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EXAMINING THE RELATIONSHIP BETWEEN DIFFERENT PITCHING MECHANICS AND THROWING INJURIES BY

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EXAMINING THE RELATIONSHIP BETWEEN DIFFERENT PITCHING MECHANICS
AND THROWING INJURIES

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Abstract

Throwing injuries in baseball are increasing amongst major league baseball pitchers. Injuries to the shoulder complex and elbow ligamentous structures are increasing. Variables including pitch count, pitch type, throwing style, and duration of the game have all been “linked” to potential injury. Noticing the relationship between these variables and injuries can lead to an upward trend in the decrease of throwing injuries.
Introduction

Over 12 million children and young adults participate in baseball leagues across the United States annually.\(^1\) There are approximately 27,000 to 45,000 collegiate baseball players across the United States.\(^2\) Combined with 30 major league baseball teams consisting of 25 to 40 players and 244 minor league baseball teams consisting of the same amount that accumulates to a large population for potential injuries to occur.\(^3\) In fact, Little League Baseball in the United States has seen an astounding increase in year round participation, single-sport specialization, increased exposure from playing in multiple leagues, and showcase turnout increase despite the drop of overall participation.\(^4\) In 2015 baseball ranked as the 3\(^{rd}\) most common sport to have at a high school level and 4\(^{th}\) most athletes participating with 15,956 programs totaling 488,815 male athletes.\(^5\) An additional 254 programs also allowed 1,290 female athletes to participate in baseball.\(^5\) Baseball is considered to be relatively safe compared to other sports because of low impact injuries. However, baseball is filled with injuries. One study found that baseball, when compared to other sports, had the second highest percentage of injuries resulting in loss of participation lasting longer than seven days.\(^6\)

Pitchers sustain more injuries on average than any other position in baseball. A study of major league baseball players ranging from 2002-2008 saw a mean of 46 more injuries to pitchers than any other position.\(^7\) In fact, not only did they experience more injuries in that 7 year span, but pitchers also spent more time on the injury list, had a higher injury incident rate, and experienced a greater number of upper extremity injuries.\(^7\) Pitchers sustained 67\% of all the upper extremity injuries found in the study.\(^7\) An alarming 57\% of all injuries sustained by pitchers were either injuries to the shoulder or elbow.\(^7\)
Throwing athletes place very high forces on their shoulders and elbows during the typical throwing motion. During each phase of the throwing motion, forces ranging from 550 N to over 1000 N are placed on the shoulder and elbow. A combination of varus and valgus forces to the elbow and distraction forces to the shoulder make the throwing motion one of the most tasking motions that happens in less than 30 seconds.

The overhand throwing motion is one of the most complex motions the human body performs and is commonly used in baseball, softball, javelin throwing, and water polo. Throwing injuries are becoming a frequent occurrence in all levels of sports, specifically baseball. In the past ten years 948 baseball pitchers between the minor league and major league have sustained a torn ulnar collateral ligament (UCL). Pitching at that high of a level contributes to shoulder injuries. Recent literature focuses more on the UCL since that particular injury is becoming extremely common. Many variables have been linked to pitching injuries including: overuse, pitch type, throwing mechanics, fatigue, pitch velocity, hip musculature tightness and glenohumeral internal rotation deficit. The purpose of this professional paper is to explore the research to determine the relationship between improper mechanics and throwing injuries.

**Biomechanics of Pitching**

The throwing motion, particularly pitching, consists of six stages. These stages include the windup, early cocking, late cocking, acceleration, deceleration, and follow through (Fig. 1). The six stages happen in one fluid motion. The legs and trunk serve as the main force generators of the kinetic chain (KC). An interaction between the legs and core with the shoulder musculature allows the body to transfer the force efficiently from the core to the upper extremity.
Pitching can be described as one of the most highly dynamic skills in all sports. The lower extremity provides vital energy, which is transferred through the trunk to the shoulder, arm, and hand during every pitch. The larger muscles in the legs, hip, and trunk act as force generators while the smaller musculature of the shoulder and hands funnel the force to pitch the ball. When the KC is disrupted, pitchers may accommodate by placing a greater amount of force in the smaller upper extremity musculature. Thus, the pitching cycle is not thought of just an upper extremity movement; instead it is considered an integrated motion involving the entire body to optimize performance and reduce the risk of injury.

The KC links the entire body together from the toes to the head. The larger muscles of the core and legs produce approximately 55% of the kinetic energy that is transferred through the entire upper extremity. One particularly large connective tissue, the thoracolumbar fascia, is involved with KC during throwing and connects the lower extremity via the gluteus maximus to the upper limb through the latissimus dorsi. The deep muscles of the back like the multifidi, internal oblique, and transverse abdominus also play a role. In order for the KC to be efficient, flexibility, strength, and proprioception all have to be working together cohesively. Breakdown in the KC from factors such as variation in motor control, inadequate muscle strength, or flexibility impairments may all lead to a phenomenon called the “catch-up”. This is described as “breaks” in the KC that alter forces in distal segments leading to possible pain or injury.

An assessment of the KC when it pertains to the throwing motion includes eight positions and motions to achieve the most efficient throw. These positions include trunk control over the back leg, hand on top of the ball in the arm-cocking phases, front leg directed towards home plate or the target, control of lumbar lordosis in acceleration, hips facing home plate or the target, scapular retraction/arm horizontal abduction/maximal external rotation during the arm-cocking
phases, elbow above the shoulder, and finally long axis rotation at ball release. These positions are discussed in detail with discussion of each phase of the pitching cycle and how they correlate with performance and injury.

The first stage of the windup happens from the stretch or the full windup phase. The only difference is that the full windup phase requires more lower body movement, but ultimately both phases meet at the “windup” phase pictured in Figure 1. This process is deemed as the correct or proper pitching mechanics for overhand throwing.

*Windup*

The pitching cycle begins with the windup. This stage is achieved in multiple forms. Pitchers vary this stage by changing arm position, torso torque, and even certain pauses. Ultimately, the goal of this stage of the pitching cycle is to generate enough force to pitch using a combination of lower extremity muscles including the glutes and hip musculature. This starts with the thrower in a dual leg stance. The windup begins with the initial movement of the contralateral leg, and the power is generated with the elevation of the lead leg to the highest point comfortable for the pitcher. Maintaining balance on the back leg requires isometric contraction of the quadriceps and eccentric contraction of the hip extensors. The pitcher’s goal is to keep his center of gravity over his back leg, which allows the pitcher to generate the maximum amount of forward motion.

Breakdown in the KC during this phase can correlate to injury. Weakness of the back leg hip abductors and knee extensors produces an unstable base during this phase which potentially could lead to the aforementioned “catch-up” phenomenon. Studies indicate that decreased hip abduction during this phase is associated with increased shoulder workload which correlates with
posterior superior labral tears.\textsuperscript{14} If a player has poor single leg balance on the back leg, impaired trunk control, or moves toward their target too quickly, these can all lead to increased forces on the KC, thus promoting further injury to occur.

*Early Cocking*

Once the lead leg begins towards the desired target, early cocking has begun. External rotation of the lead hip and internal rotation of the stance hip allows the pitcher to create energy strong enough to propel the pitcher towards the target. On average the pitching shoulder moves into approximately 90° of shoulder abduction, 20° of horizontal abduction, and 60° of external rotation by the end of this phase transitioning into late cocking.\textsuperscript{11} The pelvis achieves maximum rotational velocity during early cocking at a rate of 400-700° per second.\textsuperscript{8} During this high velocity the scapula is also brought into protraction, forward tilt, and lateral rotation by the serratus anterior and upper trapezius muscles.\textsuperscript{14} Early cocking requires lower extremity musculature proper firing and stability. The action is achieved by the stance leg gluteus maximus. This particular muscle fires to maintain a slight trunk extension and provide pelvic stability and trunk stabilization.\textsuperscript{8,14} The phase ends when the lead foot makes contact with the ground.

The rapid upper torso rotation causes the arm to lag behind the torso. The shoulder anterior force places significant stress upon the anterior capsule of the shoulder.\textsuperscript{15} A common injury associated with this portion of the early cocking phase is anterior instability.\textsuperscript{15} As the arm lags behind the torso, the shoulder is placed into abduction. With this position the shoulder experiences tremendous abduction forces as well as compressive forces on the glenohumeral joint. The compressive forces stress the posterior tissues of the shoulder, specifically the posterior rotator cuff and labrum. One of the most common injuries associated in this phase of
throwing is posterior impingment. During this particular phase, hip internal rotation of the back leg is critical for transfer of energy throughout the entire KC. If there are restrictions of hip internal rotation in the back leg, this could lead to early forward rotation of the pelvis resulting in potential increased stress on distal portions of the KC including the elbow or shoulder. (Figure 2)

A study performed by Laudner et al. took 34 collegiate baseball pitchers and tested the relationship between measured hip internal rotation and the biomechanics of throwing. The pitchers attended one pitching session and went through motion analysis during a trial of five fastballs. Their results found that the pitchers with decreased lead leg hip external and internal rotation ROM had increased amounts of shoulder external rotation during the throwing motion. The decreased external rotation of the hip also resulted in an increase in horizontal adduction of the shoulder while throwing. The study concluded that decreased hip ROM can cause pitchers to throw across their body, which disrupts the transfer along the KC. Ultimately, hip deficits in ROM can alter the transmission of forces through the KC, placing increased stress on the upper extremity. This may lead to potential injury to the shoulder or elbow.

Late Cocking

Once that lead foot makes contact with the ground, late cocking begins. The phase ends with maximal shoulder external rotation. The scapula is brought into retraction, the elbow flexes, and the humerus is brought into abduction and external rotation. The shoulder complex experiences a significant amount of force during this stage of the pitching cycle. The quadriceps in the stride leg contracts to decelerate the flexed knee which stabilizes the stride leg and provides a stable base. Energy is transferred up the KC through the pelvis and lumbosacral complex as the torso begins to rotate towards the target. Eccentric contraction of the abdominal
obliques prevent excess hyperextension of the lumbar spine during torso rotation.\textsuperscript{14} The upper extremity lags behind in this stage which results in a distraction force at the shoulder registering over 750 N.\textsuperscript{11} This distraction force is primarily countered by the rotator cuff providing a compressive force of approximately 550 to 770 N.\textsuperscript{8,11} As the shoulder approaches maximum external rotation the subscapularis, latissimus dorsi, and pectoralis major are all eccentrically contracting. This action applies a stabilizing anterior force to the glenohumeral joint, thus halting external rotation.\textsuperscript{8} The serratus anterior works with the aforementioned muscles to prevent further scapular retraction and initiate the start of protraction signaling the end of this phase.\textsuperscript{8}

With maximum external rotation the forearm lags behind the arm, which forces the shoulder into external rotation. This position places external rotation forces on the shoulder and increases elbow valgus stress.\textsuperscript{15} Multiple tissues are stressed in these two positions during this phase. When discussing the shoulder, tension and shear stresses are placed on the superior labrum. The compressive stresses are placed upon the posterior rotator cuff and posterior labrum.\textsuperscript{15} The elbow experiences tension stresses on the flexor-pronator mass, ulnar nerve and UCL. Additional stresses include radial head compression and shear stresses to the olecranon.\textsuperscript{15}

Weakness or tightness of the stride leg knee extensors can alter knee motion which makes an unstable base. This can also result in decreased throwing performance, impaired force generation, and overuse injuries in the shoulder and elbow.\textsuperscript{14} Weakness of the abdominal obliques can lead to early rotation of the trunk during throwing. Early rotation of the trunk has been shown to increased valgus torque on the elbow.\textsuperscript{14}

Since there are multiple stresses in this phase of the throwing progression there are also multiple injuries associated with this phase. Superior labrum anterior-posterior (SLAP) lesions, posterior and subacromial impingement, and growth plate injuries are all common shoulder
injuries in this portion of the phase. This phase also introduces various elbow injuries including: UCL sprain, medial epicondylitis, ulnar neuritis, stress fractures, and even osteochondral defects.15

**Acceleration**

The acceleration phase is defined as the time between maximum external rotation of the shoulder and release of the ball towards the target.8,11,14 This is the shortest phase in the throwing cycle. The trunk continues to rotate as the potential energy from the lower extremity in the previous phases transfers to the upper extremity. The arm experiences a rapid motion of as much as 175° of external rotation to approximately 100° of internal rotation in a span of 42 to 56 milliseconds.8 Studies indicate that the subscapularis, pectoralis major, and latissimus dorsi reach maximum activity as high as 185% of their maximum strength.8,14 The serratus anterior also reaches maximum activity to promote scapular protraction which promotes a stable glenoid for humeral rotation occurring during this phase.8,14 The elbow also plays a key role in the acceleration process. From elbow flexion of approximately 90-120° to a rapid movement of approximately 25° of extension, the elbow experiences a quick release of energy in order to release the object being thrown. Extension of the elbow in this process results from a combination of the centrifugal force generated by the torso rotating and the concentric force of the triceps working to extend the elbow.8 Once the elbow reaches maximum extension the ball is forced out of the hand. Ball release is acted from wrist flexion to neutral in a 20 millisecond window.

Non-dominant musculature are also important in this phase. Muscle force counter balancing is used by the body to perform the acceleration phase. Relative to the throwing arm, the contralateral rectus abdominus, abdominal obliques, and lumbar spine musculature all show
significant activity compared to their dominant counterparts.\textsuperscript{8,14} This group of muscles accentuate pelvic and trunk rotation tilt.\textsuperscript{8,14} To maximize the energy transfer from the lower to upper extremity the lead leg must be positioned correctly during this particular phase of the throwing motion.\textsuperscript{13} The trunk moves from a hyperextended position to a forward flexed position. Contraction of the rectus femoris contributes to hip flexion of the stride leg and knee extension, which provides a stable anterior base.\textsuperscript{14} Hyperlordosis places increased load on the abdominals and causes the throwing arm to lag behind, which causes the shoulder to be placed into increased abduction and external rotation.\textsuperscript{14} This increases the compression loads at the shoulder. The increased hyperlordosis that occurs during this phase could ultimately lead to the development of spondylolysis.\textsuperscript{14}

The acceleration phase is the shortest in duration, but generates the greatest shoulder and elbow joint distraction forces. The short duration combined with the forces on the elbow and shoulder stress various tissues in those two complexes.\textsuperscript{15} The biceps tendon, rotator cuff, and joint capsule are all affected in the shoulder. While the UCL, flexor-pronator mass, and the joint capsule of the elbow all feel the stress of the acceleration phase.\textsuperscript{15} Common injuries that correlate with this particular phase include biceps tendonitis, rotator cuff strains, medial epicondylitis, and UCL sprain.\textsuperscript{15}

\textit{Deceleration}

The deceleration phase begins with the release of the ball and maximal shoulder internal rotation.\textsuperscript{8,11,14} The stride leg absorbs some of the energy that is produced during the acceleration phase before the leg is planted during deceleration.\textsuperscript{14} Structures of the rotator cuff and the long head of the biceps eccentrically contract together to rapidly decelerate the shoulder.\textsuperscript{11} This is the most violent and abrupt phase in the throwing motion. This phase also results in the greatest
amount of joint loading during throwing. Multiple forces including excessive posterior, inferior shear, elevated compressive, and adduction torques all occur during the deceleration phase. Those forces are measured as high as 400 N, 300 N, and > 1000 N respectively. The posterior shoulder soft tissues structures dissipate these forces equally as the arm continues through the process of acceleration and deceleration. Throughout deceleration the biceps brachii and brachialis activity is high and causes the elbow to rapidly extend and the forearm to pronate. Musculature including the trapezius, rhomboids, and serratus anterior also assist the pitcher in deceleration of the shoulder girdle. The muscles also help in scapular stabilization during this phase.

The aforementioned musculature experiences shoulder adduction forces during this phase. The biceps tendon, superior labrum, posterior rotator cuff, and the joint capsule all feel tensile tissue stresses. In addition, the biceps tendon and rotator cuff also experience compressive tissue stresses. The injuries associated with this phase are biceps tendinitis, SLAP lesions, rotator cuff strains, and subacromial impingements.

Deceleration puts the most combined stress on the entire KC. In fact, most of the overuse injuries to the posterior arm and trunk occur during this phase. A greater amount of force is needed to decelerate the arm. Large eccentric contractions are needed along the trunk and most pitchers are not conditioned to withstand high repetitions of these forces that likely occur over the course of a full season.

Follow Through

The last phase of the pitching cycle is the follow through phase. This phase begins with maximal shoulder internal rotation and continues until the motion ceases with the thrower in the
fielding position.\textsuperscript{8,1,14} The trunk decelerates and is flexed over the stride leg, which is extended during that time. The stride leg provides stability and absorbs the ending of the force as the back leg is brought to the ground with maximal hip rotational motion.\textsuperscript{14}

This phase overall requires a lower amount of force than every other phase excluding the windup. However, the follow through phase does require force to continually decelerate the trunk and arm effectively. If a thrower abruptly stops the arm motion during this phase, then the energy is not allowed to dissipate along the KC, resulting in the shoulder complex absorbing the majority of this force potentially causing injury.\textsuperscript{14}

\textit{Factors influencing Pitching Biomechanics}

Biomechanists, athletic trainers, and coaches all agree that there are numerous factors that influence any pitch at any time during an outing. With the evolution of baseball and competitive sports, coaches and athletes do whatever it takes to win. Outside “proper” pitching biomechanics, there are a multitude of factors that pitchers use to effectively get their opponents out, but also potentially put the pitchers at harm for injury.

\textbf{Type of Pitch}

Very few pitchers effectively use one single pitch in competitive baseball. To form a new pitch the pitcher grips and puts pressure on the ball differently than a normal throw. In order to keep the opponents off of their game the pitcher develops an arsenal of pitches he uses to deceive the hitter.\textsuperscript{11} The most common pitches include a four-seam fastball, curveball, slider, and changeup.\textsuperscript{8,11,16} Other pitches that require different grips include two-seam fastball, cutter or cut-fastball, and a splitter. The ways to grip the aforementioned pitches are shown in Figure 3.\textsuperscript{17} Some believe that the type of pitch ultimately factors into throwing injuries. Fleisig et al\textsuperscript{16}
conducted a study of the kinematics of the four most common pitches used. Twenty one collegiate pitchers were analyzed throwing the four aforementioned pitches to see what kind of forces are placed on the elbow and shoulder during each pitch. The study showed that the curveball produced less elbow proximal force than the fastball and less shoulder horizontal adduction torque and proximal force than the slider. The slider also produced more shoulder horizontal adduction torque than the fastball. The change-up produced significantly less internal rotation torque, horizontal adduction torque, adduction torque, and proximal force than the other three pitches in the study. Compared to the fastball and curveball the change-up also accumulated less elbow varus torque and compared only to the curveball, the change-up produced less elbow flexion torque. Elbow flexion, shoulder horizontal adduction, and knee flexion were greater in the change-up than the other three pitches. The curveball showed the greatest forward and lateral trunk tilt compared to the other pitches. The curveball on average produced the lowest velocity, but it was in fact the change-up that produced the least amount of angular velocities of the upper trunk, elbow, and shoulder. They found that the change-up likely has the lowest risk for injury.

Fleisig et al. found only one significant kinetic difference (elbow proximal force) between the fastball and curveball. There was also one kinetic difference (shoulder horizontal adduction torque) between the fastball and slider. They found that shoulder and elbow kinetic measurements were significantly less for the changeup compared to the fastball, curveball, and slider. The consensus was that the changeup had the lowest injury risk potential to the shoulder and elbow. Every pitch places forces on the elbow and shoulder. The adversity pitchers face can vary from the weather to the length in between innings. Either way, every pitcher needs to be ready to pitch every game played which can ultimately be the end of their career.
Length of Game / Pitches Thrown

Baseball is one of the few sports in the world that doesn’t have time regulation. The longest single game in baseball history lasted eight hours and six minutes and the shortest single game in baseball history lasted 51 minutes. Each half inning requires the pitcher to throw at least three pitches due to the three-out rule in baseball. There is no limit on maximum pitch count. The longest complete inning in baseball history happened in 2004 where one team faced 54 pitches total and scored eight runs while the other faced 56 pitches total scoring 10 runs. The entire inning saw 110 pitches thrown by various pitchers and lasted one hour and eight minutes. Baseball has become one of the more rigorous sports for players. The MLB season spans over an average of 7 months consisting of on average 34 games for Spring Training, 162 games for the regular season, and if the team makes the playoffs that can add up to an additional 20 games. Some studies believe that overuse and fatigue, due to increased length of seasons, pitches thrown per outing, and lack of rest may lead to injury.

A study by Grantham et. al investigated into the impact of fatigue on pitching kinematics. The study took 11 healthy National Collegiate Athletic Association (NCAA) Division I starting pitchers and filmed them throughout the 2012 spring baseball season. None of the pitchers had a history of upper extremity injuries prior to this study. Data including pitch count, duration of each inning pitched, duration of rest in between innings, and pitch velocity were all recorded. Questionnaires were also completed assessing the participants levels of fatigue following a game pitched using a 10-point visual analog scale. A total of 26 games were filmed consisting of 162 innings. They found 62 of the 162 innings pitched consisted of more than 15 pitches, and 5 innings lasting more than 30 pitches. In order for the study to determine a difference in pitching mechanics throughout the game, a statistical analysis was performed.
comparing the parameters of the first fastball of an inning to the 15th pitch of an inning. The innings lasting longer than 15 pitches showed increased hip lean and stride length during the early cocking phase. Digital markers were placed on elbow, shoulder, and hip landmarks then the pitchers were filmed during games to analyze their mechanics. Hip flexion increased during late cocking. The elbow height of each was elevated during late cocking and the shoulders had a greater amount of tilt during the acceleration phase. The position of pitcher endures massive amount of pressure. They will push their body to the max in order to achieve their task of getting the batter out. Pitch count was also a variable that the group thought would affect the pitcher’s fatigue and ultimately, mechanics.

The subjects averaged 96.7 +/- 16.1 pitches per game. The group found that subjects, on average, reported a 14% increase in fatigue from questionnaires, and continued to pitch regardless of fatigue. However, this reported fatigue did not correlate with a significant decrease in velocity. During the game analysis was performed of the kinematics during the first fastball thrown and the last pitch of the appearance. There was a statistically significant decrease in maximum shoulder external rotation by 2.3°. As pitch count increased during the game there was a minor association that elbow height decreased at the late cocking phase. This has been known to put more stress upon the elbow.\(^1\)

Studies have found that pitching for longer than 8 months in a year led to a 5-fold increase in the risk of elbow surgery in baseball players.\(^1,2\) Throwing more than 80 pitches have also led to a 4-fold increase in their surgery risk.\(^1,2\) The main kinematic difference found in the study was that elbow height dropped as fatigue increased.\(^1\) The shoulder becomes fatigued during a vast amount of over-hand throwing and in result it is natural for the elbow to drop which decreases the stress placed upon the shoulder complex. This is a defense mechanism for the
shoulder which places a significant amount of stress upon the throwing elbow and could lead to injury.\textsuperscript{1} The study also found that by the end of the season pitchers had greater hip lean which they correlated to greater amounts of torque on the shoulder and valgus stress on the elbow.\textsuperscript{1} The difficulty to measure fatigue is understood, however it is known that fatigue is a factor in altering pitching mechanics. As a result the upper extremity is likely to be injured.

\textit{Common Injuries}

Upper extremity injuries account for slightly more than half of all injuries in baseball. Studies demonstrate that 32-35\% of baseball players experience shoulder pain and approximately 17-58\% experience elbow pain.\textsuperscript{15} Pitchers are particularly susceptible to upper extremity injuries due to the increased workload pitchers experience over the course of a season or career. In fact, injuries sustained by pitchers tend to be greater in severity compared to position players. In high school baseball, 73\% of injuries that resulted in surgery were sustained by pitchers.\textsuperscript{15}

\textbf{UCL Injuries}

Throwing exerts tremendous forces through the medial elbow joint. The UCL of the elbow, specifically the anterior band, is the primary soft tissue stabilizer to the valgus stress of throwing in throwing athletes.\textsuperscript{22} Elbow joint forces and torques are generated throughout the arm cocking phase as previously mentioned in cocking phases. A low to moderate flexion torque of 0 to 32 N-m is produced at the elbow throughout the arm cocking phase.\textsuperscript{23} The rotation of the pelvis and upper trapezius with the addition of rapid external rotation produces a large valgus torque at the elbow. That valgus torque on the elbow, more specifically on the UCL, is equal to about 64 N-m.\textsuperscript{24} To counter act this torque the body generates an equal 64 N-m of varus torque before maximum external rotation to resist the valgus torque.\textsuperscript{23,24} That amount of force is
equivalent to holding 150 baseballs all at once. The anterior bundle of the anterior band of the UCL is the primary restraint to valgus stress at 30°, 60°, and 90° of elbow flexion. The ultimate valgus torque of the UCL is only about 33 N-m, so every pitch a pitcher throws generates maximum torque on the UCL complex. In addition to the anterior bundle being a primary restraint, the flexor pronator mass of the arm also can be damaged. It has been speculated that the flexor pronator mass works as a dynamic stabilizer during throwing to help disperse the force that can be placed on the UCL at once.

From 2000 to 2011 a mean of 16 UCL tears per year occurred in MLB. An increase in UCL tears from 2011 to 2014 occurred with the mean averaging around 26 per season. Common belief is that only MLB players tear their UCL because of the velocity they typically generate. This belief is completely wrong, and in fact the UCL rupture is a very common injury in all levels of the sport. Reports show that 28% of all youth pitchers report a history of elbow pain. UCL reconstructions have actually doubled in high school baseball compared to little league pitchers because of the growth of the medial epicondyle in more mature athletes. It is more common that adolescent pitchers experience an injury called little leaguer’s elbow instead of damage to the UCL. The UCL is the popular injury the media likes to focus all of its attention on. What the media and the rest of society do not focus on is the shoulder complex where the majority of throwing injuries occur.

SLAP lesions

SLAP lesions are common in any throwing sport. A study in 2001, using data from the disabled list, reported injury rates of 58 injuries per 100 participants during that season. Shoulder injuries were the most common location of injury at a rate of 27%. The mechanism of injury (MOI) of an individual SLAP lesion can be difficult to identify, but it has been suggested
that throwing and overuse of the shoulder can lead to a SLAP lesion.\textsuperscript{15,29} The late cocking phase of throwing is most associated with SLAP lesions. The position of the late cocking phase increases the torsional forces on the biceps anchor and leads the labrum and biceps tendon to displace over the glenoid medially which is often referred to as the peel back mechanism of a SLAP lesion.\textsuperscript{29,30} The increased horizontal abduction beyond the coronal plane of the scapula during late cocking results in higher contact pressure between the posterior superior glenoid and the articular side of the rotator cuff.\textsuperscript{29} This specific mechanism may put throwers at risk for a SLAP lesion. Mihata et al.\textsuperscript{31} demonstrated that a fatigued or weak subscapularis muscle may contribute to the peel back mechanism of a SLAP lesion. The study reported cadaver data that demonstrated shoulders in the abducted position decreases subscapularis strength and results in greater external rotation despite a similar applied external rotation torque.\textsuperscript{31} This finding results in significantly decreased glenohumeral contact area and increased glenohumeral contact between the articular side of the cuff and the posterior-superior glenoid, which could potentially lead to SLAP lesions.\textsuperscript{29,31}

**Little League Shoulder**

The two aforementioned injuries occur at all levels, but there are specific injuries that occur to adolescents that are not seen in mature pitchers. Early detection of any throwing injury is vital to reduced further harm in skeletally immature pitchers. Proximal humeral epiphysiodesis, also known as Little League shoulder (LLS), is an overload injury to the proximal humeral epiphysis.\textsuperscript{32} This condition can be categorized as chronic repetitive micro-traumatic shear, torque, or traction forces imposed on the incomplete ossified cartilage of the proximal humeral physis of the throwing arm.\textsuperscript{33} LLS studies have found that this condition commonly presents itself in youth baseball pitchers who have thrown or pitched in great amounts.\textsuperscript{32,33} Additional
studies have indicated that the maximal point of tenderness is the proximal humerus during throwing.\textsuperscript{32} This condition typically occurs between the ages of 11-15, and is likely due to the torsional overload at the proximal epiphysis near the exact time of maximal external rotation.\textsuperscript{27,32} One particular study showed that patients who are experiencing LLS had continuing widening of the proximal epiphysis after their symptoms have dispersed. This shows that this syndrome is similar to a stress fracture or a Salter-Harris type I injury to the proximal humeral physis.\textsuperscript{32}

\textit{Demographic}

Once a player reaches the professional level their mechanics in throwing are unchangeable. By the time they reach the professional level, baseball pitchers have been throwing the same way for years. Most of MLB pitchers will admit they have a “funky” motion while throwing, but they wouldn’t change it because it’s too effective. Biomechanics is a sensitive subject in the MLB with some utilizing the science, while others stick to the old school way of teaching baseball pitching. Don Cooper, who is the Chicago White Sox pitcher, has been quoted saying, “I’m not going to let new-school ways get in the way of my old-school thinking. I don’t need biomechanics. I have experience. I have my eyes. I just watch and look.”\textsuperscript{34} Understandably, pitchers won’t change their mechanics because they earn a living off performing that specific craft to perfection. Every MLB pitcher started out as a high school freshman ready to competitively pitch. The change for proper pitching mechanics needs to happen starting at the adolescent-high school (AHS) age (11-15 years).

The majority of the 11.5 million athletes playing baseball in the United States compete at a high school and club level.\textsuperscript{27} High school participation in throwing sports has increased over the past few decades. The increase of participation comes with the price of the increase in throwing injuries. Of all 130,000 high school baseball injuries from 2005-2007 more than 17%
of them were shoulder injuries. Studies reported an injury rate of 1.72 injuries per 10,000 high school baseball athletes. Pitcher’s injury rate at the high school level is increasing and there needs to be an understanding of why.

The first and major difference between the adolescent pitcher and the MLB pitcher is the developed anatomy, specifically the shoulder complex. Epiphyseal plates do not completely ossify until the late teens. When referring to the shoulder complex the proximal humerus, glenoid, and clavicle’s epiphyseal plates don’t completely ossify until the age of 17-18, 16-18, and 18-20 years respectively. Additionally, the major protein of ligaments and tendons (type III collagen), is produced at a significantly higher rate than adults. This potentially leads to increased laxity in the shoulder complex. This combination of anatomical variables and the amount of force during throwing may predispose the AHS pitcher to shoulder injury.

Another major difference that could potentially lead to an increased AHS pitching injury rate is the biomechanics of their throwing motion. A study by Keeley et al. specifically focused on the trunk rotation in the pitching motion of adolescents compared to adults. In this study the researchers indicate that AHS pitchers initiated trunk rotation earlier in the throwing motion. They hypothesized that the “opening up” of the trunk causes anterior shoulder instability with repetitive stress from an increased in the horizontal abduction angle of the shoulder during the early cocking phase. Early trunk rotation also results in an increase amount valgus stress on the elbow which could lead to UCL damage. The AHS pitcher could have proper energy transfer through the KC and still be at danger by looking at the shoulder mechanics. When examining the throwing shoulder of a baseball pitcher findings consistently demonstrate greater humeral external rotation and less internal rotation on that side. This is commonly referred to as glenohumeral internal rotation deficit (GIRD). A deficit of 10°-17° of internal rotation is
common in the throwing arm of athletes who haven’t had a shoulder injury.\textsuperscript{35} Hibberd et al.\textsuperscript{36} took 47 high school pitchers to analyze their overall range of motion in their shoulder complex. They found that 40 of the pitchers (85\%) had GIRD. During the early cocking phase of the throwing cycle GIRD is shown to increase risk of SLAP tears, shoulder impingement, rotator cuff tears, and valgus elbow strains.\textsuperscript{14} This is due to the hand and elbow lagging behind the shoulder complex because of this range of motion deficiency. Although anatomical factors just mentioned play a contributing role in injury rates for AHS pitchers, there is one non-anatomical factor that equally contributes.

Pitch count and pitch type were previously mentioned on how they affect major league pitchers, but these two variables may play an even larger role in the injury rate for AHS pitchers. Lyman et al.\textsuperscript{37} performed a study on over 400 potential pitchers with the age ranging from 9-13 years olds to see why youth baseball players develop arm pain. They found a statistically significant relationship between an increased amount of pitches during a game and the risk of shoulder pain. If the pitcher reached 75 pitches or more, the odds were more than doubled for a shoulder injury. The researchers also found there was an increased risk of elbow pain, but the risk wasn’t as statistically significant. The group also took a look at the factor of the pitch type specifically the fastball, curveball, slider, and changeup. Results were pretty shocking. There was an overall 86\% of an increased risk of elbow pain when throwing the slider, specifically in the 13-14 year old group. Use of the curveball accounted for a 52\% increased risk of shoulder pain collectively in all groups. The changeup use was the most interesting finding. Lyman et al. found that the changeup showed a 12\% reduction in risk of elbow pain and a 29\% reduction in risk of shoulder pain.
Recommendations

Prevention of throwing injuries is a task that should revolve around limiting the use of potential risk factors previously, proper coaching, and proper education. Proper throwing mechanics need to be stressed from the first day of pitching. It is clear that in the MLB there is no “proper” technique to pitch a baseball. Each MLB pitcher has their own way of pitching, so it would be pointless to try and change their way. Pitchers need to learn the proper mechanics from an early age in order for this prevention model to work.

The prevention recommendation starts with proper education. First, the parents and coaches should watch for signs of fatigue (i.e. decreased ball velocity, decreased accuracy, upright trunk during pitching, elbow drop, or if the pitcher looks generally fatigued). Knowing that pitchers throwing mechanics become altered with increased fatigue, pitchers should be pulled from the game once fatigue begins to set in. The coaches should also be providing feedback on proper pitching mechanics. The coach should have a general knowledge on the six phases of the pitching cycle and how to properly coach their athlete through each step. If proper coaching begins at an early age, the potential that the pitcher uses proper pitching mechanics to reduce stress on the elbow and shoulder is high. Stressing the proper mechanics as early as possible is key. Pitch count should also be monitored for the safety and care of the pitcher. Organizations should consider limiting pitchers of the AHS group to 75 pitches per outing and no more than 100 per day. The type of pitch should also be taken into account. Pitchers of the AHS group should not be throwing curveballs or sliders and mainly focus on fastball and changeup command. The coach should be instructing their pitchers on how to throw low to batters to force double plays and ground balls instead of trying to strike every batter
out. The coach or health care provider needs to take into account the maturing body of the pitcher and understand that their body can’t take the normal stresses of an MLB pitcher.

The Thrower’s Ten Program (TTP) is an exercise program designed by the researchers at the Andrews Institute to specifically target the muscles used for throwing during rehabilitation. The program has also shown to be a great tool for prevention of injury and even an improvement in overall performance in a 6-week time period. The TTP is an organized and concise program that needs to be implemented into every warm-up for adolescent baseball players, but especially players who are pitchers. The exercises included in the TTP include the following: diagonal pattern (D2) extension/flexion, external rotation/internal rotation at 0° with tubing, shoulder abduction at 90° with tubing, scaption with external rotation, sidelying external rotation, prone flies, prone rows, triceps press-ups, push-ups, elbow flexion (bicep curls), triceps extensions, wrist curls, wrist extensions, and an increment of pronation/supination exercises. The program is a great tool for improving the musculature that is involved in throwing (biceps, rotator cuff, triceps, flexor pronator mass, supinator, deltoid, etc.), but these specific muscles are not the only ones that need to be exercised. Previously mentioned in the paper there was a discussion about the role the kinetic chain plays on throwing. The aforementioned variables of GIRD, hip rotation deficits, and overall kinetic chain imbalances are examples of why a prevention program should include exercises involving the kinetic chain. In addition to the TTP exercises focusing on strengthening the kinetic chain should be incorporated into a prevention exercise plan. Appendix B will show a designed addition to the TTP that coaches could implement into their warmups for their future pitchers.
Conclusion

The art of pitching is a medical anomaly if one thinks about it. The fact that a pitcher can generate enough force to rupture one of the main ligaments in the elbow with every pitch is eye opening. The process of the throwing cycle is something that needs to be implemented across the entire sport. Overall, AHS pitchers are different anatomically, biomechanically, and mentally than MLB pitchers. Knowing this there should specific guidelines regarding specific strength & flexibility exercises, type of pitch thrown, how many pitches are thrown in one outing, and how to properly perform the throwing cycle. With these tools there won’t be a stoppage of throwing injuries, but the amount of injuries prevented will be substantial.
References


5. NFSHSA. *2015-16 High School Athletics Participation Survey*.; 2015.


## Appendix A

![Figure 1: Phases of the Pitching Motion](image)

<table>
<thead>
<tr>
<th>Time point</th>
<th>Stride foot contact</th>
<th>Maximal shoulder external rotation</th>
<th>Ball release</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase</strong></td>
<td>Arm cocking</td>
<td>Acceleration</td>
<td>Deceleration</td>
</tr>
<tr>
<td>Kinematics</td>
<td>Rapid upper torso rotation causes the arm to lag behind the upper torso and force the throwing shoulder into horizontal abduction</td>
<td>Forearm lag behind the arm and force the shoulder into external rotation (170-190°)</td>
<td>Rapid shoulder internal rotation (6000-7000°) and elbow extension</td>
</tr>
<tr>
<td>Kinetics*</td>
<td>Shoulder anterior force</td>
<td>Shoulder horizontal abduction moment</td>
<td>Elbow valgus moment</td>
</tr>
<tr>
<td>Tissue (stress)</td>
<td>Anterior capsule/ligament (tension)</td>
<td>Posterior rotator cuff and labrum (compression)</td>
<td>Superior labrum (tension/shear); Posterior rotator cuff and labrum (compression)</td>
</tr>
<tr>
<td>Injury</td>
<td>Anterior instability</td>
<td>Posterior impingement</td>
<td>SLAP lesion, posterior and subacromial impingement, growth plate injury</td>
</tr>
</tbody>
</table>

## Figure 2: Types of Injuries with Throwing
Figure 3: Various Pitching Grips
Appendix B

Preventative Exercise Program

This program can be used in addition with the Thrower’s Ten Program provided by the Andrews Institute

**Stage 1: Kinetic Chain Control**

These specific exercises are used to target kinetic chain musculature to prevent future weakness and in result impaired throwing mechanics. All exercises can be performed starting on a stable surface progressing to an unstable surface for increased difficulty and increased proprioceptive input. All exercises should be performed at 3 sets of 15 repetitions for endurance. All stretching exercises should be performed for 2 sets of 30 second holds.

**Single Leg Squat**

Start with normal single leg squats. Progress to a corkscrew twist at the end of the squat once normal single leg squats become easy.

**Modification:** Double leg
**Lateral Lunges**

Start with a normal lateral lunge. Progress to ending with a 5 second single leg balance once lateral lunge becomes too easy. **Modification:** Forward Lunges

**Hamstring Flexibility**

Hamstring Flexibility is essential for kinetic chain balance. Progressing to a partner should be incorporated once sitting becomes easy. The partner needs to push the foot down to emphasize calf stretching as well.
Hip Internal and External Rotation Stretching

7a & 7b: Hip internal rotator stretches
7c & 7d: Hip external rotator stretches

Stage 2: Shoulder / Scapular Focus

The following exercises will focus on different shoulder exercises that the Thrower’s Ten Program does not. All exercises can be modified with increased weight to add difficulty to the exercise. Each exercise should be performed at 3 sets of 15 repetitions for endurance. All stretches should be performed at 2 sets of 30 second holds.

Scapular Wall Slides
**I’s Y’s T’s**

Make sure patient/athlete isn’t using their upper traps to move the arms up, rather making sure they use the scapular muscles to elevate the scapula.

Progress to a Theraband when normal slides become easy.

Start on Table and progress to stability ball once exercises become easy.

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**Sleeper Stretch**

The Sleeper stretch helps improve GIRD. Do this stretch every day to prevent GIRD.

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**Overhead Stretch**

The overhead stretch will stretch the rotator cuff after performing the Thrower’s Ten Program.
**Crossover Stretch**

The crossover stretch allows the athlete to stretch the posterior capsule effectively.

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**Stage 3: Core Stabilization**

These exercises will focus on core strength and stabilization as the core is a key stabilizer in the pitching cycle. Each exercise can be modified on an unstable surface for added difficulty and increased proprioceptive ability. Each exercise will be performed at 3 sets of 20 repetitions.
**Bird Dogs**

Bird Dogs

Once normal bird dogs become easy the athlete should progress to the bird dog crunch.

**Planks**

Planks

Once the front planks become easy the athlete should progress to side planks. Make sure to perform side planks on both sides.

**Lumberjacks**

Lumberjacks

A complete core exercise. This focuses on the entire core to complete a great exercise. To make this exercise more difficult you can have the athlete stand on an uneven surface or increase weight.