Clinical Commentary/Current Concept Review

Stride Length and Torso Biomechanics As They Relate To Medial Elbow Injuries In Adolescent Aged Baseball pitchers: A Clinical Commentary

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There is a limited amount of literature examining torso biomechanics and stride length while addressing their relationship to medial elbow injuries in the adolescent baseball pitcher. Anatomical changes, growth, early sport specialization, multiple team participation, mound distance, mound height, and high pitch counts place adolescent pitchers at an exceptionally higher risk for medial elbow injuries. Existing evidence indicates that decreased stride length and altered trunk rotation is correlated with increased medial elbow loading for the adolescent overhead athlete. Further research is required to quantify adequate parameters for torso kinematics, control, and their correlation to stride length, in order to positively affect the biomechanical transfer of energy and potentially prevent injuries during the overhead throwing motion. The purpose of this clinical commentary is to examine and summarize the role of torso biomechanics and stride length in relation to medial elbow injuries in adolescent baseball pitchers.

Level of Evidence

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INTRODUCTION

As competitiveness increases from youth to high school baseball, so do external pressures, expectations, and physical demands. Adolescent pitchers in particular experience a tremendous increase in volume of overhead throwing as age and level of play increase. Zaremski et al. suggest that adolescent pitchers throw an average of 119 pitches per game, including the warm-up, bullpen activity, and in-game pitches.[1] Additionally, improving velocity and throwing a variety of different pitches normally become a higher priority in adolescence and beyond. These factors, along with anatomical changes, growth, early sport specialization, participation on multiple teams, mound distance, mound height, and high pitch counts place adolescent pitchers at an exceptionally higher risk for medial elbow injuries. Utilizing proper throwing mechanics, specifically torso rotation and stride length, is one way to minimize this risk without compromising performance. The purpose of this clinical commentary is to examine and summarize the role of torso biomechanics and stride length in relation to medial elbow injuries in adolescent baseball pitchers. Currently, there is a limited amount of literature connecting torso biomechanics and stride length while addressing their relationship to medial elbow injuries in the adolescent baseball pitcher population.

ELBOW FORCES WITH OVERHEAD PITCHING

A valgus moment at the elbow consists of a medially directed load, which is greatest during the cocking phase of the pitching motion when the shoulder is abducted and externally rotated. This valgus moment is counteracted by the muscle-tendon units crossing the medial elbow, creating a varus moment during the late cocking phase. As the arm internally rotates through the late cocking phase, at velocities up to 7,500 degrees per second, torque is produced, which places tension on the ulnar collateral ligament and com-

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pression at the radiocapitellar joint.[2] Pitchers with upper extremity range of motion deficits may compensate from other areas of the body, which could lead to injury. Current literature regarding biomechanical analysis of torso rotation also states that a decrease in synergistic control of torso musculature during the pitch leads to an increased varus moment on the elbow, placing higher torque upon the upper extremity.[3–7] Therefore, prior literature has shown how optimizing torso biokinematic control through hip and shoulder separation can aid in increasing pitch velocity.[8] In the author's opinion, this information could be extrapolated to lower the probability of medial elbow injuries.

OVERVIEW OF THE PITCH CYCLE

To best describe and evaluate biomechanical control, the process of throwing a pitch needs to be broken down and defined. The baseball pitch utilizes all aspects of the kinetic chain where each segment receives elastic potential energy from the previous segment. The segments follow the summation principle, in which energy is transferred when the subsequent segment begins rotating as the prior segment has reached maximal angular velocity. Stability and neuromuscular control from the lower extremities, lumbopelvic structures, and core musculature are essential to optimize the effects of the summation principle.[9] This stability establishes a platform for the upper extremities to receive energy and generate velocity.[9] The overhead pitch is routinely broken down into sequential phases related to the generation and transfer of potential and kinetic energy.

After initiation of the pitch cycle, the conversion of potential energy into kinetic energy occurs during the stride phase as the pitcher steps toward home plate.[10] The completion of the stride phase is seen as the lead foot makes contact with the ground, the throwing arm reaches its initial point of cocking, and is followed by the initiation of pelvic rotation towards the batter.[11–13] As the hips rotate towards home plate, the upper quarter continues into its cocking phase producing lower quarter and upper torso dissociation.[3,14,15] This separation aids with achieving maximal shoulder external rotation during the later portion of the cocking phase and creating a pre-stretch to abdominal musculature to eventually aid with energy transfer. Improper timing, lack of segment separation, or loss of energy transfer into the acceleration phase could be a critical point for the necessity of compensatory upper extremity energy generation.[10] The acceleration phase follows, as the summation of energy is transferred into shoulder internal rotation and to the point of ball release.

As baseball players age, there are natural changes in pitching mechanics that occur due to a combination of experience, confidence, coaching, and growth. As pitchers mature, there are consistent adaptive changes that occur related to natural physical development as well as related to throwing. These changes include throwing shoulder internal and external rotation range of motion, increased segmental trunk separation, increased stride length, and a decrease in stride forefoot angle.[8,15–17] Additionally, this natural physical development is accompanied by kinetic changes producing a resultant increase in velocity and elbow torque.[8,12] All of these changes could pose a risk for elbow associated injuries for the developing athlete.

Table 1. Risk Factors and Likelihood of Upper Extremity Injury[23]

Risk Factors	Likelihood of Significant Upper Extremity Injury
Pitching faster than 85 mph	2.5x
Throwing >80 pitches/game	3.8x
Throwing >8 months/year	5x
Pitching fatigued	36x

Mph= miles per hour

INFLUENCE OF TRUNK ROTATION ON RISK OF INJURY

Chaudhari et al. have suggested that inappropriate trunk rotational timing when pitching has been associated with injury.[9] Error in timing of trunk rotation correlates with increased demand on the upper extremity, which could lead to a medial elbow injury.[10,18,19] The lack of synchronization between trunk rotational timing and stride limits the amount of energy transfer from the trunk to the upper extremity. Loss of rotational range of motion could be the main factor of injury. Previous authors indicate that fatigue and pitching velocity are the best predictive factors of medial elbow injury, which was the driving factor for USA Baseball and Little League Baseball, Inc to implement age-based guidelines for pitch-count maximums and required rest times.[4,6,20–22] The question remains: Are pitch-count regulations enough to prevent throwing related injuries in the adolescent population? Other modifiable factors could further aid in reducing overuse injuries. Pitch-counts do not consider the individual kinematics of the pitcher, the transfer of energy through the kinetic chain, the volume a pitcher throws per year, or how fatigue influences the biomechanics of the pitch. Olsen et al. suggest the following modifiable risk factors and suggest that they are related to the predisposition of adolescent pitchers to medial elbow injury: inadequate pitch counts, pitch velocity greater than 85 miles per hour, throwing more than eight months in the year, and throwing through fatigue all exponentially increase risk of injury (Table 1).[23] In addition, this clinical commentary presents considerations regarding the kinematic chain that predispose the baseball pitcher to medial elbow injury. Optimizing safe kinematics could ultimately aid with injury prevention and provide a positive effect towards an athlete's baseball career.

Although several factors change from adolescence to young adulthood, studies aiming to identify how pitching mechanics affect elbow loading and velocity are consistent across various ages. As one would expect, velocity, demands, and torque continue to increase with age, but these variables' relationship with mechanics does not fluctuate.[24] For this reason, the biomechanics regarding the pitch cycle are often applied across different age demographics. Previous research has displayed a link between trunk rotation and internal elbow varus moment in college-aged athletes.[25] Cohen et al. have shown that increased trunk rotation away from the throwing hand correlates with a more significant increase in varus force than in velocity.[25] Furthermore, early rotation of the trunk has been found to cause alterations in shoulder positioning for pitchers between the ages of 9 through 18.[26] There is no evidence to support an ideal amount of rotation to balance the risk and benefit, but there is support for excess trunk rotation being harmful.

INFLUENCES OF STRIDE LENGTH ON RISK OF INJURY

Previous authors have utilized a focused approach to pelvic and torso rotation as a power generator for the overhead athlete.[25,27] Research falls short when comparing stride length abnormalities to upper extremity injuries in the adolescent population. Stride length, as defined by Ramsey et al. is the horizontal distance between the location of the drive-foot calcaneus at peak knee-height and the calcaneus of the contralateral foot at ground contact.[28] This is a highly modifiable aspect of pitching mechanics that has been found to impact various body segments along the kinetic chain during the pitching motion, including forces experienced at the shoulder and elbow.[29] Prior authors have reported a desired stride length (DSL) among highly skilled and proficient pitchers aged 17-21, ranging from 80-87% of body height, but DSL has been reported to be as low as 66% of body height in less experienced middle school and adolescent aged athletes. Pitchers that exhibit a shorter stride length decrease potential force development throughout the kinetic chain due to a reduced trunk rotation moment.[19] Exceeding stride length norms can cause increased physiologic demands on the body; however, are associated with decreased stress to the upper extremity, potentially due to the increased total body momentum towards the plate that occurs with overstriding.[28] Current evidence indicates that exceeding or failing to meet an optimal stride length can potentially lead to increased fatigue, kinematic compensations, and upper extremity injuries.[28–30] Finally, it is important to note that Sgori et al. have determined that a 10% increase in stride length and its relationship to increased pitch velocity are a natural sign of physical growth and development.[8]

The pitch cycle is a sequence of events where multiple segments of the body are interconnected through the kinetic chain.[18] Efficiency of movement is based on their interdependence to transfer momentum from the ground to the upper body.[18] As stride length nears foot contact, highly efficient pitchers will demonstrate a closed foot angle. Closed foot angle is defined as the forefoot being angled toward the thrower's arm (Figure 1). Overhead athletes who demonstrate excessive closed foot angle upon stride foot contact cause their arm to be ahead of the rotating shoulder during the late cocking phase, leading to a closed front hip, throwing across their body, and lack of efficient force transfer from the pelvis to the upper extremity.[22] If the forefoot angle becomes more open toward the glove side, undesirable anterior translational stress can be produced at the shoulder.[22] This could be due to early pelvic rotation or altered trunk separation from the upper extremity.[10,24]

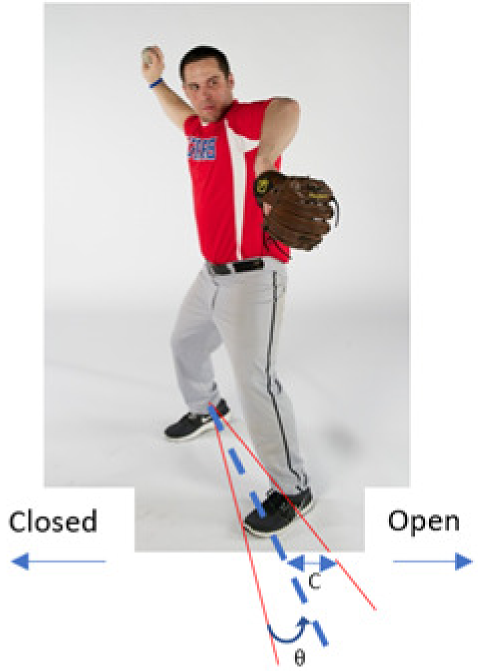

Figure 1. Stride Leg Positioning

C = stride foot offset, θ = forefoot angle, - - - = neutral/neither open nor closed

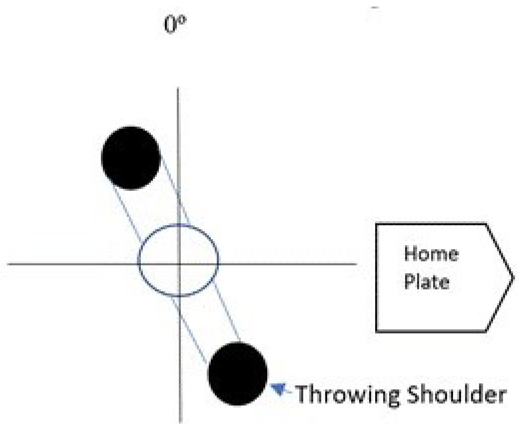

Figure 2. Internal Trunk Rotation Angle at Ball Release

Adapted from Cohen et al[25]

Anterior translated force at the shoulder combined with maximal external rotation range of motion during the late-cocking phase produces increased valgus loading at the elbow, increasing the risk for elbow injuries.[22] In contrast, pitchers that demonstrated more of a closed angle at stride foot contact did not present with increased valgus loading at the elbow.[22]

Another aspect related to stride foot angle is stride foot offset, the horizontal distance between the center of the lead ankle and center of the trailing ankle (Figure 1). An excessive stride foot offset angle, known as "opening up" (Figure 1), can disrupt the timing and efficiency of torso rotation, transfer of energy up the kinetic chain, causing increased humeral internal rotation torque, and as a consequence could lead to valgus load at the medial elbow.[10,18,22,24] Stride foot offset, a component that has not

Table 2. Pitch Cycle Biomechanical Nodes for the Adolescent Baseball Pitcher

Biomechanical Node	Normative Mechanical Values
Forefoot Position	Slightly closed 9 y/o 23 ° (±3) as one ages to 15 y/o 14 ° (± 4) [15]
Stride Length	66% of body height (SD 7.1%) pitchers 9-14 y/o [33] Each year of age associated with a 10% increase in stride length[8]
Stride Foot Offset	9 y/o 2 ±2 cm open as one ages to 15 y/o 18 ±3 cm closed [15]
Trunk Separation (Axial rotation of upper trunk relative to the pelvis)	9 y/o 23 ° (±2) as one ages to 15 y/o 42 ° (±3) [15]
Internal Trunk Rotation at BR (Throwing arm side towards home plate; Figure 2)	8-13.5 y/o 25 ° (±9)[13] (Compared to 18-24.8 y/o 23 ° (±8); for every additional 10° increased elbow stress)[25]
Single-Limb Support (Dominant leg = same side as throwing arm)	10.2 sec (SD 5.9)[33]

y/o = years old, SD = standard deviation, BR = ball release, sec = seconds

been widely researched, plays a pivotal role in force generation for the overhead athlete.

EXAMINATION AND EVALUATION OF THE PITCH CYCLE

Examination and evaluation can be used to quantify the range of motion, balance, and physical performance capabilities needed to complete the pitch cycle and provide further insight into clinical judgement for correction. This can be accomplished through standard anthropometric measurements and biomechanical analysis. A current concept being explored includes the impact of drive leg hip internal rotation range of motion and its impact on trunk rotation.[31,32] Further research is needed to quantify the optimal range of hip internal rotation that is specifically needed for the adolescent baseball player. However, some evidence supports the examination of bilateral hip flexion and internal rotation range of motion due to its resultant influence on elbow injury.[31] Prior authors have described a relationship between pitching skill level and lower extremity function as it is related to lower extremity power and single-limb balance.[33] Additional physical performance metrics for lower extremity power, such as the double-leg vertical jump, have shown a moderate correlation to stride length in the younger baseball athlete.[33] To provide thorough analysis of the pitch cycle, it is advisable to utilize video analysis software that can reduce body motion velocity and capture segmental change.[6,34] Additionally, various kinematic values based on age can be utilized to capture lower extremity and trunk positioning (Table 2). Correction of any deficits found can be addressed using therapeutic exercise and education, such as stretching and balance training.[35] This could also include methods of motor learning, such as constraints led approach or differential learning, to coordinate patterns of movement and explore solutions for movement error.[36]

CONCLUSION

Existing evidence indicates that altered stride foot positioning and trunk rotation is correlated with increased demand on the upper extremity.[8,10,18,24,33] Inefficiency throughout the kinetic chain leads to compensation from the upper extremity and increases the tensile forces at the medial elbow. The forces traveling through the kinetic chain lose momentum, leading to the increased demand of the upper extremity to maintain adequate force production. Over time, the increased forces placed upon the throwing arm may lead to overuse injuries in the medial elbow.

Current evidence also indicates that optimal stride length changes according to the age and growth/maturation of the pitcher.[8] Optimal torso rotation has not yet been quantified, but problems with early and late rotation have been identified. Both biomechanical components likely impede the transfer of energy throughout the kinetic chain, and compensatory motion transpires. Additional research should be conducted to specifically evaluate the correlation between torso biomechanics and stride length, quantify adequate torso kinematic parameters, as well as their collective effects on elbow injuries in the adolescent population

CONFLICT OF INTEREST

There are no conflicts of interest to disclose.

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