always present. Athletes often recover with rest, rehabilitation, drug therapy, or surgical intervention. Unlike infectious diseases, repeated injury does not cause the body to develop antibodies, so there is always the potential for repeated injury.

This brings us to one of the most intriguing challenges in sports medicine research: how to deal with repeated injuries in a single athlete. Examples include the basketball player who sprains his ankle one season, rehabilitates, recovers, and sprains it again the next season; or the football player who sustains a concussion in week one, another in week six, and yet another in a playoff game. How do we treat these injuries statistically? Are the injuries dependent or independent of one another? These are vitally important questions when determining which analytical technique to use because one of the primary assumptions of many statistical tests is that the events, injuries in this case, are independent of one another.

Unfortunately, this independence assumption is often violated when hypothesis testing is conducted on sports medicine data. Fortunately, a new tool was recently added to the epidemiologist's workshop. Longitudinal data analysis techniques have been developed over the past decade to deal with repeated measurements in subjects over time. Of particular interest to sports medicine epidemiology is the marginal, or population-average, model, which is used to evaluate longitudinally the relationship between various independent variables and a categorical dependent variable of interest. This particular technique is an intermediate method between analysis in which all observations are independent and the random effects model in which each subject is a random variable.

Marginal models determine the average dependence between observations within subjects and model the average risk in the population. Random effects modeling techniques model the individual risk for each subject. Therefore, if it is reasonable to assume that the individual risk is consistent between individuals with the same characteristics, then the marginal model results in an appropriate estimation of individual risk through population averages.

An example of data that could be analyzed in this fashion is the NCAA Injury Surveillance System data, in which each athlete is eligible for an injury during each athlete-exposure [3]. In other words, injury status is measured after each practice and game. Most of the time an athlete is coded as *uninjured*, but occasionally he or she becomes *injured*. He or she may then become uninjured again at a later game or practice, only to become injured in the game or practice after that. Marginal modeling is able to handle this repeated measuring of injury status, as well as repeated measuring of other time-variant exposures that may affect the risk of injury (e.g., shoe type worn, drills performed during practice, weight).

Independence of injury events is not assumed by marginal modeling, and the amount of dependence is measured using a covariance matrix. The matrix structure may be specified in the case of a relationship that is well established, but may also be left unstructured if the relationship is unknown. The estimates of association produced by marginal modeling remain robust even if a suboptimal covariance matrix structure is specified [4]. In sports medicine epidemiology, the structure is most often unknown because of the paucity of information regarding time-dependent variations in injury and injury recurrence.

METHODS

Just how much does the choice of analytic technique influence the results of an epidemiological investigation? This influence is demonstrated using data from a study of youth baseball pitchers performed by the American Sports Medicine Institute. American Baseball Foundation. and University of Alabama at Birmingham School of Public Health. Youth baseball pitchers ($N = 298$) were followed over two consecutive spring baseball seasons. Each pitcher was contacted after each game pitched to determine injury status. An injury was defined as a self-reported complaint of shoulder pain as a result of pitching in a league game. This prospective design would classically have been analyzed by using either a multivariable regression (e.g.. logistic regression) or survival analysis (proportional hazards) technique. However, as a result of the nature of the design. each pitcher was eligible for more than one event; that is, multiple games could be followed by shoulder pain. Repeated pain episodes would not necessarily be independent of one another. though a typical regression equation or proportional hazards model would treat them as such. A type of marginal. or population-average. model known as a generalized estimating equation (GEE) can account for these repeated complaints of pain in an individual pitcher [4].

For the purposes of this report. the data from the youth baseball pitching study were analyzed using two logistic regression modeling techniques, cumulative risk analysis and game-specific risk analysis. Cumulative logistic regression analysis used each subject as an observation based on season totals, ignoring the multiple games pitched by each subject. Game-specific logistic regression analysis used each game pitched as an independent observation, ignoring repeated games pitched by individual subjects.

The results were then compared to the results from the same data analyzed with the GEE. Logistic regression was chosen as a comparison technique because both logistic regression and the GEE produce odds ratios as the estimate of relative risk. The dependent variable of interest for both analyses was the presence of shoulder pain as a result of pitching. For the cumulative logistic regression model, this was defined as having experienced shoulder pain during the follow-up period (yes or no). For the game-specific logistic regression model and the GEE, this was defined as having experienced shoulder pain during a game (yes or no). Whereas cumulative logistic regression in this instance produces an estimate of effect on cumulative risk, the GEE and game-specific logistic regression model produce an estimate of game-specific risk.

Three independent variables were chosen for this analysis. Change-up use was chosen as an example of a static variable. A static variable is one that is determined at one point in time during the follow-up period and does not change from observation to observation within a subject. Cumulative pitches thrown and arm stiffness in previous pitching appearance were chosen as examples of dynamic variables. Dynamic variables are determined at each observation and may change from observation to observation within a subject.

Change-up use was defined as the self-reported use of the change-up pitch and remained constant for each subject during the study period. For cumulative logistic regression, cumulative pitches thrown was treated as a static variable, representing cumulative game pitches during the study period. For game-specific logistic regression and the GEE, cumulative pitches thrown represented the total number of game pitches thrown prior to each game. Cumulative pitches were categorized for both logistic regression and GEE for ease of interpretation. The differences are demonstrated in Table 1, which shows cumulative pitches up to each game as well as cumulative pitches during the study period. For cumulative logistic regression, arm stiffness was defined as having reported arm stiffness after pitching in a league game at some point prior to the first game in which shoulder pain was experienced. For game-specific logistic regression and the GEE, arm stiffness was defined as the pitcher reporting arm stiffness after the previous league game pitched.

Analyses were performed using the SAS System 6.12 (SAS Institute, Cary, NC).

Table 1. Data Representing Subject's Pitching Appearances and Cumulative Pitches

Subject's pitching appearances	Pitches thrown during appearance	Cumulative pitches GEE, LRGS[a]	Cumulative pitched LRC[b]
1st game	75	0	
2nd game	33	75	
3rd game	27	108	
4th game	17	135	
5th game	44	152	
			196

[a] Game-specific logistic regression.
[b] Cumulative logistic regression.

RESULTS

Table 2 compares the results of cumulative logistic regression analysis. game-specific logistic regression analysis. and GEE analysis. Cumulative logistic regression analysis indicated that pitchers who used a change-up were at a statistically significant 51% decreased odds of having pitching-related shoulder pain during the season. Game-specific logistic regression analysis and the GEE analysis indicated that pitchers who used a change-up were at a nonsignificant decreased odds of having shoulder pain as a result of pitching in a given game during the follow-up period.

When analyzed using cumulative logistic regression, total pitches thrown was significantly associated with a 2.5- and 3.2-fold increased odds of shoulder pain during the season for the categories 300-599 and ≥600 pitches respectively. compared with <300 pitches. However. analysis of these same data with game-specific logistic regression and the GEE revealed that once a pitcher reaches the 300-599 pitches category, he or she has more than 50% lower odds of shoulder pain than when a pitcher is in the <300 category. Likewise. once a pitcher enters the ≥600 category, he or she has 86% lower odds of shoulder pain than when in the <300 category.

When analyzed using cumulative logistic regression, experiencing stiffness after the previous game pitched resulted in a more than fivefold increased risk of shoulder pain. Game-specific logistic regression analysis of stiffness in the previous game pitched resulted in a twofold increased risk of shoulder pain. However, when analyzed using GEE. stiffness after the previous game demonstrated no association with shoulder pain.

Table 2. Results of Logistic Regression v. Longitudinal Analysis using a Generalized Estimating Equation

Variable	OR_{LRC}[a]	*P*	OR_{LRG}[b]	*P*	OR_{GEE}[c]	*P*
Change-up use	0.49	0.02	0.83	0.43	0.89	0.70
<300 pitches	Referent	-	Referent	-	Referent	-
300-599 pitches	2.49	<0.01	0.49	<0.01	0.46	<0.01
600+ pitches	3.21	<0.01	0.14	0.05	0.14	<0.01
Stiffness in previous game	5.64	<0.01	2.04	<0.01	0.86	0.69

[a] Cumulative logistic regression.
[b] Game-specific logistic regression.
[c] Generalized estimating equation.

DISCUSSION

Interpretation of the results from the three models is quite different even when the odds ratios are not. The results of the cumulative logistic regression suggest that use of a change-up will reduce the odds of shoulder pain over the course of a season by nearly half. However, the results of the game-specific logistic regression model and the GEE suggest that if any reduction is present for decreasing the odds of shoulder pain during a given game, it is minor. This result would be expected. For any given game pitched, the effect of change-up use is slight, but when compounded for the length of the study, change-up use has a significantly protective effect.

Although this change in results is dramatic and could have a significant impact on the interpretation of the study findings and subsequent recommendations made by health professionals, it is not as dramatic as the effect that may be seen with a dynamic variable.

Cumulative logistic regression results suggest that pitchers who throw 300 or more game pitches in a season have two times the odds of shoulder pain compared with pitchers who throw fewer than 300 game pitches. Likewise, pitchers who throw 600 or more game pitches in a season have three times the odds of shoulder pain compared with pitchers who throw fewer than 300 game pitches. Conversely, results from game-specific logistic regression and the GEE demonstrate that complaints were most frequent during the first 300 pitches, with a significantly decreased odds of shoulder pain in a given game after 300 or more pitches had been thrown. The interpretation of the cumulative logistic regression results is that increased pitch totals result in increased shoulder pain, whereas the interpretation of the GEE results is that as pitch totals increase, likelihood of shoulder pain decreases. Shoulder pain in youth baseball may be the result of underdevelopment of the muscular tissue of the glenohumeral joint. This would be most likely early in the baseball season, when the players have not had the opportunity to adequately strengthen their pitching arms. Thus, although the more times one pitches, the probability of ever having shoulder pain increases, the probability in any given game decreases as the number of previous games increases. The measures that one might recommend to prevent shoulder pain could be very different. Based on the cumulative logistic approach, one might be tempted to reduce the number of pitches thrown, whereas the other models would suggest additional preseason or early season shoulder strengthening.

This discrepancy is explained in Table 3, which presents hypothetical game-specific risk and the corresponding cumulative risk. In this example, the game-specific risk decreases for each game played, but the cumulative risk continues to increase after each game pitched. Therefore, whereas the average game-specific risk is only 12.5%, the cumulative risk after four games is 42%. As a result, a variable such as cumulative

Table 3. Hypothetical Example of Game-specific v. Cumulative Risk

Game number	Game-specific risk (%)	Cumulative risk (%)
1	20	20
2	15	32
3	10	39
4	5	42

pitches would demonstrate an increased risk when using cumulative logistic regression because cumulative pitch totals are dependent on the number of pitching appearances. On the contrary, when cumulative pitches were evaluated using the game-specific methods, the result would be a protective effect because the game-specific risk decreases over time, resulting in a lower risk for higher cumulative pitch counts.

The results from game-specific logistic regression and the GEE model have been relatively consistent to this point, suggesting that there is not much dependence between observations within specific subjects. In other words, the results of the analysis of change-up and cumulative pitches are not highly correlated across games in an individual pitcher.

Experiencing stiffness in the previous pitching experience resulted in a greatly increased risk when analyzed using cumulative logistic regression and in a significant increased risk when analyzed using game-specific logistic regression, but in no increase when analyzed using the GEE. This finding is due to the dependence between episodes of stiffness in individual pitchers. Although it cannot be deduced directly from the data presented in Table 2, the adjustment for dependence between observations for a few subjects can be quite apparent. As an example of observation dependency, Table 4 presents data from all pitchers who reported shoulder pain in a game after reporting

Table 4. All Pitchers Reporting Stiffness After One Pitching Appearance and Shoulder Pain in the Next Pitching Appearance

Episode number	Pitcher number	Game date
1	1	April 11
2	2	April 11
3	3	April 16
4	4	April 21
5	5	April 23
6	**6**	**April 26**
7	**7**	**April 30**
8	**8**	**May 2**
9	9	May 4
10	10	May 8
11	**7**	**May 8**
12	**8**	**May 9**
13	**7**	**May 14**
14	11	May 14
15	12	May 18
16	13	May 18
17	14	May 19
18	**6**	**May 22**
19	15	May 24
20	**8**	**June 6**
21	16	June 12

Note: Bold observations (subjects 6,7,8) exhibit dependency.

stiffness. Sixteen pitchers reported this combination a total of 21 times. However, 8 of the 21 episodes were in three individuals. When analyzed as if each observation were independent, prior stiffness resulted in an increased risk of shoulder pain. However, once the dependence between episodes in pitchers six, seven, and eight was adjusted for in the GEE, the association disappears.

Conclusion

The utility of repeated measures techniques such as the GEE is broad. The ability to analyze multiple observations per subject is especially useful in sports medicine research because athletes are exposed to the risk of injury during discrete periods of time (i.e., during athletic participation). The GEE and other repeated measures techniques can easily adjust for dependence within a subject across observations. These techniques adjust for repeatability of injuries across observations and for the fact that one injury does not preclude a different injury from occurring. Finally, the effects of both static and dynamic variables can be evaluated in the same study with the same statistical tool. This allows for more precise evaluation of cumulative or event-specific variables while controlling for variables that remain constant over time. These benefits, coupled with the obvious need for such analytic techniques, make repeated measures analysis an important tool for sports medicine investigators.

Longitudinal analysis, including marginal models such as the GEE, is under-used in most areas of epidemiologic endeavor, not the least of which is sports medicine. However, sports medicine is one of the disciplines that would profit greatly from increased implementation of these techniques. The repeated measures technique presented here is robust regardless of the underlying covariance structure and variability in the number of observations per subject, suggesting that there is no reason to avoid the use of such techniques if the data warrant such analysis. Although the interpretation of results may be more difficult, this should easily be overcome with careful consideration of the data. Caution should be used when implementing these techniques, but the robustness of these methods makes them useful in a large number of scenarios.

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DISCUSSION

Purpose

The purpose of this study was to quantify the relationship between arm pain and pitch volume, pitch type, and other factors thought to be associated with elbow and shoulder pain in youth baseball pitchers. This purpose was chosen due to the paucity of information available to youth baseball coaches, parents, and participants throughout the world. The two most common questions asked of the American Sports Medicine Institute regarding youth baseball are, "How many pitches should my child throw?" and "How old should my child be before learning to throw a curve ball?" [25].

This research is thought to be important because the pain reported in these ages may result in more serious elbow and shoulder injuries in the future, and identifying risk factors can result in the development of effective prevention of these injuries.

In an attempt to answer these compelling questions and identify other factors that may be associated with arm pain in youth baseball pitchers, we followed 298 youth baseball pitchers in the Birmingham, Alabama metropolitan area over two consecutive spring baseball seasons.

Strengths

This represents the second largest study of youth baseball pitchers and equals the longest follow-up period of any study of its kind. This is also the first study to make a concerted effort to identify multiple risk factors for elbow pain and the first study attempting to identify any risk factors for shoulder pain in young pitchers.

The analytic methods used for this project were new to the field of sports medicine research in general and to youth baseball pitching research in particular. Previous studies had rarely even used hypothesis testing, whereas this study not only used hypothesis testing, but also collected data after each pitching appearance rather than at the beginning or ending of the season. This allowed for longitudinal analysis, which has not previously been used with this type of data. This longitudinal analysis allowed for measurement of repeated reports of pain in individual pitchers, game-specific analysis of dynamic variables (i.e., variables that change from observation to observation), and controlling for dependence between observations within an individual pitcher.

Inter- and intrarater reliability measures were high with regard to the questionnaires used in this study and the pitch count books also exhibited good reliability. This suggests that the variables collected are accurate to the best knowledge of the researchers.

Limitations

The outcome measures, elbow pain and shoulder pain, are self-reported. This is a limitation in all previous studies of this kind, and this project is no exception. Serious arm injuries are very rare in pitchers in this age group [7]. Therefore, studies evaluating arm injury in these ages have relied on self-reported pain as an indicator of potential injury, though this may reflect a bias toward counting children with low pain tolerances more often than children with higher tolerances. The only argument against this potential bias is that pitching is a highly stressful, highly visible activity and may select the heartier participants among a group of participants that are already heartier than the general population in these ages. This might reduce the likelihood that children with low pain tolerances would make it into the ranks of pitchers.

Another limitation of this study is the lack of an objective measure of development. These children were asked for their age, height, and weight, but these are not ideal measures of skeletal maturity. Due to a lack of resources, x-rays could not be taken of these children to identify their bone age, let alone look for degenerative changes in the elbow or shoulder joints. Future studies should incorporate an objective measure of development so that the role of the developing juvenile skeleton can be assessed as a causal factor for arm pain in these pitchers.

This study did not use any measure of pitching mechanics or pitching motion despite the body of knowledge concerning the injury potential of poor mechanics [17,18]. This area of endeavor may be the single most pressing need in the study of arm pain in youth baseball. The pitching motion, which has already been modeled biomechanically, should be analyzed to identify phases of the motion that are associated with arm pain.

A limitation of the analytic method used is that it does not measure the cumulative effect of pitching over the course of the study, but rather the game-specific effect of cumulative pitching. This is considered an acceptable limitation because the pain reported by a majority of these pitchers was transient, rather than chronic.

Overview of Results

The primary finding of this study was that elbow and shoulder pain have overlapping, but unique risk profiles. Some factors were even protective for one pain location but contributed to pain in the other location. This finding suggests that arm pain in youth baseball pitchers should not be grouped together in future research. but each site of pain should be analyzed separately. Also. any recommendations that are made should be preventative of elbow or shoulder pain without contributing to the other.

Results of the study showed that pitchers who threw more pitches over the course of the season had an increased risk of elbow pain. but a decreased risk of shoulder pain. The decreased risk of shoulder pain is likely a result of pitchers injuring their shoulders early in the season and decreasing their pitching from that point on. This notion is supported by the fact that pitchers were at increased risk of shoulder pain as their game-specific pitches increased regardless of cumulative pitch totals.

As had been expected. use of the change-up pitch reduced the risk of elbow and shoulder pain. though the finding was significant only for elbow pain in 11- and 12-year-old pitchers. The slider appeared to be protective of shoulder pain as well. though this finding did not hold up in multivariable analysis.

Increased height and playing tennis were protective factors for elbow pain. whereas increasing age. private pitching instruction. weight lifting. and playing baseball outside of league games and practices were all independent risk factors for elbow pain. Playing catcher and playing first base were protective factors for shoulder pain. Whereas increasing height and playing third base were independent risk factors for shoulder pain.

These findings identify the factors in which improvement will most likely make an impact on the risk of elbow and shoulder pain in youth pitchers. Age, height. and weight are largely nonmodifiable risk factors for these children. so attention should focus on modifiable factors such as pitch limits, weight lifting, baseball play outside of the league, arm fatigue, and primary position played.

Implications

Little or no reduction was found in the frequency of elbow pain when comparing the current study with studies conducted prior to the initiation of the current pitching regulations [5,6]. Therefore, we may infer that more stringent limitations on pitching and training should be placed upon pitchers in this age group. Since no previous study has been conducted for shoulder pain in a similar population, it is difficult to make this same inference. The answer may be a pitch count regulation. However, it is possible that more stringent innings limits, batter limits, or appearance limits for the season would better retain the integrity of the game. The concern with pitch limits is that savvy coaches might do their best to use up the pitches for an opposing team's star pitcher so that his team has a better chance of success against another young arm. If an inning or batter limit were used, those same coaches would know they will see that pitcher for those innings or batters, so they might be less likely to alter their strategy.

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 in order to lower the risk of shoulder, and possibly elbow, pain. Although the cumulative pitches issue is less clear, it appears that throwing more than 600 game pitches in a single season may be a risk factor for elbow pain.

From the age-specific results regarding pitch types, it appears that pitchers at 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 harmful, but because the change-up is safer. The findings also suggest that pitchers who use the sinker ball 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. Also, pitchers who reported arm stiffness after the prior game pitched were more likely to report elbow pain. Therefore, pitchers with complaints of fatigue should perhaps be removed from pitching in the game, and pitchers who complain of stiffness might be encouraged to reduce their pitching.

Other recommendations supported by these results include shoulder exercises designed for pitchers and reducing the pitching done in nonleague games.

Conclusions

With a paucity of information available in the medical literature regarding the epidemiology of arm injuries in youth baseball, it is hoped that this study will contribute to the existing body of knowledge and improve the abilities of parents, coaches, and health professionals to keep young pitchers free from pain. It is also hoped that this research will serve as a foundation for future studies. The next primary advancement in the understanding of arm pain in youth baseball pitchers should be in the area of the pitching motion. Although overuse and other factors contribute significantly to arm pain in this population, it is unlikely that any single factor has as great an impact as pitching mechanics.

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APPENDIX A

BASELINE COACHING QUESTIONNAIRE

COACHING QUESTIONNAIRE

I. PERSONAL INFORMATION:

Full Name: ______________________________

Home Telephone: _____-________ Work Telephone: ______-________

Address: ______________________ City: ______________, AL zip: ________

II. COACHING INFORMATION:

Park: **Cahaba Heights** **Hoover East**

Age Group: **9-10** **11-12** **11** **12**

Team Name: ______________________

Seasons coaching youth league baseball: **Fall:** ______ **Spring:** ______

III. TEAM INFORMATION:

1. How many practices do you have per week prior to the season? _____
2. How many practices do you have per week during the season? _____
3. Do you allow pitchers to pitch BETWEEN games? **YES** **NO**

   If YES, how often:

   Daily **Every other day** **2x week** **3x week** **Less often**

   When they pitch between games, how many minutes do they throw? ____
4. Do you allow pitchers to throw batting practice? **YES** **NO**
5. Do you limit your pitcher's innings per GAME? **YES** **NO**

   How MANY innings if less than the league limit? _____ **innings**
6. Do you limit your pitcher's innings per WEEK? **YES** **NO**

   How MANY innings if less than the league limit? _____ **innings**
7. How often does each pitcher throw in practice?

   Every practice **Every other practice** **Less Often** **Never**
8. When a pitcher throws in practice, how many minutes does he throw? ___

9. Do you TEACH your pitchers any of the following pitches?

Curveball	**YES**	**NO**
Slider	**YES**	**NO**
Change-up	**YES**	**NO**
Forkball / Split-finger	**YES**	**NO**
Other ______________	**YES**	**NO**

10. Do any of your pitchers THROW any of the following pitches?

Curveball	**YES**	**NO**
Slider	**YES**	**NO**
Change-up	**YES**	**NO**
Forkball / Split-finger	**YES**	**NO**
Other ______________	**YES**	**NO**

11. How many pitchers will you use THIS season? **1 2 3 4 5 6**

12. Please name all of your pitchers:

	NAME
1	
2	
3	
4	
5	
6	
7	
8	

13. May a study representative call you after EACH game during the season to find out who pitched in that game?
YES **NO**

14. Each team will receive a pitch count book. We'd like you, an assistant, or team parent to be responsible for counting pitches during the season. Will this be a problem?
YES **NO**

If YES, Why? ____

If NO, Who will be responsible? ____________________________

APPENDIX B

INFORMED CONSENT FORM

INFORMED CONSENT

Name: ______________________________ **Date:** ______________

EXPLANATION OF PROCEDURES: You are being asked to participate in a research project conducted by the American Sports Medicine Institute (ASMI), in cooperation with the International Baseball Foundation (IBF) and the University of Alabama at Birmingham School of Public Health (UAB). The goal of the study is to evaluate determinants of arm injury among youth baseball pitchers. Those factors include: number of pitches thrown, types of pitches thrown, and other potential factors.

If you decide to participate, an initial interview will be conducted prior to the beginning of the upcoming spring season. A follow-up interview will also be conducted at the end of the season. These interviews will each take approximately 10 minutes to complete. Additionally, during each week in which you pitch in a game, a study representative will contact you via telephone to discuss your game experiences. These telephone interviews will take less than 5 minutes to complete. The results of these tapes will be mailed to you at the end of the season. Approximately 200 pitchers ages 9-12 from the Birmingham, Alabama metropolitan area will be followed.

RISKS AND DISCOMFORTS: The only discomfort which may occur is the inconvenience of responding to the telephone interviews. No other risks or discomforts are expected other than those normally associated with baseball.

BENEFITS: Your participation will provide valuable information about arm injuries among youth league baseball pitchers. In addition, this information may be useful in preventing injuries in the future, and if you are still pitching at that time, this may result in preventing an injury to you.

ALTERNATIVES: The alternative is to decline your right to participate in this study. Your non-participation will not result in a loss of opportunity or any repercussion. Participation in this study is entirely voluntary.

CONFIDENTIALITY: The information collected about you will be kept strictly confidential. Your interview responses will not be available to any party not officially associated with the study. When the results are published, no single participant will be identified.

WITHDRAWAL WITHOUT PREJUDICE: You are free to withdraw from the study at any time without penalty.

COST TO SUBJECT FROM PARTICIPATION IN RESEARCH: There will be no cost to you except your time. Any telephone or postage charges will be incurred by ASMI, IBF, or UAB.

PAYMENT FOR PARTICIPATION IN THE RESEARCH/RESEARCH-RELATED INJURIES: No payment is available to subjects for participation or for research-related injuries. No research-related injuries are anticipated. Neither ASMI, IBF, nor UAB bear any responsibility for injuries sustained during study participation.

QUESTIONS: If you have questions about the research, Stephen Lyman will be glad to answer them. Mr. Lyman's telephone number is (205)934-7131. If you have any questions about your rights as a research participant. Ms. Carolyn Reid, Health South Representative (ASMI) will answer them. Ms. Reid's telephone number is (205)930-7703.

LEGAL RIGHTS AND SIGNATURES: A copy of this signed consent form will be mailed to you upon request. You are not waiving any of your legal rights by signing this consent form. Your signature below indicates that you agree to participate in this study.

As a parent or guardian, you are making a decision whether or not to have your child participate in this study. Your signature indicates that you have decided to allow your child to participate and that you have read (or been read) the information provided.

________________________________ ______________________
Signature of Parent or Person Responsible Date

________________________________ ______________________
Signature of Investigator Date

________________________________ ______________________
Signature of Witness Date

ASSENT OF CHILD:

________________________ (name of child) has agreed to participate in this research.

________________________________ ______________________
Signature of Participant Date

APPENDIX C

BASELINE PITCHING QUESTIONNAIRE

YOUTH BASEBALL PITCHING STUDY
Baseline Pitching Questionnaire

Pitcher Name: ________________________________Home Phone: (205) ____-________

Address: ________________________City: ___________________, AL Zip: ___________

DOB: ___/___/___ Height: _____ **in.** Weight: ____ **lb.** Hand: **R** **L** Gender: **M** **F**

BASEBALL INFORMATION

1. Which park do you play in?: _____________

2. Which age level do you play?: **9-10** **11-12** **13-14** **15-16**

3. How old were you when you first played in a baseball league? _____ **years old**

4. How old were you when you first played any kind of baseball? _____ **years old**

5. Not counting games and practices do you play any other baseball during the season?

   YES **NO**

   If YES, how many days a week? _____ **days**

6. Have you ever attended a baseball camp? **YES** **NO** how many camps? _____

   If YES, which camps? ____

7. Which positions do you play? *(circle ALL that apply)* **P** **C** **1B** **2B** **3B** **SS** **OF**

Which ONE position do you play most often? **P** **C** **1B** **2B** **3B** **SS** **OF**

9. Which ONE position is your favorite to play? **P** **C** **1B** **2B** **3B** **SS** **OF**

III. PITCHING INFORMATION

10. Have you EVER pitched in a baseball league? **YES** **NO**

    If YES, how many SPRING and FALL seasons have you pitched? ___ **Spring** ___ **Fall**

    AND have you ever been an ALL STAR pitcher in a league? **YES** **NO**

    If YES, how many seasons? ____

11. Have you ever been helped by a pitching instructor other than a coach or parent?

    YES **NO** *If YES,* who was your instructor? __________________________

12. Besides games and practices, do you do any other pitching during the season? **YES** **NO**

    If YES, how many days a week? ____ **days**

    If YES, how many MINUTES do you usually pitch each time? ____ **minutes**

13. Do you pitch during the OFF SEASON? **YES** **NO**

    If YES, how many days a month? ____ **days**

    If YES, How many MINUTES do you usually pitch each time? ____ **minutes**

14. Which of the following pitches did you throw in games?

FASTBALL **YES** **NO** Type of fastball: **2-seam** **4-seam** **3-finger** **Cut**

Age learned to throw: ______ ______ ______ ______

How many pitches out of ten?: ______ ______ ______ ______

CHANGE-UP **YES** **NO** Circle type of change-up: **3-finger** **Circle** **Palm** **Other:** _____

Age learned to throw: _____ _____ _____ _____

How many pitches out of ten?: _____ _____ _____ _____

CURVEBALL **YES** **NO** *If YES,* How old were you when you learned a curveball? ___

In a game, how may pitches out of ten would be curveballs? ____

SINKER **YES** **NO** *If YES,* How old were you when you learned a sinker? ___

In a game, how may pitches out of ten would be a sinker? ____

SLIDER **YES** **NO** *If YES,* How old were you when you learned a slider? ___

In a game, how may pitches out of ten would be a slider? ____

OTHER **YES** **NO** *If YES.* How old were you when you learned this pitch? ___

What other pitch?: ____________________

In a game, how may pitches out of ten would be this pitch? ____

INJURY INFORMATION:

15. Have you EVER hurt your throwing arm doing something OTHER than playing baseball?

YES **NO**

If YES, what were you doing, what did you hurt, and how old were you?

PITCHING INJURY INFORMATION

16. Have you EVER been REMOVED from pitching in a game due to arm pain?

YES **NO**

17. Have you EVER felt pain or soreness in your throwing arm from pitching in a game?

YES **NO**

If YES, answer the following questions. *If NO, skip to question #18.*

How old were you the first time you felt this? _____

Thinking of the FIRST time:

Did you feel arm pain before, during or after pitching? **BEFORE** **DURING** **AFTER**

For how long? ____ **minutes** ____ **hours** ____ **days**

What part of your arm bothered you?

ELBOW **SHOULDER** **WRIST** **FOREARM** **UPPER ARM** **OTHER:**__________

Did you go see a doctor for your injury? **YES** **NO** diagnosis: ________________

Did you receive treatment for your injury? **YES** **NO** treatment: ________________

When was the last time you felt this? ____________________

Thinking of the LAST time:

Did you feel arm pain before, during or after pitching? **BEFORE** **DURING** **AFTER**

For how long? ____ **minutes** ____ **hours** ____ **days**

What part of your arm bothered you?

ELBOW SHOULDER WRIST FOREARM UPPER ARM OTHER:__________

Did you go see a doctor for your injury? **YES NO** diagnosis: ____________________

Did you receive treatment for your injury? **YES NO** treatment: ____________________

Which time did it hurt the most? FIRST LAST ANOTHER TIME

IF Another Time, answer following questions, else skip to #2.

How old were you when it hurt the most? ________________________

Thinking of the time when it hurt the most:

Did you feel arm pain before, during or after pitching? **BEFORE DURING AFTER**

For how long? ____ **minutes** ____ **hours** ____ **days**

What part of your arm bothered you?

ELBOW SHOULDER WRIST FOREARM UPPER ARM OTHER:__________

Did you go see a doctor for your injury? **YES NO** diagnosis: ____________________

Did you receive treatment for your injury? **YES NO** treatment: ____________________

18. How often do you feel:

arm pain or soreness WHILE pitching?

ALWAYS USUALLY SOMETIMES RARELY NEVER

Where: **ELBOW SHOULDER WRIST FOREARM UPPER ARM OTHER:**________

arm pain or soreness AFTER pitching?

ALWAYS USUALLY SOMETIMES RARELY NEVER

Where: **ELBOW SHOULDER WRIST FOREARM UPPER ARM OTHER:**________

stiffness in your arm after pitching?

ALWAYS USUALLY SOMETIMES RARELY NEVER

Where: **ELBOW SHOULDER WRIST FOREARM UPPER ARM OTHER:**________

Times:

During the season I'll be calling you to ask you about each game that you pitch. Because we have so many coaches and pitchers to call, I'd like to know when I can call you:

During the week? ____:____ AM/PM to ____:____ AM/PM

On the weekend? ____:____ AM/PM to ____:____ AM/PM

That's all the questions I had for you. Do you have any questions for me? Thank you very much for your help!

APPENDIX D

PITCH COUNT BOOK INSTRUCTIONS AND SAMPLE PAGE

General Instructions

This pitch count book is being used to track the pitchers of every pitcher in your league. It is very important that this is done for every pitcher in ever game this season. The findings will go a long way in determining how many pitchers is too many for a young pitcher to throw. It is hoped that this information will help protect young pitchers against elbow and shoulder injuries.

The following are some simple instructions for the use of this booklet:

1. Please fill out a page for each game played by your team during the season.

2. Count pitches for your team only. The other team will track their own pitches.

3. If more than 5 pitchers appear for your team in a single game. go to the next page and being with "First Relief Pitcher". Do not begin with "Starting Pitcher".

4. Please fill in all information on the page including Date, Opponent. Pitchers Names (in the order they appear in the game), Winning Team. and Final Score.

5. At the end of the game, please fill out the summary table at the bottom of the page.

6. Every time a pitch is thrown, check (X or /) a new box.

7. Boxes are in groups of 10 making it easy to count up the pitches at the end of the game. Please write the total number of pitches thrown by each pitcher in the "Total Pitches" column at the bottom of the page.

8. Each row of boxes represents an inning. Please start a new row of boxes for each inning a pitcher appears in.

9. If a pitcher throws a partial inning (0.1.2 outs), please make note in the innings pitched column at the bottom of the page using the following codes:

   0/3 = pitched in the inning, but recorded no outs
   1/3 = recorded 1 out
   2/3 = recorded 2 outs

   For example, a pitcher throwing 2 complete innings and then pitching, but getting no outs in a third inning would be coded as 2 0/3 innings pitched.

Again, Thank you for you help!

Instructions: Enter all information on each game. Start a new row for each inning. Do NOT continue counting on the same line if an inning has ended. For relief pitchers, 1-5 represent the pitcher's 1st inning-5th inning pitched, not the game's 1st inning-5th inning. If more than 5 pitchers appear in a game, continue on next page (skip "Starting Pitcher" section, start with 1st relief pitcher).

Date: ___/___/99 Opponent: ______________ Final Score (your team 1st): ___-___

Inning: Starting Pitcher Name: __________________________________

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Second Relief Pitcher Name: _______________________ Inning Entered Game: ____

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Third Relief Pitcher Name: _________________________ Inning Entered Game: ____

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Fourth Relief Pitcher Name: ________________________ Inning Entered Game: ____

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Pitcher Name	Innings Pitched	Batters Faced	Total Pitches	Runs Against	Win/Loss/ Save
1.					
2.					
3.					
4.					
5.					

APPENDIX E

POSTGAME PITCHING QUESTIONNAIRE

GAME INTERVIEW

PITCHER: ______________________ **PHONE:** ____-______ **INTERVIEWER ID:** _____

LEAGUE: ____________________________ **TEAM:** ____________________

DATE: ___/___/99 **TIME:** ____:____ **AM/PM**

PITCHING - GAME INFORMATION

1. When was your last baseball game? Date: ___/___/99 Day: **M T W R F Sa Su**
2. Were you the starting pitcher? **YES NO**
3. How would you rate your pitching in the game?

   EXCELLENT GOOD AVERAGE FAIR POOR

4. About how many innings and pitches did you throw in the game? ___.___ **inn.**______ **pitches**

   For 5 and 6 ask how many innings they played at each position and write in the space

5. Which other positions did you play before you pitched?

   C ___ 1B ___ 2B ___ 3B ___ SS ___ OF ___

5. Which other positions did you play after you pitched?

   C ___ 1B ___ 2B ___ 3B ___ SS ___ OF ___

INJURY INFORMATION			**Is this USUAL?**	
7. Did your arm get tired while pitching?	**YES**	**NO**	**YES**	**NO**
8. Did your arm get stiff or tight after pitching?	**YES**	**NO**	**YES**	**NO**
9. Did you feel any pain in your elbow from pitching?	**YES**	**NO**	**YES**	**NO**
10. Did you feel any pain in your shoulder from pitching?	**YES**	**NO**	**YES**	**NO**
11. Did you feel any pain in any other part of your arm from pitching?	**YES**	**NO**	**YES**	**NO**

[If 7-11 = NO, then end interview]

FATIGUE (if YES to 7 under INJURY INFROMATION):

12. How many innings had you pitched before your arm started to feel tired? _______ **innings**

STIFFNESS (if YES to 8 under INJURY INFORMATION):

13. What part of your arm was stiff or hard to use?

    SHOULDER ELBOW UPPER ARM FORE ARM

    WRIST HAND FINGER OTHER ____________________

14. Did this stiffness begin before, during, or after the game? **BEFORE DURING AFTER**

    If DURING, did your stiffness make you stop pitching in the game? **YES NO**

    If DURING, how many innings had you pitched before stiffness started? _______ **innings**

15. How long did the stiffness last? ____ minutes ____ hours ____ days

ANY COMPLAINT OF PAIN/SORENESS (YES to 9, 10, or 11 under INJURY INFORMATION):

16. Can you throw with your usual pitching motion? **YES NO** Does this hurt? **YES NO**

ELBOW PAIN (if YES to 9 under INJURY INFORMATION):

17. Did your elbow pain start before, during, or after the game? **BEFORE DURING AFTER**
    If DURING, did your pain make you stop pitching in the game? **YES NO**
    If DURING, how many innings had you pitched before pain started? _______ **innings**
18. Does your elbow still hurt? ————————————→ **YES NO**
    If YES, is your elbow tender when you touch it or press on it? **YES NO**
19. Can you straighten your arm/elbow? **YES NO** Does that hurt? **YES NO**
20. Can you bend your elbow all the way? **YES NO** Does that hurt? **YES NO**
21. How long did the pain last? ____ minutes ____ hours ____ days
24. What part of your elbow hurts?
    INSIDE (closest to body) **OUTSIDE** (furthest from body) **BOTH**
23. Did it hurt all the time, just to move it, or just when throwing? **ALWAYS MOVE THROW**
25. Is the feeling a sharp pain, dull ache, or something else?
    SHARP ACHE OTHER _____________

SHOULDER PAIN (if YES to 10 under INJURY INFORMATION):

25. Did your shoulder pain start before, during, or after the game? **BEFORE DURING AFTER**
    If DURING, did your pain make you stop pitching in the game? **YES NO**
    If DURING, how many innings had you pitched before pain started? _______ **innings**
26. Does your shoulder still hurt? ————————————→**YES NO**
    If YES, is your shoulder tender when you touch it or press on it? **YES NO**
27. Can you lift your arm over your head? **YES NO** Does this hurt? **YES NO**
28. How long did the pain last? ____ minutes ____ hours ____ days
29. What part of your shoulder hurts? **FRONT BACK TOP BOTTOM SIDE**
30. Did it hurt all the time, just to move it, or just when throwing? **ALWAYS MOVE THROW**
31. Is the feeling a sharp pain, dull ache, or something else?
    SHARP ACHE OTHER _____________

OTHER ARM PAIN (if YES to 11 under INJURY INFORMATION):

32. What part of your arm was sore or painful?
    UPPER FOREARM WRIST HAND OTHER ________________
33. Did your pain start before, during, or after the game? **BEFORE DURING AFTER**
    If DURING, did your pain make you stop pitching in the game? **YES NO**
    If DURING, how many innings had you pitched before pain started? _________ **innings**
34. Does this place still hurt? ————————————→ **YES NO**
    If YES, is it tender when you touch it or press on it? **YES NO**
35. Can you move this part of your arm? **YES NO** Does this hurt? **YES NO**
36. How long did the pain last? ____ minutes ____ hours ____ days

37. Did it hurt all the time, just to move it, or just when throwing? **ALWAYS MOVE THROW**

38. Is the feeling a sharp pain, dull ache, or something else?

    SHARP ACHE OTHER ____________

TREATMENT OR DOCTOR VISIT (if ANY complaint of arm pain):

39. Did you do anything to make your arm feel better, like ice, aspirin, tylenol, advil, icyhot rub?

    YES NO what did you use? ____________________

40. Did a doctor, nurse, or other health person look at your arm? **YES NO**

    If YES, which did you see? **DOCTOR NURSE OTHER** ____________________

40. Did you visit a doctor's office, hospital, ER, or another health facility because of the pain?

    YES NO If YES, which did you visit? **OFFICE HOSPITAL ER OTHER** __________

43. (if yes in 40 or 41, ask to speak with parents) Is it true that your son/daughter went to a health professional because of arm pain from pitching? **YES NO**

42. (if yes) What did they say (diagnosis) about his/her arm?

____

APPENDIX F

POSTSTUDY FOLLOW-UP PITCHING QUESTIONNAIRE

YOUTH BASEBALL PITCHING STUDY
Follow-up Pitching Questionnaire

Pitcher Name: ______________________________ Height: _____ **in.** Weight: _______ **lb.**

1. Which positions did you play? *(circle ALL that apply)* **P C 1B 2B 3B SS OF**
2. Which ONE position did you play the most? **P C 1B 2B 3B SS OF**
3. Did a pitching instructor help you during the season? **YES NO** If YES. Who? __________
4. Which of the following pitches did you throw in games?

FASTBALL **YES** **NO** Type of fastball: **2-seam 4-seam 3-finger Cut**

Age learned to throw: ______ ______ ______ ______

How many pitches out of ten?: ______ ______ ______ ______

CHANGE-UP **YES** **NO** Circle type of change-up: **3-finger Circle Palm Other:** ___

Age learned to throw: ______ ______ _____ ______

How many pitches out of ten?: ______ ______ _____ ______

CURVEBALL **YES** **NO**

If YES, How old were you when you learned to throw a curve? ___ years old

In a game, how may pitches out of ten would be curveballs? ____

SINKER **YES** **NO**

If YES, How old were you when you learned to throw a sinker? ___ years old

In a game, how may pitches out of ten would be a sinker? ____

SLIDER **YES** **NO**

If YES, How old were you when you learned to throw a slider? ___ years old

In a game, how may pitches out of ten would be a slider? ____

OTHER **YES** **NO**

If YES, How old were you when you learned to throw this pitch? ___ years old

What other pitch?: ____________________

In a game, how may pitches out of ten would be this pitch? ____

5. Did you play any other sports for fun during the baseball season?

   Football Basketball Tennis Soccer Golf Racketball

   Rollerblading Swimming Biking Other: ___________

6. Did you do any type of exercise/training during the season? **YES NO**

   If YES, what kind of training did you do?

   Weight-lifting Push-ups Running **Other:** ___________

7. Did you go see a doctor about arm pain or soreness during the season? **YES NO**

   If YES, what did he say? ____

8. Did you ice your arm after each game you pitched? **YES NO**

   If YES, what part did you ice? **ELBOW SHOULDER OTHER:** _____________

9. Did you take any aspirin, tylenol, or advil after each game you pitched? **YES** **NO**
10. Did you miss any practices because your arm was hurting? **YES** **NO**
11. Did you miss any games because your arm was hurting? **YES** **NO**
12. Did you stop pitching for the season because your arm was hurting? **YES** **NO**
13. Does your family have email access? **YES** **NO** Do you use it? **YES** **NO**

    If YES, what is your email address? ______________________________

14. Would you be willing to have us call you again next season if you pitch? **YES** **NO**

APPENDIX G

IRC APPROVAL LETTER

HEALTHSOUTH
Medical Center

Memorandum

TO: Glenn S. Fleisig, Ph.D.

FROM: Ronald C. McCoy, M.D.
Chairman, Institutional Review Committee

SUBJECT: Youth Baseball Pitching Study

DATE: May 16, 1997

The Institutional Review Committee approved your request to conduct the following described study:

Protocol: Youth Baseball Pitching Study
Sponsor: American Sports Medical Institute
Patient Informed Consent
Principal Investigator: Glenn S. Fleisig, Ph.D., ASMI
Stephen Lyman, MSPH - University of Alabama
E. David Osinki - International Baseball Foundation
Protocol Summary: To elucidate the effect of pitch volume, pitch type, and pitching mechanics on risk for arm injury among youth league baseball pitchers as well as to evaluate other potential determinants of these injuries. It is the hope of the investigators that the results of this study will quantify the incidence of arm injury in youth baseball pitchers and qualify the determinants of these injuries. Additionally, it is hoped that the results will be utilized by youth league organizations, coaches, and pitchers to prevent these injuries in the future.

PROTOCOL: X Was approved

INFORMED CONSENT: X Was approved with the addition of a Medical Center representative added to the Informed Consent on page 2.

If you have any questions, please contact Carolyn Reid, Medical Staff Coordinator, at 930-7703.

Ronald C. McCoy, M.D.

Ronald C. McCoy, M.D.
Chairman, Institutional Review Committee

1201 11th Ave. South • Birmingham, AL 35205 • 205 930-7000

GRADUATE SCHOOL
UNIVERSITY OF ALABAMA AT BIRMINGHAM
DISSERTATION APPROVAL FORM
DOCTOR OF PHILOSOPHY

Name of Candidate Stephen L. Lyman

Major Subject Epidemiology

Title of Dissertation Arm Complaints in Youth Baseball Pitchers: Frequency and Associations with Pitch Volume, Pitch Type, and Other Factors

I certify that I have read this document and examined the student regarding its content. In my opinion, this dissertation conforms to acceptable standards of scholarly presentation and is adequate in scope and quality, and the attainments of this student are such that _he may be recommended for the degree of Doctor of Philosophy.

Dissertation Committee:

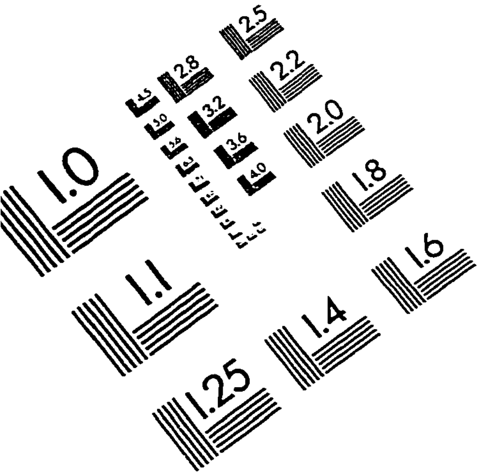
Name	**Signature**
Jeffrey M. Roseman, **Chair**	Jeffrey Roseman
Glenn S. Fleisig	Glenn Fleisig
Ellen Funkhouser	Ellen Funkhouser
LeaVonne Pulley	LeaVonne Pulley
John Waterbor	John Waterbor

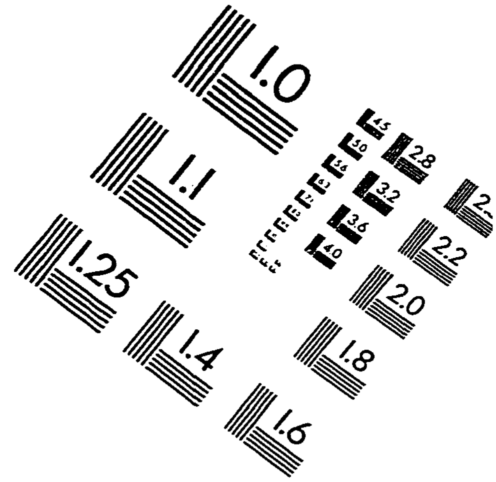
Director of Graduate Program Jeffrey Roseman

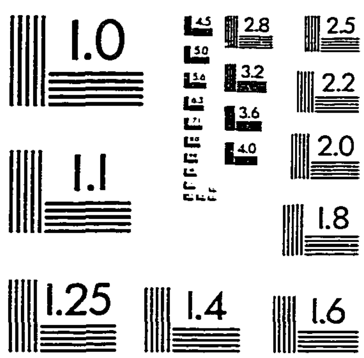
Dean, UAB Graduate School Joan F. Lorden

Date 6/14/99

IMAGE EVALUATION TEST TARGET (QA-3)







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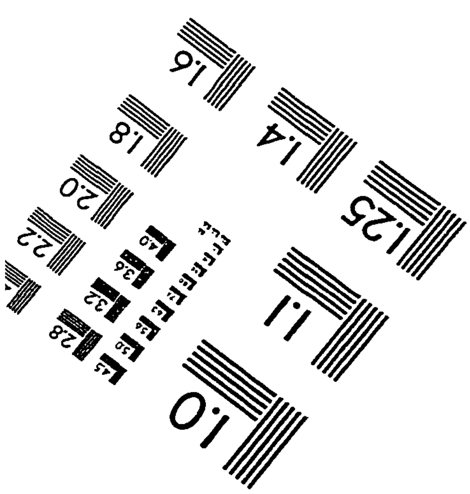

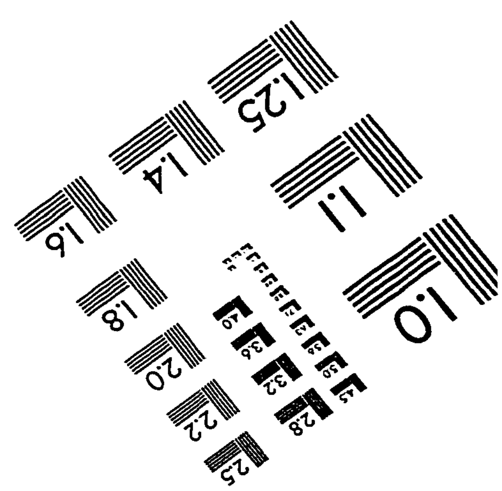

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