[Orthopaedic Surgery]

The Curveball as a Risk Factor for Injury: A Systematic Review

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Context: The curveball is regarded by many as a potential risk factor for injury in youth baseball pitchers.

Objective: To critically evaluate the scientific evidence regarding the curveball and its impact on pitching biomechanics and the overall risk of arm injuries in baseball pitchers.

Study Type: Systematic review.

Level of Evidence: Level 3.

Data Sources: Ovid MEDLINE from 1946 to 2012.

Study Selection: Ten biomechanical studies on kinematic or electromyographic analysis of pitching a curveball were included, as well as 5 epidemiologic studies that assessed pain or injury incidence in pitchers throwing the curveball.

Data Extraction: When possible, demographic, methodology, kinetics, and kinematics variables and pain/injury incidence were compiled.

Results: Two biomechanical studies found greater horizontal adduction of the shoulder at ball release and less shoulder internal torque during the curveball pitching motion. Two studies demonstrated less proximal force and less torque at the elbow as the arm accelerated when throwing a curveball compared with a fastball, as well as greater supination of the forearm and less wrist extension. Electromyographic data suggested increased activity of extensor and supinator muscles for curveballs. No studies found increased force or torque about the elbow or shoulder. Three epidemiologic studies showed no significant association between pitching a curveball and upper extremity pain or injury. One retrospective epidemiologic study reported a 52% increase in shoulder pain in pitchers throwing a curveball, although this may have been due to confounders.

Conclusion: Despite much debate in the baseball community about the curveball's safety in youth pitchers, limited biomechanical and most epidemiologic data do not indicate an increased risk of injury when compared with the fastball.

Keywords: curveball; throwing injuries; baseball; pitching

The growing popularity of competitive baseball among adolescents has been accompanied by a rise in the incidence of unique throwing-related injuries.[8] Notably, there has been an increase in the number of medial ulnar collateral ligament reconstruction ("Tommy John") procedures being performed on injured throwers.[5,9,17] Many factors have been cited as proximate causes for the increasing prevalence of throwing-related injuries, including overuse, high pitch counts, poor throwing mechanics, and the curveball. Many upper extremity injuries occurring in baseball may be preventable with improvements in pitching mechanics and pitch selection.[2,4,13] While recommendations regarding global overuse are supported by the available evidence, data regarding curveballs at a young age—a commonly accepted risk factor for injury—are unclear. A critical review to evaluate whether curveballs put pitchers at increased risk has not been performed. We hypothesized that the current evidence does not support increased injury risk from the curveball, despite widespread acceptance of this idea among baseball trainers, coaches, and physicians.

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Table 1. Epidemiologic studies

Study	Data Collection Period	Participants, n[a]	Mean Age, y (Range)	Level of Competition	Method
Lyman et al[15]	1997-1998	298 (99, 33.2%)	10.8 (8.1-12.4)	Youth	Baseline and postgame telephone interviews of pitchers
Lyman et al[13]	1999	476 (252, 52.9%)	12 (9-14)	Youth	Baseline and postgame telephone interviews of pitchers
Petty et al[18]	1995-2000	24	17.4 (15.9-19)	High school	Telephone survey of pitchers following ulnar collateral ligament reconstructive surgery
Olsen et al[17]	2003-2004	140[b]	18.5 ± 1.6 (14-20)	High school and college	Survey given to pitchers with a serious pitching-related injury and healthy pitchers
Fleisig et al[8]	1999-2008	481 (290, 60.3%)	12.0 ± 1.7 (9-14)[c]	Youth	Annual survey of pitchers

[a]Parentheses indicate the number and percentage that pitched a curveball.
[b]Injured, n = 95; healthy, n = 45.
[c]At beginning of study in 1999.

METHODS

Literature Search

A systematic review of the published English language literature assessing the impact of pitching a curveball in baseball was performed using the Ovid MEDLINE database from 1946 to March 1, 2012. The search included the terms *curveball* and *baseball pitching injuries*. All studies with a cohort of athletes (youth through professional levels) who were followed to determine the risk of pitching a curveball were included. Studies were divided into 2 categories: biomechanical and epidemiologic. Biomechanical studies analyzed the muscle activation, kinematics, and/or kinetics of pitching a curveball in comparison to a fastball, while epidemiologic studies attempted to correlate curveball use to pain/injury. The references of all included studies were reviewed to incorporate all relevant articles. Review articles and case reports were not included.

Data Abstraction

Two reviewers independently extracted relevant data from the studies. Comparisons were organized by impact on the torso, shoulder, elbow, forearm, and wrist.

The data by Glousman et al[10] on muscle activity in healthy versus medial collateral ligament–insufficient pitchers were aggregated to compare results in healthy (n = 30) and injured pitchers (n = 10) separately. Only provided with sample size, mean, and standard deviations from the study, a paired t test assuming a small correlation value ($r = 0.1$) was used to determine statistical significance ($P < 0.05$).

RESULTS

Literature Search

A total of 10 biomechanical and 6 epidemiologic studies met the inclusion criteria. Of these, that by Lyman et al[14] was excluded because the data collection period coincided with a larger study[15] at the same institution.

Five epidemiologic studies published between 2001 and 2011 were identified for inclusion: 1 case-control, 1 retrospective cohort, and 3 prospective cohort studies (Table 1). Three studies included athletes aged 8 to 14 years, and the other 2 used high school and college athletes aged 14 to 20 years. Ten biomechanical laboratory studies comparing the stresses and kinematics of the curveball to the fastball were included (Table 2). Three studies included electromyographic data; 7, kinematic measures; and 4, throwing kinetics. Youth athletes were included in 1 study, high school–aged pitchers in another, and college and/or professional athletes in the remaining 8. The dates of publication range from 1979[11] to 2009.[16]

Table 2. Biomechanical studies[a]

Study	Participants, n	Mean Age, y	Level of Competition	Method
Hang et al[11]	10	Not reported	College and professional	Accelerometers, EMG telemetry, stroboscopic photography
Elliott et al[6]	6	25	International	2 cameras at 200 Hz and 1 camera at 300 Hz, painted landmarks
Sisto et al[20]	8	19-22	College	EMG telemetry, cameras at 450 Hz
Sakurai et al[19]	6	21 ± 1	College	2 cameras at 200 Hz, reflective markers, reference sticks
Barrentine et al[3]	8	20 ± 0.6	College	4 cameras at 200Hz, markers, reference stick
Escamilla et al[7]	16	19.9 ± 1.8	College	4 cameras at 200 Hz and 1 camera at 500 Hz, reflective markers, wrist band
Glousman et al[10]	40[a]	22	College and professional	EMG telemetry, cameras at 400 Hz
Fleisig et al[9]	20	20 ± 1	College	6 cameras at 240 Hz, reflective markers
Dun et al[5]	29	12.5 ± 1.7	Youth	8 cameras at 240 Hz, reflective markers
Nissen et al[16]	33	16.6 ± 1.5	High school	12 cameras at 250 Hz, reflective markers

[a]Medial collateral ligament injury, n = 10; healthy, n = 30.

All comparisons between curveball and fastball pitches were significant ($P < 0.05$) unless otherwise stated.

Epidemiologic Studies

A 2001 study utilizing postgame telephone interviews with 298 youth pitchers revealed no significant association between pitching a curveball and shoulder or elbow pain (Table 3).[15] With a similar study design in 2002, there was a 52% increase in shoulder pain in 476 pitchers when pitching a curveball.[13] In a retrospective cohort of pitchers who underwent elbow ulnar collateral ligament reconstruction, 67% reported throwing a curveball before the age of 14 years.[18] In a comparison of adolescent pitchers who had elbow or shoulder surgery and healthy pitchers without an arm injury, there was no significant association between the age that a pitcher began throwing a breaking ball and arm injury.[17] Additionally, there was no association of arm injury with the number of years throwing a breaking ball before shaving (a measure of developmental maturity). A 10-year prospective study that utilized annual surveys of arm pain or injury found no relationship between throwing a curveball before 13 years of age and arm injury in the 481 youth pitchers.[8]

While 3 of the 5 epidemiologic studies found no significant association between pitching a curveball and elbow or shoulder pain,[8,15,17] other factors were noted that may increase risk of pain and/or injury. All 5 studies implicated an increased amount of pitching as a significant risk factor for arm pain or injury (Table 3).[8,13,15,17,18]

Torso Kinematics

Significantly less maximum pelvis angular velocity was found while pitching a curveball as compared with a fastball (560-590 vs 600-640 deg/s, respectively) (Table 4).[5,7,9] Less upper trunk angular velocity with the curveball was also shown.[5,7,9] While 1 of the collegiate studies and the youth study found no difference in forward and lateral trunk tilt between pitches,[5,7] Fleisig et al found 4° greater forward and 3° greater lateral trunk tilt at ball release; this is of unknown clinical significance.[9]

Shoulder Kinematics and Kinetics

Five of the 10 biomechanical studies described the kinematics of the shoulder during the delivery of a curveball and fastball.[5,7,9,16,19] Two studies of collegiate athletes (n = 26) found no difference between the 2 pitches with respect to shoulder abduction, horizontal adduction, and external rotation.[9,19] Two studies found greater shoulder abduction at arm acceleration[7] and ball release[5] while noting greater horizontal adduction at arm cocking and ball release with the curveball. Youth pitchers also had less

Table 3. Epidemiologic data

Study	Curveball Risk	Other Factors Increasing Risk of Pain/Injury	Other Factors Decreasing Risk of Pain/Injury
Lyman et al[15]	No significant association between pitching a curveball and shoulder/elbow pain	Increased odds of elbow and shoulder pain when pitching with arm fatigue and lower self-satisfaction with performance; increased odds of elbow pain in older, heavier, and shorter pitchers, pitchers playing baseball outside of the league, weight lifting, and pitching a split-finger pitch; increased odds of shoulder pain with the greater number of pitches per game	Decreased odds of elbow and shoulder pain when pitching 300 to 599 cumulative pitches in the season; decreased odds of elbow pain when pitching a changeup; decreased odds of shoulder pain with a greater number of pitches during the season and each additional game pitched in the season
Lyman et al[13]	52% increased risk of shoulder pain	Increased odds of elbow and shoulder pain with a greater number of cumulative pitches in a season; increased odds of elbow pain when pitching a slider; increased odds of shoulder pain with a greater number of pitches per game	Decreased odds of elbow and shoulder pain when pitching a changeup
Petty et al[18]	67% of ulnar collateral ligament reconstruction patients reported throwing curveballs before age 14 years	Overuse, high velocity	
Olsen et al[17]	No significant association between the age at which pitchers began throwing a breaking ball and arm injury; no significant association between the number of years throwing a breaking ball before shaving and arm injury	Increased risk of injury in starting pitchers, taller and heavier pitchers, and those with a higher self-rating of pitching skill; increased risk of injury with pitching more months per year, games per year, innings per game, pitches per game, pitches per year, and warm-up pitches before a game; increased risk of injury with pitching with arm pain, fatigue, and higher velocity; increased risk of injury with more aerobic activity, use of nonsteroidal anti-inflammatory drugs, and use of ice	
Fleisig et al[8]	No significant association between throwing a curveball before 13 years of age and injury	Increased risk of injury when pitching more than 100 innings per season	

Table 4. Biomechanical data

	Pitch Velocity, m/s				
Study	Fastball	Curveball	Torso Kinematics	Shoulder Kinematics	Shoulder Kinetics
Hang et al[11]	Not reported				
Elliott et al[6]	35.1 ± 1.5	28.2 ± 1.0			
Sisto et al[20]	32.2	26.8			
Glousman et al[10]	29.1	23.7			
Sakurai et al[19]	35.0 ± 1.8	28.6 ± 1.0		ND	
Barrentine et al[3]	34 ± 2	28 ± 2			
Escamilla et al[7]	35 ± 2	28 ± 2	Less maximum pelvis and upper torso angular velocity at arm cocking	Greater maximum horizontal adduction at arm cocking and ball release, greater average abduction at arm acceleration	
Fleisig et al[9]	35.1 ± 1	29.1 ± 1	Less pelvis and upper trunk angular velocity, greater forward and lateral trunk tilt at ball release	ND	ND
Dun et al[5]	26.3 ± 3.8	22.1 ± 3.2	Less pelvis and upper trunk angular velocity	Greater horizontal adduction at arm cocking and ball release, greater abduction at ball release, less maximum external rotation at arm cocking	Less internal rotation torque at arm cocking, less proximal force at arm acceleration
Nissen et al[16]	29.5 ± 2.1	25.9 ± 2.8		Less overall arc of motion, less maximum internal rotation angular velocity	Less maximum internal rotation moment, less maximum flexion moment

ND, study found no difference between curveballs and fastballs.

maximum external rotation at arm cocking when pitching a curveball versus a fastball (176.2° vs 178.2°, respectively).[5] However, the other 4 studies that included high school and collegiate pitchers did not find a difference in maximum external rotation.[7,9,16,19] Nissen et al described less overall arc of motion at the glenohumeral joint (117° vs 124°) and less maximum internal rotation angular velocity (3409 vs 3619 deg/s).[16] The internal rotation velocity results were duplicated in youth but not collegiate pitchers.[5,7]

One of the 4 kinetics studies found no differences at the shoulder joint in collegiate pitchers.[9] However, studies of youth and high school pitchers revealed less internal rotation torque (31.9 vs 34.8 Nm and 52.0 vs 56.8 Nm, respectively).[5,16] Less proximal force at arm acceleration was also seen in youth pitchers[5] and reduced shoulder flexion moments in high school pitchers.[16] No studies indicated increased force or torque at the glenohumeral joint when throwing a curveball compared with a fastball.

Elbow Kinematics and Kinetics

Elbow kinematics in 4 studies involving collegiate pitchers (n = 6-40) show no significant differences between curveballs and fastballs (Table 5).[7,9,10,19] In high school pitchers, less overall arc of motion was demonstrated in the curveball (81° ± 14° vs 83° ± 14°).[16] Dun et al[5] found greater elbow flexion at ball release and less extension velocity in youth pitchers. Elbow flexion at other phases of the throwing motion was similar for both types of pitches. Six international athletes showed increased mean elbow peak angular velocity just before release (985.5 vs 968.3 deg/s), but this study was not powered adequately for statistical analysis.[6]

Electromyographic studies of pitchers' elbows examined the biceps, brachioradialis, and triceps maximum muscle activity during 4 phases of the pitching motion. Sisto et al[20] found less brachioradialis activity in the earlier phases—early cocking, late cocking, and acceleration—in curveball pitches, but statistical significance analysis was not provided. Glousman et al[10] also found less brachioradialis activity at acceleration and follow-through but no difference in the activities of the biceps or triceps.

The first kinetic study in 1979 demonstrated inconsistent measures of normalized elbow forces, with 2 adult pitchers showing increased forces at the elbow and 2 others showing decreased forces when throwing a curveball.[11] Since then, less proximal elbow force at arm acceleration has been seen with the curveball (934 vs 988 Nm in collegiate pitchers and 428.2 vs 461.9 Nm in youth pitchers).[9] These 3 studies of elbow flexion torque disagree; the 29 youth pitchers had less elbow flexion torque at arm acceleration,[5] but the 20 collegiate athletes did not show a difference.[5,9] In addition, 2 studies examining elbow varus torque both found reduced moments when throwing curveballs (54.1 vs 59.6 Nm in collegiate pitchers and 31.6 vs 34.8 Nm in youth pitchers).[5,16]

Forearm Kinematics and Kinetics

Seven of 8 studies of forearm position in pitching found greater supination with the curveball than the fastball, with differences ranging from 7.3° to 19.8° particularly at arm-cocking and acceleration phases.[3,5,6,11,16,19,20] One study noted greater forearm supination when throwing a curveball but did not quantify the differences between the pitches.[6] In an electromyographic study, greater supinator muscle activity was found in the late cocking phase when a curveball was thrown.[20] Decreased pronator teres activation (47% vs 85% maximum muscle strength test at acceleration) has also been shown.[10]

Collegiate pitchers did not demonstrate a difference in forearm pronation torque.[9] However, in youth pitchers, increased forearm supination torque at arm acceleration was recorded when pitchers threw a curveball compared with a fastball (1.2 ± 0.9 vs 0.9 ± 0.7 Nm).[5]

Wrist Kinematics and Kinetics

Elliott et al was the first to report greater wrist flexion, ulnar deviation, and angular velocity when releasing a curveball, which allows the pitcher to command the appropriate spin necessary for the ball to curve.[6] Five other studies show less wrist extension, ranging from 6° to 13°, when the arm is cocking, but the ulnar deviation was not significant in 4 of them.[3,5,9,16,19] Nissen et al[16] found slightly greater ulnar deviation of the wrist at ball release and maximum internal rotation. The wrist demonstrated greater curveball radioulnar range of motion (17° vs 14°) and greater ulnar angular velocity (360 vs 154 deg/s) at ball release with the curveball than the fastball.[16]

Electromyographic data are inconsistent, as Sisto et al[20] found greater wrist extension associated with the curveball since the extensor carpi radialis longus and extensor carpi radialis brevis had greater activity in the late cocking, acceleration, and follow-through of the curveball than with the fastball. While other researchers found decreased flexor carpi radialis muscle activation at late cocking and acceleration, they also found decreased extensor carpi radialis longus and extensor carpi radialis brevis activity at acceleration.[10]

Mixed results are also found with wrist kinetics. Fleisig et al[9] found no difference in the forces and torques about the wrist in collegiate pitchers. Nissen et al[16] saw reduced maximum flexion moments (7.8 vs 8.3 Nm) but greater wrist ulnar moments (4.9 vs 3.2 Nm).[9] Contradicting this were youth pitchers who demonstrated greater wrist flexion torques at arm acceleration (2.3 vs 1.5 Nm).[5]

DISCUSSION

Overuse has been implicated as a risk factor for upper extremity injuries in baseball pitchers, prompting Little League Baseball to institute maximum pitch counts.[12] Most youth and high school leagues have similar restrictions, usually limiting the number of innings pitched.[1,21] While there are currently no rules in baseball restricting the use of the curveball, many suggest that it is a potential risk factor for injury. USA Baseball recommends that breaking pitches (curveballs, sliders, etc) not be thrown until after bone

Table 5. Biomechanical data

	Elbow		Forearm		Wrist	
Study	**Kinematics**	**Kinetics**	**Kinematics**	**Kinetics**	**Kinematics**	**Kinetics**
Hang et al[11]		No difference in normalized elbow force	Greater supination[a]			
Elliott et al[6]	Less sagittal velocity at ball release[b]		Greater supination[a]		Greater flexion,[b] ulnar deviation at ball release,[a] angular velocity[b]	
Sisto et al[20]	Less brachioradialis activity at early cocking[b]		Greater supination at late cocking[a]		Greater ECRL/ECRB activity at late cocking, acceleration, follow-through[b]	
Glousman et al[10]	Less brachioradialis at acceleration (injured pitchers) and follow-through (healthy)		Less pronator teres activity at acceleration (healthy pitchers) and follow-through (injured)		Less FCR activity at late cocking and acceleration (healthy pitchers); less ECRL (injured)/ECRB (healthy) activity at acceleration	
Sakurai et al[19]	ND		Greater supination at max external rotation and ball release		Less extension at max external rotation	
Barrentine et al[3]			Greater max supination at arm cocking		Less extension at arm cocking; greater ulnar deviation at ball release[a]	
Escamilla et al[7]	ND					
Fleisig et al[9]	ND	Less proximal force at arm acceleration	ND	ND	Less extension at arm cocking	ND
Dun et al[5]	Greater elbow flexion at ball release; less extension velocity	Less varus torque at arm cocking; less flexion torque and proximal force at arm acceleration	Greater supination at arm cocking	Greater supination torque at arm acceleration	Less extension at arm cocking	Greater wrist flexion torque at arm acceleration
Nissen et al[16]	Less overall arc of motion	Less max varus moment	Greater supination and max pronation angular velocity; less ROM	ND	Less extension; greater ulnar deviation at ball release and max internal rotation, radioulnar ROM, and ulnar angular velocity at ball release	Less max flexion moment; greater max ulnar moment

ECRL, extensor carpi radialis longus; ECRB, extensor carpi radialis brevis; FCR, flexor carpi radialis; ND, study found no difference between curveballs and fastballs; max, maximum; ROM, range of motion.
[a]Observational statement.
[b]*P* value not given.

maturity.[22] These recommendations are primarily based on baseball expert opinion.[22]

One of the studies cited in support of current curveball guidelines is confounded by pitch counts, which increases the odds of arm pain in a game and season.[13] Youth pitchers with the highest pitch counts are likely the better pitchers on the team and therefore more inclined to throw a curveball earlier in their careers, further emphasizing overuse as a confounding variable. Additionally, a prior study using identical methods found no difference in the incidence of arm pain.[15]

A retrospective review of pitchers who underwent ulnar collateral ligament reconstruction supporting USA Baseball's recommendation did not compare with a healthy age-matched control group to determine statistical significance.[18] A more recent study attempted to mitigate the lack of a study control group by comparing injured with uninjured pitchers and found no correlation of injury with the age at which the curveball was first thrown.[17] As such, the epidemiologic evidence to support limitations on the curveball is lacking rigor in study design. Two studies found that throwing a changeup pitch reduced the incidence of elbow and/or shoulder pain.[13,15]

Consistent kinematic differences were increased horizontal adduction of the shoulder, increased forearm supination, and decreased wrist extension. Kinetics were not increased at the shoulder or elbow.[5,9,11,16,19] Two studies found less proximal force and less varus torque at the elbow, with no data suggesting greater kinetic forces.[5,9,16] Youth pitchers, the population of greatest concern, were the subjects in 1 of these studies.[5] In addition, 2 studies on kinetics found decreased proximal forces and internal rotation torques at the shoulder,[5,16] highlighting the disconnect between biomechanical and epidemiologic studies. Whether these differences are due to pitchers' discomfort with the grip, decreased arm speed for a slower pitch, or the minor mechanical differences required to produce the ball spin for a curveball, it does not appear that the curveball places additional strain on an athlete's arm. The current biomechanical evidence does not support limiting the use of curveballs at any level of baseball.

While the curveball does not appear to put additional biomechanical strain on a pitcher's arm, electromyographic and kinematic studies consistently found that the curveball requires greater supination of the forearm.[3,5,6,10,11,16,19,20] This is consistent with the widespread technique of imparting spin onto the curveball with a strong "over the top" wrist supination snap. In addition to strengthening the rotator cuff muscles, the forearm muscles should be trained for the curveball.[10,20] We support USA Baseball's recommendation to teach proper mechanics and use of the changeup to prevent arm injuries.[22]

CONCLUSION

Despite much debate in the baseball community about the safety of the curveball, biomechanical and most epidemiologic studies do not demonstrate an increased risk of pain and/or injury when compared with the fastball. Current recommendations to discourage throwing curveballs at a young age, while well intentioned, are based on observational data and expert opinion that have not been validated by biomechanical studies. However, there is limited biomechanical and electromyographic evidence suggesting that youth pitchers throwing curveballs may benefit from conditioning programs focused on forearm supination.

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