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Elbow stress in youth softball windmill pitchers: predictors of increased torque

Abstract

Purpose: To assess torque at the elbow in the underhand throwing motion utilizing wearable sensor technology and discover the predictors of medial elbow toque in young female softball pitchers.

Methods: Female softball players 12 to 18 years old whose primary position was pitcher and actively participating in sport were studied. Players experiencing throwing arm pain, lower extremity injury hindering pitching motion, or prior surgery were excluded. Age, handedness, height, weight, and throwing arm dimensions were measured and recorded. Pitchers threw 15 pitches, max effort from 43 feet and were given 30 to 60 second rest between pitches. A wearable sensor was placed inside an athletic compression sleeve which recorded data. Measurements included medial elbow torque (Newton-meters; NM), arm speed (peak rotational velocity of the forearm; in rotations per minute; RPM), arm slot (forearm angle in relation to the ground at release; in degrees), and shoulder rotation (maximum forearm angle during the 12 o'clock phase; in degrees). Peak ball velocity in miles per hour (MPH) was measured by a radar gun.

Results: Twenty females mean age 15.2 years (range, 12.6-16.9 years) achieved an average elbow stress of 35.5 NM (14-78 NM). Average arm speed measured 583.8 RPM (3502.8 deg/sec) and ball speed ranged from 33-56 mph with an average of 44.1 mph. Multivariate analysis demonstrated arm stress significantly associated with increasing age (P-value 0.00003), and arm length (P-value 0.000006); however, increased forearm length measured a decreased arm stress (P-value 0.00007).

Conclusions: There was significant stress measured across the medial elbow in young softball pitchers. Elbow torque was associated with increasing age and total arm length; however, increased forearm length was associated with decreased elbow torque.

Keywords: biomechanics, elbow stress, underhand pitching, wearable sensor technology, motus global

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Introduction

Injuries to the medial elbow in overhand throwers have been extensively documented.[1–5] Stress encountered at the elbow in the late cocking and early acceleration phases of the overhand throwing motion is high, putting medial elbow structures at risk for injury. In baseball, the pitching position is associated with the highest incidence of elbow injuries,[2,4–6] and significant injuries are being noted at young ages. Much less is understood regarding elbow stress of the underhand, or windmill pitching motion utilized in softball. Elbow torque in windmill pitching has been reported to be as high as that seen in overhand pitchers.[7–9] To reduce the rate of upper extremity (UE) injury in baseball pitchers, there are specific pitch count recommendations, with further recommendations regarding number of days of rest prior to return to pitching. For 15–16-year-olds, a maximum of 95 pitches in a day is recommended, with 4 days rest if a pitcher throws 76+ pitches in a day. Softball pitchers in Little League Junior and Senior Divisions (12-14y and 13-16y respectively) have no restrictions for innings pitched in a day or required days rest after pitching.[10] There are restrictions for innings pitched in a day (12 innings), and days of rest required (1 day) if a pitcher throws 7+ innings in a day at the Minor and Major Divisions (5-11y and 9-12y respectively). Softball teams tend to carry less pitchers on their rosters than baseball teams. In a study of high school softball and baseball teams over a single season, softball rosters averaged 1.5 pitchers/team compared to 3.8 pitchers/team in baseball teams.[5]

High school girls' softball participation has increased through the years. According to the 2018-19 survey of the National Federation of State High School Associations, there were 362,038 participants in girls' softball, making it the 5th highest participation sport for females.[11] With increasing participation comes the increased risk of injury. The injury rate in girls' softball was reported at 1.13/1000 athlete exposures (AEs) in 2005-06,[12] a subsequent study of injury in the 2009 season demonstrated an injury rate of 5.6/1000AEs.[5] The rate of medial elbow injuries in softball pitchers, however, is low.[6,13] The purpose of our study was to determine if a wearable sensor designed to measure arm stresses in overhand athletes could be used to evaluate the underhand throwing motion to determine if

a) Elbow torque in windmill pitching is similar to overhand pitching,

b) Determine possible predictors of torque at the medial elbow among female, adolescent softball pitchers.

We hypothesize the wearable sensor will consistently obtain measurements during underhand pitching, and that arm speed and pitch velocity will be most predictive of torque across the elbow during the underhand pitching motion.

Methods

Institutional review board approval was granted for this study (Henry Ford Health System Institutional Review Board Committee, No. 13644) and all participants and guardians provided written consent to participate in the study. The manufacturer of the sensor and sleeve had no participation in the study, and the study was self-funded by the research institution. Players were recruited through an indoor softball training facility by approval from the coaching staff and all parents and players gave consent/assent before participation. Inclusion criteria included female softball players aged 12 to 18 years (but still in high school), whose primary position was pitcher and who were actively competing in school or other leagues. Exclusion criteria included players whose primary position was not pitcher or if they were not currently competing. Pitchers were also excluded if they were currently experiencing arm pain in their throwing arm, a lower extremity injury which would interfere with the pitching motion, or prior surgery to the throwing arm. An intake form was used to record age and handedness. Height, weight, and throwing arm dimensions (arm in the neutral position) were measured and recorded and body mass index (BMI) was calculated. The total arm length (tArm) consisted of the distance from the acromion to the distal aspect of the 5th digit. The throwing arm was subdivided into the upper arm length (uArm), and forearm length (fArm); uArm was defined as the distance from the acromion to the lateral epicondyle of the humerus and fArm defined as the distance from the lateral epicondyle of the humerus to the styloid process of the radius. Elbow circumference (eCirc) was measured around the medial and lateral epicondyles. All measurements were performed by a single author.

Stress measurements were made with a wearable sensor placed inside a pocket of an athletic compression sleeve (Motus global). The sensor was positioned approximately 1.5 inches distal to the medial epicondyle according to manufacturer specifications. The sensor contains a triaxial gyroscope and a triaxial accelerometer that indirectly measures torque as well as other throwing variables. This information is recorded at 1000 Hz and transmitted via Bluetooth LE to a custom-built smart phone application where proprietary software performs biomechanical algorithms. While this has been validated as an accurate measurement of medial elbow torque during the overhand throwing motion[14,15] compared to high-speed motion analysis (r=0.93),[14] its utility in measuring variables of the underhand pitch is unknown. Sensor data were displayed on the accompanying smart phone application and immediately inputted onto the intake form. Measurements included torque across the medial elbow (Newton-meters; NM), arm speed (peak rotational velocity of the forearm; in rotations per minute; RPM), arm slot (angle of the forearm in relation with the ground at release; in degrees), and shoulder rotation (maximum angle of the forearm during the 12 o'clock phase; in degrees). For each pitch, peak ball velocity in miles per hour (MPH) was measured by a radar gun (Stalker Sport II Radar Gun). Before beginning the recorded pitching session, players were advised to warm up as they would before competition. No restrictions were placed on warm-up pitch count. Each pitching session was conducted from the standard distance to home plate (43 feet). Behind the plate was a net or catcher. Only fastball pitches were studied. Instructions were given to throw at maximum effort for each pitch. Between pitches, players were timed to rest for 30 to 60 seconds to minimize fatigue. Sensor positioning was checked periodically during the pitching session to ensure appropriate position.

Statistical analysis

Descriptive statistics of demographics were described using means and standard deviations. Repeated measures mixed models were used to test for association between arm stress and other characteristics of the pitcher including but not limited to age, height, weight and BMI. Factors that were significant in the univariate analysis were subsequently considered for the multivariate model. Only the significant factors remained in the final multivariate model. Analyses were performed with SAS software v 9.4 (SAS Institute INC, Cary, NC). A P-value of ≤0.05 was considered indicative of statistical significance.

Results

Twenty adolescent female softball pitchers were enrolled in the study. All pitchers completed the study. The mean age of subjects was 15.2 years (range, 12.6-16.9 years). Eighteen were right arm dominant. Information regarding age, height, weight, BMI, tArm, uArm, fArm, and eCirc of the participants appear in Table 1. Each participant threw 15 fastball pitches. For each pitch, primary outcomes included elbow torque, arm speed, arm slot and ball velocity. The contribution of pitcher characteristics on elbow torque during the throwing motion was also studied. Two separate sensors were used for data collection, and it was noted that arm slot was often not reported at all by one of the sensors and was inconsistently reported by the other. To reduce the risk of injury from study participation, it was decided we would not ask pitchers to throw extra pitches simply to obtain additional information regarding arm slot. Each sensor consistently reported elbow torque and arm speed. The average elbow stress with underhand pitching was 35.5 NM, but there was a very wide range of values recorded (14-78NM). Arm speed measured at an average of 583.8 RPM (3502.8 deg/sec). Ball speed ranged from 33-56mph with an average of 44.1mph. Arm slot was not consistently measured but averaged 60.8 degrees. Full information collected by the sensor device appears in Table 1. The contribution of pitcher characteristics on elbow torque including age, height, weight, BMI, tArm, uArm, fArm, eCirc as well as ball speed were evaluated via univariate analysis. Increase in elbow stress was found to be significantly associated with increasing age, height, tArm, fArm and ball speed; it was not associated with weight, BMI or eCirc (Table 2). Arm slot was also found to have a significant correlation with elbow stress, but as noted, arm slot was inconsistently measured. Multivariate analysis was then conducted on factors that were significant in the univariate model. Increasing age, tArm and arm slot were factors associated with increased elbow stress in the multivariate model. In multivariate analysis, increasing fArm was associated with decreased arm stress (Table 3). Height and ball speed showed neither a positive nor negative effect in the multivariate analysis.

Table 1 Pitcher characteristics and arm stress measurements

Pitcher characteristics	Mean ± SE (N=20)	Median	Range
Age	15.2 ± 1.2	15.3	12.6 – 16.9
Height	166.0 ± 4.6	165.5	159 – 181
Weight	65.4 ± 9.4	64.8	47.5 – 83.2
BMI	23.3 ± 3.2	23.4	18.5 – 29.8
Arm Length			
Total	68.6 ± 2.2	68.75	64 – 73
Upper	30.6 ± 1.4	30.25	28.5 – 33.5
Forearm	27.4 ± 3.9	26.25	24 – 39
Elbow Circumference	25.1 ± 1.4	25.25	23 – 28
Arm Stress Measurements			
Elbow Stress	35.5 ± 14.9	32	14-78
Arm Speed	583.8 ± 168.8	557.5	242-948
Arm Slot	60.8 ± 17.0	62	19-94
Ball Speed	44.1 ± 4.8	45	33-56

Age represented by years; Height represented in centimeters; Weight represented in kilograms; Arm length, elbow circumference represented in centimeters; Elbow stress reported in Newton meters; Arm speed represented in rotations per minute; Arm slot reported in degrees from horizontal; Ball speed represented in miles per hour.

Abbreviations: SE, standard error

Table 2 Univariate association with arm stress

		Arm stress	
Covariate	**N**	**B (95% CI)**	**P-value**
Age	300	4.75 (0.65-8.85)	**0.023**
Height	300	1.51 (0.81-2.21)	**0.00002**
Weight	300	-0.07 (-0.29-0.14)	0.517
BMI	300	-1.24 (-2.67-0.20)	0.091
tArm	300	2.71 (0.62-4.80)	**0.011**
uArm	300	2.58 (-1.61-6.76)	0.228
fArm	300	1.18 (0.55-1.80)	**0.0002**
eCirc	300	1.77 (-1.92-5.46)	0.347
Arm Speed	300	0.02 (0.00-0.04)	**0.032**
Arm Slot	132	0.48 (0.02-0.93)	**0.039**
Ball Speed	300	1.04 (0.63-1.45)	**0.0003**

P-values with significance (≤0.05) are indicated by Bold text

Abbreviations: tArm, total arm length; uArm, upper arm length; fArm, forearm length; eCirc, elbow circumference

Table 3 Multivariate association with arm stress

		Arm stress	
Covariate	**B**	**95% CI**	**B P-Value**
Age	6.27	33.3 to 9.21	**0.00003**
tArm	4.56	2.58 to 6.54	**0.000006**
fArm	-2.20	-3.28 to -1.12	**0.00007**
Arm Slot	0.53	0.20 to 0.86	**0.001**

P-values with significance (≤0.05) are indicated by **Bold** text

Abbreviations: tArm, total arm length; fArm, forearm length

Discussion

The underhand, or windmill pitching style used in softball is considered a more natural motion than overhand throwing. This does not mean significant forces are not generated, or UE injury is unlikely. The windmill pitch is divided into 4 parts: wind-up, stride, delivery and follow-through.[7] UE kinematic and kinetic parameters are low magnitude during wind-up and stride phases. It is in the late delivery phase of the windmill pitch, just before ball release when elbow valgus forces are greatest in youth, collegiate and elite softball pitchers.[7–9] Our data revealed a mean elbow torque with the underhand pitching motion of 35.5 Nm. There are no other published studies on softball pitchers using the Motus sleeve. Unpublished data from Melvin et al., comparing high school softball and baseball pitchers revealed that baseball players created more arm stress than softball players, but specific numbers were not reported. Careful review of the softball pitcher data presented in graph format is consistent with elbow stress of <25Nm.[16] Studies calculating medial elbow torque using high-speed video technology reported elbow torques higher than in our study, with torques of 4-9% body weight x height[7-9] which equated to 64-104 Nm.[17] In our cohort, only 6% (18/300) of pitches reached an elbow torque of 64 Nm or greater. Perhaps values calculated from high-speed video analysis overestimates medial elbow torque encountered by softball pitchers. Studies of high school,[18] a combination of high school/collegiate,[15] and professional[19] baseball pitchers revealed elbow torque with the fastball of 47.3 Nm, 45.6 Nm and 54.3 Nm respectively. Pitchers in our study demonstrated an average arm speed of 583.8 rpm. This is consistent with the information presented by Melvin et al., which shows an estimated arm speed of 575 rpm.[16] This compares to arm speed in high school, high school/collegiate[15] and professional[19] baseball pitcher studies which demonstrated arm speeds with the fastball of 898.5 rpm, 842.4 rpm and 916.2 rpm respectively.[18] Two of our subjects reached arm speeds over 900 rpm, though not consistently.

With univariate analysis, increased elbow stress was found to be significantly associated with increasing age, height, tArm, fArm and ball speed in our study population (Table 2), scatter plots showing this data is presented in Figure 1. No studied parameter was associated with a significant reduction in elbow torque. In high school baseball pitchers, no characteristics were associated with increased elbow torque, while increasing age, height, weight, BMI, all arm length measurements, and elbow circumference were associated with decreased elbow torque.[18] In professional baseball pitchers, no individual characteristic was associated with increased elbow torque, while BMI was associated with decreased elbow torque.[19] Whether body weight and/or BMI plays a role in elbow injuries in softball pitchers is unknown. Softball pitchers who have more mass experience UE pain more often.[20] In collegiate softball pitchers, injury rate increased with increasing body weight, but injury incidence was not significantly related to weight.[13] Increased whole body fat mass significantly predicted peak throwing shoulder distraction force.[21] In our study population, elbow torque was not associated with body weight or BMI. Using multivariate analysis, only increasing age, increased tArm and decreased arm slot were associated with increased elbow torque in softball pitchers. This is different from findings in high school baseball pitchers in which increased ball speed, increased BMI and decreased arm slot were associated with increased elbow torque.[18] In professional baseball pitchers, no individual characteristics were associated with increased elbow torque.[19] In our cohort, increased fArm was associated with decreased elbow torque, which was not the case in high school[18] or professional[19] baseball pitchers. Characteristics associated with decreased elbow torque in baseball pitchers included increased age, tArm and elbow circumference in high schoolers[18] and increased BMI in professionals.[19] If elbow torque experienced with windmill pitching indeed rivals that of overhand pitching, it would follow that medial elbow injury rates and possibly surgery rates in softball pitchers would rival those of baseball pitchers, but this does not appear to be the case. Oliver et al., reported on 85 elbow injuries in high school softball players, 17.5% were in pitchers compared to 27.5% in outfielders and 23.8% in infielders.[20] From 2005-06 to 2014-15, using the High School Reporting Information Online data collection tool, a total of 75 elbow injuries were reported in female softball players; only 11% of the injuries were in pitchers. Over the same timeframe 214 elbow injuries occurred in baseball players, with 50.2% in pitchers.[4] In a study following high school softball and baseball teams in a single city over a single season, 14 elbow injuries were reported in softball players, but not one elbow injury was noted in a pitcher.[5] Elbow injuries make up 15.5% of all musculoskeletal injuries (compared to 24.8% in the shoulder) in high school softball players and only 8.6% of all MSK injuries in collegiate softball players (compared to 33.8% in the shoulder).[22]

UCL injury and UCL reconstruction (UCLR) surgery is more commonly reported in males. As the rate of UCL injury increases in throwers, UCLR surgery is becoming more common in young athletes. In a study utilizing a private-payer database in the United States from 2007-11, 790 patients underwent UCLR, with over half of the procedures performed on 15–19-year-olds; females comprised 12% of UCLR cases (95/790).[1] Hodgins showed that males were 11.8 times more likely to undergo UCLR compared to females.[3] Women in this study comprised 8.1% of surgical cases, roughly 4 cases/year during the study period. A systematic review of UCLR published in 2015 revealed that only 3% of surgeries take place in female athletes (60/2019), and only 11 patients (0.5%) were softball players; there was no mention if the softball players were pitchers or field players.[2] Study of outcomes of UCLR in female athletes showed that of 19 cases over a 7-year period, 11 injuries were in throwing athletes, 8 of whom were softball players; only one of the softball athletes was a pitcher.[23]

This study has several limitations. We were only able to study 20 athletes throwing a low number of pitches in a simulated setting. It is possible that in a game situation, effort may be increased, leading to different outcomes. Our subjects were young and may not have developed optimal mechanics of the pitching motion. Only fastball pitches were studied. Studies in baseball pitchers have evaluated a variety of pitches. Because several of our subjects had, to date, only learned to throw the fastball, we felt it necessary to only test fastball pitches. The wearable sensor used in this study is still considered experimental and was designed to measure stresses in overhand pitching, it has not been validated in underhand throwing. The technology has, however, been validated in overhand throwing, and measurement of arm speed and elbow torque should be similar regardless of overhand or underhand motion. It is not known if the torque measured across the medial elbow during pitching is measuring actual stress across the UCL or an aggregate of stress across multiple medial elbow structures. The area in which we thought the device would have the most difficulty was arm slot, as it was designed to measure arm slot angle above the horizontal plane. Indeed, arm slot was not consistently measured in our study.

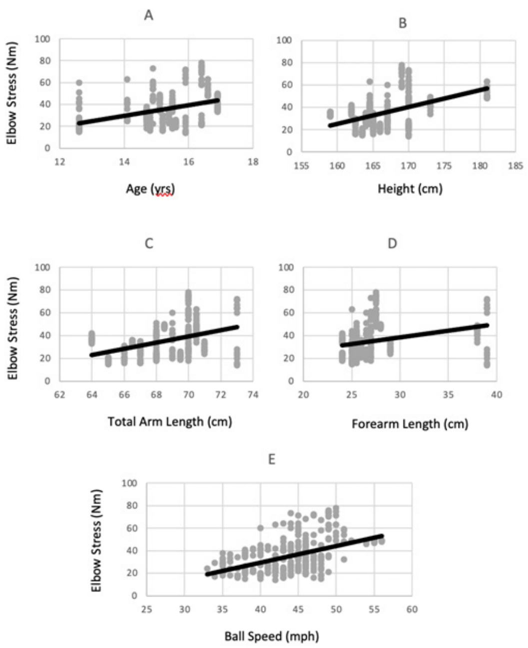

Figure 1 (A) Scatter plots with trend lines comparing elbow stress to age, (B) height, (C) total arm length, (D) forearm length, (E) ball speed.

Conclusion

A wearable sensor and sleeve system consistently records elbow torque and arm speed, but not arm slot in softball pitchers. This may prove to be a simpler and more cost-effective way to investigate upper extremity stresses in underhand pitching compared to video analysis techniques. The underhand pitching motion produces a considerable amount of stress across the medial elbow and arm speed in adolescent softball pitchers, though less than amounts noted in baseball pitchers. Elbow torque in our study is lower than calculated stresses from prior studies, which may explain why despite high torque values previously reported, softball pitchers experience relatively few medial elbow/UCL injuries and subsequent UCLR surgeries compared to baseball pitchers. Increasing age and total arm length were associated with increased elbow torque in softball pitchers, where increased forearm length was associated with decreased elbow torque. Future studies should evaluate elbow stress in other types of softball pitches and overhand softball throwing.

Acknowledgments

This project (#13644) was approved by the Henry Ford Health System Institutional Review Board.

Conflicts of interest

The authors declare no conflict of interest in the completion of this study. All the results are presented in a clear and honest way without fabrication or falsification.

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