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A System or Method of Analysis for Injury Prevention in Sports, Youth Fastpitch Softball Pitchers: A Pilot Study

Rebecca L. Fahey, PhD, MD[1*]; Karen L. Fahey, DNP, FNP-BC[2]; Michael D. Fahey, BA[3†]; Peter D. Ehni, PhD[4]; Robert R. Schweyer, BA[5]

[†]*Deceased*

[1]*Epidemiologist, 1249 Kildaire Farm Road, Box 163, Cary, NC 27511, USA*
[2]*Nursing, Wheeling University, 1249 Kildaire Farm Road, Box 163, Cary, NC 27511, USA*
[3]*Professional Softball Pitcher/Pitching Coach*
[4]*Math and Science, Bethany College, 31 S Loop Campus Dr, Bethany, WV 26032, USA*
[5]*Personal Trainer/Professional Softball Pitcher/Piching & Strength Coach, 1249 Kildaire Farm Road, Box 163, Cary, NC 27511, USA*

Corresponding author
Rebecca L. Fahey, PhD, MD
Epidemiologist, 1249 Kildaire Farm Road, Box 163, Cary, NC 27511, USA; E-mail: beck@throwithot.com

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ABSTRACT

Background
The prevalence of softball injuries in young pitchers is increasing with more injuries in the upper extremity in the beginning of the season.

Research Question
Calculate the forces generated during the pitching motion of female youth pitchers at four main areas: the stride, hips, shoulder, and wrist for 2 groups. R1: u1≠u2.

Study Design
Pilot study, Cross-sectional design.

Level of Evidence
Level-2, Strength-B.

Methods
This study included a total of 15 female youth fastpitch softball pitchers (mean age, 14.33-years; mean weight, 59.01 kg) recruited to participate during the Fall Softball League (2014). Divided into two groups: 270° hip rotation group *vs.* a projected 360° hip rotation group.

Results
A paired sample *t*-test showed that the 2 groups (270° hip rotation and projected 360° hip rotation) were strongly and positively correlated (r=0.993, $p<0.001$). There was a significant average difference between 270° hip rotation and the projected 360° hip rotation forces ($t_{14}=12.996$, $p<0.001$). On average, the projected 360° hip rotation forces were 580.68 N higher than 270° hip rotation forces (95% CI [676.51, 484.84].

Conclusion
The Current Method (CM) of pitching clearly uses the shoulder as the driving force of the pitch, as pitchers created 467.96 N of force at the shoulder. Pitchers who used 270° hip rotation produced an average of 147.33 N at the hip while these same individuals can create an average of 589.30 N with full hip rotation.

Clinical Relevance
Pitchers using the CM of pitching generated an average of 468 N of force at the shoulder. Identifying interruptions in the kinetic chain is the key to reducing injuries. This is accomplished by creating the ideal kinetic chain and teaching it through a certified pitching coach program. Once identified, interruptions can be modified and changed through exercises to strengthen and improve the kinetic chain.

Keywords
Softball injury prevention; Fastpitch softball; Windmill pitch; Female youth pitchers; Windmill biomechanics.

INTRODUCTION

Injuries in youth (12-18-years-old) fastpitch softball pitchers are increasing as the demands on pitchers continue to escalate due to the increasing popularity and competitive nature of the sport.[1] Modification of programs to enhance pitchers' performance is imperative, especially for reducing the probability of injury.[2] There is insufficient literature examining injury prevention in youth softball pitchers.[3] This study identifies areas within pitching biomechanics that relate pain to injury vulnerability.[4,5]

There are key areas of coaching and pitching that need to be updated in the sport.[2] A pitching coach certification program and pitcher training are essential for injury prevention. The areas needing revising include strength and endurance training for the pitchers, skill training for the coaches to enable them to recognize biomechanical errors in pitching that may lead to injuries, and certification programs for coaches to ensure accountability.

Over two million young women, from 12-18-years-old, play fast-pitch softball each year in the United States with 368,734 of these girls playing in high school.[6,7] As the sport has grown, a competitive tournament circuit has been created allowing the girls to play softball year-round. Along with this increase in pitching opportunities, there is a lack of trained softball-pitching staff. This leaves many pitching coaches, without training and knowledge of proper mechanics, working with athletes.[3]

Adolescent female athletes present unique challenges. Coupled with high intensity physical training, the nutrient-poor American diet may predispose the adolescent female athlete to female athletic triad.[7] A decrease in bone density or brittle bones is related to hormonal imbalances. There is a public health concern when these young female pitchers are placed with coaches who are unfamiliar with the kinetics of fast-pitch and a female youth athlete's specific needs.[8] It is these factors and the intense demands of competition pitching that have produced an epidemic of fast-pitch injuries.

The prevalence of softball injuries in young pitchers is climbing, with more injuries in the upper extremity when compared to other position players, and more injuries occur at the beginning of the season.[9-12] Current research documents the increasing injuries among pitchers with estimates indicating a five-fold increase in pitching injuries from 2000 to 2009.[13] With no pitch counts or rest day regulationsyoung girls who are pitching using improper mechanics, while fatiguedor in pain, are predisposed to injury.[3]

Fast-pitch softball pitchers have comparatively the same risk for fatigue and injury as baseball pitchers, without any of the preventative injury measures.[14] Modifying programs to enhance pitchers' physical health, coordination, mechanics, and other factors reduces the likelihood of injury. Pitchers who continue to play with injuries put themselves at greater risk for more serious complications.

Research Question

What are the forces produced during the pitching motion of an average female youth pitcher at the following joints: stride, hips, shoulder, and wrist, using the current method of pitching?

Purpose

The purpose of this article is to examine the literature and illustrate the disparity existing in research on the current method of pitching in fastpitch softball and the injuries that stem from using the windmill pitch as a background for the pilot work to follow. This report will identify the mechanism of injury using the current method of fastpitch softball pitching. The results of this study will establish a basis for a public health campaign to design a prevention program to address this epidemic. The current method of pitching is defined in this study as any method utilized by a youth pitcher that goes against the natural physiology of the pitching movement. The principal reason the CM has to change is because it causes internal rotation of the shoulder and supplemental arm injuries.

Current Method Biomechanics Questions to Challenge

1. Internal rotation of the shoulder with forward bend of the torso;
2. Bent elbow with pull release at hip *versus* straight arm push past hip slightly;
3. Abduction of lag leg or ipsilateral leg without internal rotation of the femur versus that with internal rotation of the femur and hips;
4. Can hips be closed to 360° upon release or does it occur post pitch?

The Current Method

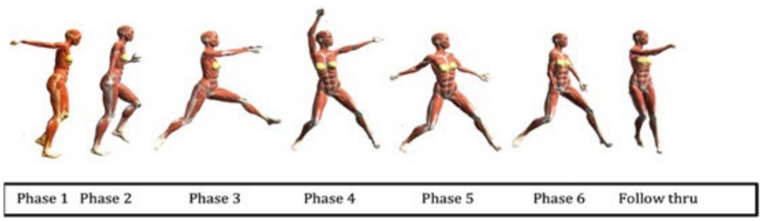
The phases of the windmill softball pitch are a context for looking at the pitcher from a side view. The pitching arm is equivalent to the clock hand moving counter-clockwise around the clock. The phases are based on the position of the humerus related to the torso as it travels through the sagittal plane.[15] In order to examine the windmill pitch, the motion is dissected into smaller phases.[15]

The term, current method (CM), will be used to describe the fast-pitch softball method most commonly discussed in the literature. In the review of the literature, the CM was found to be the method most often being studied or examined. Increasing injuries in the sport have triggered a movement in the literature to examine the kinetic chain of the windmill pitch. A pitching method to incorporate the essential elements of proper pitching mechanics based on physics and the physiology of movement will be examined. The interplay between pitching mechanics and the kinetic chain may contribute to acute and long-term injuries. The proper kinetic chain is similar to baseball's kinetic chain, continuous, while the CM kinetic chain, non-continuous (Figure 1).[16]

Cumulative Injury Disorder

The most common injury in softball pitchers is directly related to

Figure 1. *Phases of the Current Method*



Phase 1: arm behind the back; arm in internal rotation or neutral; weight on ipsilateral (lead) foot; clockwise backward movement from 6 to 9 o'clock position.21
Phase 2: 6 to 3 o'clock position; contralateral leg (lead leg) begins to lift; initiates Counter-clockwise upward movement from 6 to 3 o'clock.21
Phase 3: 3 to 12 o'clock position; arm begins external rotation; trunk rotation to same side; contralateral leg extended prior to foot contact; Arm continues to accelerate continues counterclockwise movement from 3 to 12 o'clock.21
Phase 4: 12 to 9 o'clock position; arm "opens up" to ipsilateral side (lag leg) with full external rotation; the humerus accelerates from 12 to 9 o'clock.21
Phase 5: 9 o'clock position to ball release; internal rotation of trunk and arm; arm adducted across body; release corresponds to movement from 9 o'clock to ball release.21
Follow-through: ball release with arm next to body.

the dynamics of the windmill pitch and the forces acting on the shoulder. Tears to the labrum, rotator cuff, Tommy John or ulnar collateral ligament injury, and other pitching injuries occur as a result of the repetitive stress and strain that result in micro-traumas to the shoulder. Over time coupled with general fatigue, the weakest link in the shoulder will be injured first.[17] Cumulative injury disorder describes the cycle of injury that these pitchers are going through and it may be calculated using the number of pitches thrown times the applied force on the joints.

The applied stress or accumulation of hundreds of pitches in these fatigued youth pitchers, who are more susceptible to break bones, can be destructive. During a weekend tournament softball pitchers throw 1000 to 1500 pitches.[18] The best pitcher on the softball team will pitch most of the games during a season.[9] The high forces experienced at the shoulder with the high number of pitches thrown make it easy to understand the increased potential for injury.[15]

When players are fatigued, they do not have efficient proficiency to control their form and as a result they develop dysfunctional coordination patterns, and the potential for injury is high. A baseline of coordination patterns and their unpredictability over consecutive pitches needs to be established to determine whether movement patterns might be a factor in injury risk.[15] The cumulative injury disorder (CID) calculations may be used as a baseline to assess injury potential in pitchers. CID can be determined by calculating the forces generated in the female pitcher during a pitch, , Force=mass×acceleration ($F=m\times a$)obtained from the stride, hip, arm, and wrist during a pitch.

LITERATURE REVIEW

Public Health Epidemic Criteria

- Substantial burden on youth softball society, parents, and injured athletes.
- Injury burden is distributed unfairly because youth baseball has protective measures and the injury risk for each is comparable.
- Injury incidence and prevalence are increasing (suggesting preventability).
- Public and private concern about risk.
- Preventative strategies such as pitch counts and rest day regulations are not yet in place.

Large Burden on Youth Softball Society, Parents, and Injured Athletes

Youth pitchers are much different than adult pitchers, because young pitchers are continuously growing and developing, thus requiring longer recovery times from pitching.[1] The increase in the popularity of the sport has spurred growths in enrollment, with a lack of trained pitching coaches filling the void. Some coaches are unfamiliar with a female pitcher's specific needs: the physical care needed to maintain the growth curve of a continuously developing child; the nutritional care needed to protect their bones and growth cartilage that is susceptible to the repeated stress of micro-traumas; and, the need for sequential coordination drills in fast-pitch softball pitchers to ensure the proper timing of the pitch.[6]

The most common location of injuries in fast-pitch pitchers are those to the shoulder. This is likely a result of overuse as 76.4% of pitchers throw between 300-500 a game, some while using flawed mechanics.[5] The recurring strain on the upper extremity of the pitcher can lead to damages.[5] Extremely competitive travel and club teams, comprised of elite youth fast-pitch softball pitchers, have become progressively more widespread. Tournaments featuring these teams are usually held on weekends and often result in some pitchers throwing over 200 pitches in three or more games a day. These tournaments, extended seasons, and extreme training regimens are key elements to the increased risk for injuries in youth pitchers.[16]

Pitchers in these tournaments lack sufficient time to recover from the shoulder pain, fatigue, weakness, and loss of strength and are not recovering their baseline strength with only one day of rest after pitching. This may be the cause of the increase in pregame pain and fatigue.[17] As the season progresses, the supraspinatus muscle, controlling shoulder forward flexion and external rotation, decreases in strength. Bilateral fatigue increases in the hips and scapular muscles, and unilateral fatigue occurs in the shoulder and arm muscles.[14,17] Youth pitchers compensate for fatigued muscles and joints by changing their pitching mechanics putting extra strain on the upper extremity and increasing their risk of tissue injury.[14,16,19]

Injury Burden is Distributed Unfairly

Muscle forces during the windmill pitch in softball are higher than in baseball pitching. The maximum force is generated during Phase 5, from the 9 o'clock to 6 o'clock position, which is the wrist snap.[19] Baseball researchers have classified fatigue as one of the most important risk factors for injury and a leading cause for surgery.[3,5,18] Baseball pitchers are limited to 210 pitches per week while softball pitchers can pitch 1200 to 1500 pitches in a long weekend tournament.[9] Softball teams usually pitch their number one pitcher for most games throughout a season, while baseball teams rotate pitchers.[9] When a pitcher uses improper biomechanics, and this motion is carried out repeatedly, the stress is comparable to 80-95% of the baseball pitch stress on the shoulder.[20]

Literature regarding the evaluation of injuries and their mechanism of action in fast-pitch pitchers is scarce.[3] Consistently mentioned throughout the literature is that the injury rate in softball is similar to or surpasses baseball.[15,20-22] Biomechanists discovered that the windmill pitch places strain on the shoulder comparable to baseball.[2,19,23,24] Shoulder injuries are common among youth softball pitchers.[3]

Injury Incidence and Prevalence are Increasing

Adolescent's injury risk factors include inadequate conditioning, deficient diet, cumulative fatigue, weak core muscles, poor scapular strength, and increased pitching activity. Identification of injury incidence in pitchers is essential in developing injury prevention tactics to keep these athletes healthy.[6] Past notions concerning the mechanics of the windmill pitch as safe are still evident in the softball culture. This belief is rooted in the historical perspective that the pitching motion is not harmful to the shoulder. Historically, the pitching method closely followed the natural mechanics of the body. The windmill pitch has evolved over time into the current method of pitching. Research has followed the progression of the pitching motion with limited investigation into the specific diagnostic mechanisms of injury for the 360° counter-clockwise motion of the windmill pitch.

The increase in youth pitching injuries is attributable, in part, to the rapid increase in pitching activity at the beginning of the season paired with an adolescent's weak core strength and poor paired scapular strength.[20] Adolescents have a 78% greater chance of getting injured during the first 6-weeks of the season and have a 61% chance of developing a shoulder injury. Moreover, 50% of injured pitchers lose more than 2-weeks of playing time.[6,25]

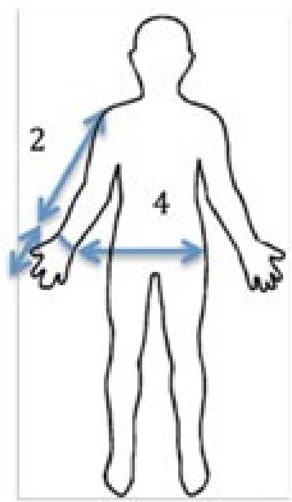
Public and Private Concern About Risk

Leading researchers in the field of sports science have stated a need for injury prevention strategies, such as pitch count and rest day regulations, to address risk factors associated with the abundance of tournament play.[3,4] The American Board of Pediatrics on Sports Medicine, for example, has recommended training principles for girls' softball because of the increase in injury incidence and to establish guidelines for injured pitchers for recovery.[13] These training principles include maximum pitch counts, physical training, and creating instruction in proper pitching mechanics.[26] Little League softball does have pitching regulations based on innings pitched, but research has concluded that inning counts and games pitched do not predict overall injury rates as well as pitch counts.[26] Descriptive studies for youth softball pitchers need to be performed to understand the connections between injuries, pitch count data, and innings played at all levels of play.

METHODS

This pilot study follows a descriptive cross-sectional study design with a total of 15 female youth fast pitch softball pitchers (mean age, 14.2-years; mean weight, 58.45 kg) recruited to participate during the fall softball league (2014). G Power 3.1 output parameters calculated total sample size at 15, power of 0.82, and degrees of freedom of 14. A paired samples t-test was used to report the difference between not using hip rotation during the pitch and using the hip during the pitch. The pitchers had to be currently pitching on their team's roster to be included in the study. The institutional review board approved this research as exempt. Informed consent

Figure 2. *Body Measurements for Calculations*

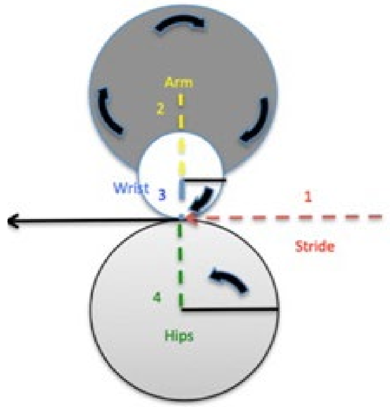


Youth measurements and their mass were used to calculate the forces generated during the pitch and are shown in Figure 3. The first measurement is the stride, the second is the arm, the third is the hand, and the fourth goes across the hip.

was obtained from all participants and their parents and/or guardians. The key variables in this study are the measurements and timing used to calculate potential velocity, acceleration, and force. A vector calculator and unit converter were used to calculate the forces created during the pitching movement.[27] Measurements (illustrated in Figure 2) and timing of individual segments (stride, arm, wrist, and hip) were used to calculate the forces generated at these segments by inserting this data into Newton's 2nd Law of Motion, F=m×a.

The magnitudes calculated for group 1 were at 270° of hip rotation (no hip), the magnitudes for group 2 were calculated as a projection using 360° or full rotation. The projection was used to show how much force is being lost per pitch when the pitcher does not utilize the hip and torso in the windmill pitch (Figure 3).

Figure 3. *Circumference and Radius Formulas and Illustration*



1. Stride length=Distance from pitching rubber to where lead foot strikes the ground,
stride acceleration=Distance/time/1 sec.
2. Arm length=Distance from shoulder joint to wrist joint circumference of a circle (2πr),
arm acceleration=2πr/time/1 sec.
3. Wrist length=Distance from wrist joint to tip of longest finger=circumference of a circle (2πr/4). The 4 is when the wrist moves 90° or ¼ of a circle,
wrist acceleration=2πr/4/time/1 sec.
4. Hip length=Distance from opposite hip across the body to the throwing arm at the hip=circumference of a circle (2πr/4). The 4 is when the hip moves 90° or ¼ of a circle when the pitcher utilizes the entire hip or 360° and the 16 is when the hip moves very little or 1/16 of a circle or 270°,
hip acceleration=2πr/16/time/1 sec. at 270°,
=2πr/4/time/1 sec. at 360°.

RESULTS AND DISCUSSION

Forces generated during the windmill pitch are calculated to establish a baseline for injury prevention. Data describing the forces generated for each participant at 270° and the data projections at 360° are located in Tables 1 and 2. Please keep in mind all pitchers were using the Current Method form and timing at 270° and 360° and the data at 360° only represents a change in hip rotation, not a change in all aspects of the pitch. The results of the paired samples *t*-test for the 2 groups (270° hip rotation and projected 360° hip rotation) were strongly and positively correlated (r=0.993, $p<0.001$). There was a significant average difference between 270° hip rotation and the projected 360° hip rotation forces (t14=12.996, $p<0.001$). On average the projected 360° hip rotation forces were 580.68 N higher than 270° hip rotation (95% CI [676.51, 484.85]. The measurements and times from the videos were used to calculate velocity. Once velocity was calculated these values were then divided by 1 second to calculate acceleration which was entered into the formula for Newton's 2nd Law of Motion, F=m×a. Other formulas used for calculations include speed=distance/time and acceleration=distance/time/second. The pitcher's stride length was computed by averaging all the pitchers stride lengths from 3-5 videos. An average stride length was determined to be 6 feet and was used for all participants. The same principle was used for the timing of hips and wrist snap for all participants; average time used was 0.066 seconds, each individual measurement was used for the hips and wrist. Individual weights were obtained from the pitchers and used for mass (m).

Table 1. *Total Force (Newton) Generated by Pitchers during the Windmill Pitch Using Hip at 270°*

Table 1: 270°	Stride (Newton)	Arm (Newton)	Wrist (Newton)	Hips (Newton)	Total Force (Newton)
P1	375.62	646.21	312.89	201.14	1349.80
P2	197.03	362.00	183.42	119.20	751.96
P3	308.42	622.51	274.27	180.96	1218.70
P4	266.39	488.67	259.15	143.46	1024.30
P5	215.24	470.56	271.85	151.51	969.56
P6	177.35	328.27	151.36	88.29	622.89
P7	322.51	542.94	277.72	185.09	1158.10
P8	260.27	488.67	240.63	138.83	999.26
P9	133.03	203.30	157.39	75.76	499.50
P10	282.37	456.56	267.35	138.82	1015.80
P11	335.90	575.14	272.70	194.04	1199.50
P12	228.04	418.60	196.08	113.13	850.28
P13	219.02	421.37	213.06	152.19	866.91
P14	196.65	333.20	181.81	94.40	717.89
P15	327.72	661.46	326.30	233.07	1336.00
Total	3845.50 N	7019.50 N	3585.90 N	2209.90 N	14,619.00 N
Average	256.37 N	467.96 N	239.07 N	147.33 N	974.60 N

The average force generated by these individuals during their pitches at 270° hip rotation was 974.60 N. Averages forces generated during the stride 256.37 N, the arm 467.96 N, the wrist 239.07 N, and the hip 147.33 N. The average forces generated for the same individuals were projected to calculate forces with one variable different, hip rotation at 360° instead of 270°. The average force projected by these individuals during their pitches was 1552.67 N.

The average forces for the stride, arm, and wrist generated for this group were the same as the 270° group because nothing was changed except the hip rotation; the stride 256.37, the arm 467.96 N, the wrist 239.07 N, and the hip 589.30 N. The projected hip rotation force was much greater in the 360° group, 589.30 N, than the 270° group, 147.33. The projected data for all 15 female youth pitchers is located in Table 2 for each variable and the total

Figure 4. *The Correct Kinetic Chain for Fast-pitch Softball Pitching*

Phase 1: Pitcher is taught to disguise the ball and perform warm up activities anterior to the body.
Phase 2: Pitchers face forward with feet pointing toward home plate or straight ahead. Pitcher pushes off from rubber with Lag foot. Lead leg begins to lift.
Phase 3: Lead leg continues to lift, and pitcher will "Show your Spike!" Pitcher shows spike to set up the proper alignment of the lead foot to land on the heel in Phase 5, a solid platform for kinetic chain activation. The arm begins its 360° counterclockwise rotation.
Phase 4: Hips and trunk rotate back to 270° the arm follows extending to the 12 o'clock position and lead leg extends toward target.
Phase 5: The pitcher pushes with back foot toward target to activate hip rotation as the hip leads the release. The hip then closes to 360° coupled with the torso, and scapula. As the hip reaches 360° the heel makes contact with the ground (feet facing forward toward target) as the shoulder flexes.
Phase 6: This sets up the upper arm to allow the elbow to be used as a catapult for the wrist snap/hip thrust and releasewith all forces directed toward the target for injury prevention. The hips finish in the neutral position as shoulder flexion finishes the pitch.
Follow Through: Finish following through straight ahead.

force for each pitcher. A blueprint for the ideal pitching motion in fast pitch softball pitchers, utilizing the windmill method based on injury prevention, is illustrated by phase in Figure 4.

Table 2. *Total Force (Newton) Generated by Pitchers during the Windmill Pitch Using Hip at 360°*

Table 2: 360°	Stride (Newton)	Arm (Newton)	Wrist (Newton)	Hips (Newton)	Total Force (Newton)
P1	375.62	646.21	312.89	804.57	2139.30
P2	197.03	362.00	183.42	476.79	1219.20
P3	308.42	622.51	274.27	723.85	1929.10
P4	266.39	488.67	259.15	573.82	1588.00
P5	215.24	470.56	271.85	606.02	1563.70
P6	177.35	328.27	151.36	353.17	1010.20
P7	322.51	542.94	277.72	740.37	1883.50
P8	260.27	488.67	240.63	555.31	1544.90
P9	133.03	203.30	157.39	303.03	796.75
P10	282.37	456.56	267.35	555.27	1561.60
P11	335.90	575.14	272.70	776.14	1959.90
P12	228.04	418.60	196.08	452.48	1295.20
P13	219.02	421.37	213.06	608.75	1462.20
P14	196.65	333.20	181.81	377.61	1089.30
P15	327.72	661.46	326.30	932.29	2247.80
Total	3845.50 N	7019.50 N	3585.90 N	8839.50 N	23,290.00 N
Average	256.37 N	467.96 N	239.07 N	589.30 N	1552.67 N

Limitations of the Study

The pitchers were from a small geographic area that included 1,050 softball players with approximately 175 pitchers. For future studies, a kilometer per hour assessment would be a better way to check the accuracy of the force calculations. The cross-sectional design of this study averaged results from one pitching encounter (3-5 pitch average). A longitudinal study, following these pitchers through-out their careers after an intervention and correction of mechanics, would be an ideal design. The 360° hip rotation projected group data only represents a change in hip rotation not a change in all aspects of the pitch. An average was used for stride length (182.88 centimeter) and average time (0.066 seconds) was used for hip rotation and wrist snap. Future studies will need to be performed on the correct pitching method using electromyography (EMG), motion analysis, range of motion analysis, muscle strength testing, balance assessment, strength training, and training on segmental sequencing or timing of the pitch to further develop a pitching method blueprint for injury prevention.

CONCLUSION

The CM of pitching clearly uses the shoulder as the driving force of the pitch. Pitchers in the 270° hip rotation group created 467.95 N of force at the shoulder.[20] Pitchers who used 270° hip rotation only produced 147.33 N at the hip while these same individuals have the potential to create 589.30 N with full hip rotation. The mechanics of the pitch must follow the natural movements of the body utilizing the stronger muscles and proper joint alignment. Softball lags behind all other youth sports in injury rate, recognition, and prevention safety rules. The windmill pitching style places a unique demand on the entire kinetic chain. The shoulder was designed for mobility not for strength and youth pitchers sustain significant shoulder instability patterns. The most common injuries are tears to the labrum, rotator cuff, and Tommy John or ulnar collateral ligament injury. The key to reducing these injuries is to update the regulations for youth softball and train coaches in off-season and preseason strength conditioning and proper mechanics, and how these mechanics should transition properly.[16,26] Pitching mechanics education is vital for keeping youth softball players healthy during the season.[24] When athletes cross train in various sports, the different movement patterns associated with each sport builds coordination. The use of additional movement patterns adds to the variability in coordination and may be an important etiological factor in decreasing softball pitching injuries.[15]

Recognizing the movement patterns involved in the windmill pitch will also allow better diagnosis of injury and specific rehabilitation and conditioning programs. A baseline of coordination patterns needs to be established to determine whether improper biomechanics play a part in injury risks.[15]

CONFLICTS OF INTEREST

The authors (Dr. Rebecca Fahey & Mr. Michael Fahey) declare that they have a provisional patent on their method of analysis for injury prevention in sports and have no other conflicts of interest.

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