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Glenohumeral Internal Rotation Deficit and Ulnar Collateral Ligament Injury in Baseball Pitchers

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This starred paper submitted by Cristina C. Nistler in partial fulfillment of the requirements for the Degree of Master of Science at St. Cloud State University is hereby approved by the final evaluation committee.

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GLENOHUMERAL INTERNAL ROTATION DEFICIT AND ULNAR

COLLATERAL LIGAMENT INJURY IN BASEBALL PITCHERS

by

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INTRODUCTION

Extensive research (9, 5, 25, 16, 40, 30, 31) has been done on injuries to the throwing arm of baseball pitchers. Especially common are injuries to the ulnar collateral ligament (UCL) (5), which are characterized by pain with throwing, decreased pitching performance, and a loss of strength (29). It has become accepted that injuries to the UCL most often occur due to accumulated microtrauma caused by pitchers throwing a high number of pitches on a regular basis over a long career (35). When this microtrauma is accumulated faster then the body is able to heal itself, more serious injury can occur. Microtrauma also affects the strength of the ligament so that a "seemingly trivial amount of stress" may deliver the final blow that ruptures a ligament (16). However, not every pitcher who throws for many years will injure the UCL–there are other predisposing conditions that contribute to lesions of this ligament. Additionally, in recent years, young pitchers have been sustaining UCL injuries at a rate that would suggest overuse is not the only culprit (25). The predisposing conditions suggested in the literature are: improper pitching mechanics, fatigue and overuse, and/or inflexibility.

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According to Chad Starkey's *Evaluation of Orthopedic and Athletic Injuries*, a deficit in the amount of internal rotation that can be achieved at the glenohumeral joint is a predisposing condition for UCL pathology.

> Over time, throwers lose shoulder internal rotation and gain excessive amounts of external rotation. A tremendous amount of valgus force is placed on the medial elbow during the cocking and acceleration phases of overhead pitching. Inclusion of range of motion exercises for increasing internal rotation of the shoulder is often needed to balance the stresses at the medial elbow" (35, p. 511)

Previous studies (3, 37) have found a difference in the total range of shoulder external and internal rotation in the dominant and non dominant arms of baseball pitchers. Pitchers typically present with increased external rotation in their dominant arm paired with decreased internal rotation. One researcher believes that decreased flexibility at the shoulder joint may lead to improper throwing mechanics (9).

The concept of a problem at one joint affecting the joint below is not new. In an activity such as pitching, several body segments are interrelated. For instance, the moments of maximum elbow varus torque and maximum shoulder internal rotation torque occur at the same time (9). This means that a great amount of stress is occurring at the medial elbow at the same time that the shoulder is maximally externally rotated and the arm is beginning to accelerate.

The intent of this paper is to review the current literature about shoulder motion as it relates to baseball pitchers and elbow injuries in order to discern whether a relationship may exist. To provide the appropriate background information for a future study addressing such a relationship, a review of elbow anatomy, shoulder anatomy and range of motion (ROM), the mechanics of an overhand baseball pitch,

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and the mechanism of UCL injury is required. This author hopes to determine whether the current literature supports a relationship between a loss of internal rotation at the shoulder called Glenohumeral Internal Rotation Deficit (GIRD) and injury to the UCL and what implications such a relationship may have.

Definitions

For the purpose of this review, definitions for the following terms are provided:

Compression–A force that can be thought of as a "pressing" or "squeezing" directed axially through a body.

Countertorque–A rotational force that opposes the direction of a given torque.

Newton Meters (Nm)–A metric system unit used to measure power and torque.

Shear–A force which is directed parallel to the surface of a body.

Tension–A pulling or stretching force directed axially through a body.

Torque–A force, applied some distance from the center of an object, which tends to rotate or turn the object. Torque is the product of a force (F) and the perpendicular distance (d) from the force's line of action to the axis of rotation. Units of torque are a force multiplied by a distance; either Nm or foot-pounds (ft-lb).

Valgus–Angulation away and outward from the midline of the body.

Valgus Torque–The torque needed to prevent rotation in a varus direction.

Varus–Angulation inward or towards the midline of the body.

Varus Torque–The torque needed to prevent rotation in a valgus direction.

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Review of Literature

The intent of this paper is to review the current literature regarding Glenohumeral Internal Rotation Deficit and injury to the Ulnar Collateral Ligament. This review will cover the following topics: elbow anatomy, shoulder anatomy and range of motion, proper and improper pitching mechanics, and the mechanism of UCL injury.

Chapter II

THE PITCHER'S ELBOW AND SHOULDER

Elbow Anatomy

The humerus, radius, and ulna are the bones at the elbow that create three distinct articulation sites. They are the radiohumeral joint, the radioulnar joint, and the humeroulnar joint. The radiohumeral joint is the articulation between the distal humerus and the proximal radius. This joint receives the compressive aspect of valgus forces. Valgus force is a force that causes an angulation of the lower arm outward or away from the body. In the case of the elbow, it is the distal part of the arm that angles outward.

The radioulnar joint is not reported to contribute to elbow stability, but its joint actions are pronation and supination. The humeroulnar joint comprises the medial aspect of the elbow and is the site of articulation between the distal humerus and proximal ulna.

Medially, the elbow is well supported by the ulnar collateral ligament (UCL). This ligament originates on the medial epicondyle of the humerus and is made up of two distinct and functional bands, the anterior and posterior oblique. There is a third band known as the transverse bundle, which does not contribute to the stability of the joint (15). The anterior oblique band inserts on the medial coronoid of the ulna. The

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posterior oblique inserts on the medial aspect of the posterior olecranon. Of these two bands, the anterior oblique has been found to provide the most support. The posterior oblique has not been found to contribute greatly to the valgus stability of the elbow unless the anterior band has ruptured completely (5). The UCL is positioned posterior to the elbow's rotational axis. This causes the ligament's tension to vary with changing degrees of flexion (15).

In addition to the anterior oblique band and the bony configuration, medial support is provided by the flexor-pronator muscle group which also originates on the medial humeral epicondyle. This muscle group includes the flexor carpi ulnaris, flexor carpi radialis, flexor digitorum superficialis, palmaris longus (if present), and the pronator teres (5). Of these, the flexor carpi ulnaris has been found to contribute the most resistance to valgus torque. This was demonstrated by a study which measured the valgus angle in a UCL deficient elbow while separately contracting the muscles of the flexor-pronator group (27). Together, the UCL and flexor-pronator group resist the large tensile forces occurring at the elbow during the pitching motion while the radial head plays only a small role in valgus resistance.

Laterally the elbow is supported by the anconeus muscle and a radial collateral ligament (RCL). The stability provided by the RCL is fairly consistent because it passes through the elbow's rotational axis (15). The radial head is surrounded by the annular ligament which allows the radius to rotate about its longitudinal axis (33). The nerves supplying the elbow are the median, radial, ulnar, and musculocutaneous.

In extension, the elbow has a slight, naturally occurring valgus angle that is called the "carrying angle." In a healthy non-athlete the carrying angle is approximately 10 to 15 degrees. It has been reported that baseball pitchers often develop an increased valgus angle (5, 15, 40), however, it is not clearly stated in any of these papers to what degree it increases.

A healthy elbow should range from 0 degrees of full extension up to about 150 degrees of flexion. Pronation and supination are typically 90 degrees in each direction, or an arc of motion of 180 degrees (35).

Shoulder Anatomy

The shoulder joint is actually composed of four articulation sites. They are the sternoclavicular, acromioclavicular, glenohumeral, and scapulothoracic joints. This review is most concerned with the glenohumeral joint which is the site of articulation between the head of the humerus and the glenoid fossa of the scapula. The glenohumeral joint is one of the most mobile joints in the human body. This great range of motion is due largely to the fact that the glenoid fossa is about twice the size of the humeral head. Additionally, the relative laxity of the joint capsule prevents it from providing much stability to the joint (2).

The shoulder joint is vital in many sports and activities of daily living. Thus the body must strike a balance between mobility and stability for optimal function. The primary static stabilizers of the glenohumeral joint are: the articulating bony surfaces, the joint capsule/glenoid labrum and a negative intra-articular pressure. Hurschler et al. (14) describes the presence of this negative intra-articular pressure as result of limited joint volume. When the humerus is distracted, the glenohumeral joint will slightly increase the joint volume, producing a slight negative pressure. This effect is lost if the glenohumeral joint capsule is disrupted. When the researchers purposefully vented the capsule, it resulted in a 2.8mm increase in superior translation (14). The labrum is a ring of fibrocartilage which surrounds the glenoid fossa and slightly increases its volume. The superior portion of the labrum is where the short head of the biceps tendon attaches. The inferior labrum is secured by the inferior glenohumeral ligament. This ligament has both an anterior and posterior band (19). These ligaments are really just thickened areas of the joint capsule. In addition to the superior and inferior, there is a middle glenohumeral ligament. These areas are more tense in the extreme ranges of motion, serving as the "final checkrein to glenohumeral stability" (19, p. 191). For instance, the inferior glenohumeral ligament (IGL) is an important stabilizer in the extreme ranges of motion found in the act of pitching a baseball because it tightens when the humerus is abducted and externally rotated. In fact, it is the primary stabilizer in 90 degrees of abduction, which is how far the humerus is abducted in the beginning phases of the pitching motion.

The dynamic joint stabilizers are the rotator cuff musculature and the scapular rotators. The rotator cuff muscles are the supraspinatus, infraspinatus, teres minor, and subscapularis. During normal shoulder function, the infraspinatus is the prime external rotator of the humerus, providing about 90% of external rotation power (2). However, during the deceleration phase of the pitching motion, the rotator cuff muscles provide a shear force which plays an important role (1). These muscles acting in the direction of external rotation serves to slow the rapidly internally rotating arm.

Muscles acting on the scapular include the levator scapulae, rhomboids, trapezius, pectoralis minor and serratus anterior. During a baseball pitch these scapular muscles work to retract, protract and then rotate the scapula to optimize position of the glenoid.

The deltoid muscle is not included in either of these groups, but it is a prime mover of the humerus. The deltoid has anterior, middle, and posterior portions, which are named based on the location of their insertion on the acromion of the scapula. The middle portion is a humeral abductor and is active in the early cocking phase of pitching a baseball (2).

Open Kinetic Chain Activities

Activities performed by the extremities of the body (walking, standing, and throwing) are often described as being open or closed kinetic chain movements (28). In either type of movement, energy from one segment of the body is transferred through successive segments, gaining momentum until reaching the final segment. A closed chain movement is one in which the distal portion of the extremity is stationary. For example, when a person is walking, the foot that is stationary or weight-bearing is said to be in a closed chain position. On the other hand, the swing leg would be considered to be in an open chain position. When pitching a baseball, the hand is the most distal portion and is freely moving in space. Thus, pitching a baseball is an upper extremity *open chain* activity. In open chain activities, the effect that one portion of the chain has on another portion is large. In the pitching motion, energy generation is begun in the pitcher's legs. The kinetic chain also consists of the hips, trunk, all segments of the arm, and finally this energy is transferred to the ball (28).

The pitcher may alter this chain when fatigued or when any one or more of the segments of the chain are not functioning properly. This malfunction increases the likelihood that one or more of the segments of the chain will become injured. An example of the relationship between segments of the kinetic chain can be seen in the sequence of events begun when a pitcher aligns his feet with the pitching rubber. At this time, the hips should be pointing towards home plate (11). If they are not, the lead leg will not land pointed forward. If the leg lands too far away from the pitching rubber, the pitcher's trunk will begin rotating towards the batter too early, while the throwing arm lags behind the rest of the body rotation. This causes increased stress on the anterior shoulder capsule and an increased valgus force on the elbow. One segment of the chain being misaligned will lead to "abnormal forces" on the subsequent segments (28).

Pitching Mechanics

When discussing any type of athletic injury, it is vital to look at the proper mechanics of the movement. An understanding of how the movement should occur allows athletic trainers, physical therapists, and other clinicians to recognize the possible mechanism of injury experienced by the athlete. For this reason, addressing how pitching mechanics and common mechanical mistakes could contribute to GIRD and UCL injury would be important.

The pitching motion can be divided into anywhere from three to six phases (37). For the purpose of this paper, a four phase description will be used. These four phases are: the windup, arm cocking, arm acceleration, and follow through.

Windup is the phase in which the pitcher's throwing hand leaves the glove and begins to cock the arm to throw (37). Important movements during this phase are: lifting the lead leg, bending the stance leg, and flexing the elbow (11). As the pitcher's hands separate he can begin the arm cocking phase (5). The arm cocking phase starts when the throwing hand leaves the glove and ends when the pitcher's front leg strides forward and makes contact with the ground. To maximize horizontal extension, the rhomboids and middle fibers of the trapezius retract the scapula. This also adds some additional tension on muscles that horizontally flex and internally rotate the humerus. This eccentric loading places more tension on the pectoralis major and minor, anterior deltoid, and serratus anterior preparing them for a more powerful concentric action. Fleisig et al. reported the serratus anterior and pectoralis minor had the most activity, working synergistically with the rhomboids and middle trapezius (11).

To complete the arm cocking phase, maxER is accomplished by rotating the trunk. As the abdominal obliques actively shorten, foot planting of the lead leg initiates truck rotation. As the trunk rotates, the arm and shoulder lag behind. When the shoulder begins to move forward, the humerus continues to externally rotate adding even greater tension to the pectoralis minor, serratus anterior, anterior deltoid and the IR muscles of the humerus. Once maxER is achieved, the third phase, arm acceleration, begins.

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During arm acceleration the scapular muscles are actively protracting and stabilizing the scapula to reposition the humeral head to optimize humeral rotation. Fleisig et al. showed significant EMG activity of the rotator cuff during this phase. The IR muscles, specifically the subscapularis, but also the latissimus dorsi and pectoralis major, are now active concentrically to propel the arm and ball forward. As expected, Fleisig et al. also showed high activity of rectus abdominus and abdominal obliques at this time (11).

Because the humerus is so quickly internally rotating, the forearm has a tendency to lag behind, creating an increased valgus stress at the elbow (11). During acceleration, the pathomechanics mentioned in windup and cocking can carry over and continue to cause problems. If the humerus had been excessively abducted and externally rotated, the compensatory motion during acceleration can be described as "whipping" the arm forward (28). Again, this increases the valgus stress on the medial elbow because the humerus tends to lead the motion and the forearm arm lags behind. Arm acceleration ends when the ball is released from the hand.

In follow-through, the arm decelerates and continues across the body. Trunk flexion aids in deceleration by increasing the time and distance to dissipate force. The rotator cuff muscles are under the greatest strain during this phase. Their role is to assist in resisting distraction of the humerus from the glenoid and to decelerate IR. Key muscles resisting IR include the posterior deltoid, infraspinatus, and teres minor, while the lower trapezius, rhomboids, pectoralis minor and serratus anterior stabilize the scapula. The brachialis, biceps brachii and supinator muscles are eccentrically active to control the last few degrees of elbow extension and pronation of the forearm, respectively (11). The follow-through phase ends when all motion has ceased (5).

Ball velocity is one of the most common markers of success for a baseball pitcher. In order to increase ball velocity, the pitcher needs to achieve the most IR velocity possible during the acceleration phase. This is achieved by attaining the greatest TROM possible via greater external rotation. This allows the arm to accelerate through a greater arc of motion (4). However, it has been shown that this ER combined with the large degrees of abduction and horizontal abduction increase valgus stress at the elbow right when the arm begins IR from the cocked position (2). The varus torque necessary to counteract this valgus stress will be provided by the UCL, flexor-pronator muscle group, anconeus muscle, and the UCL. The greatest amount of valgus stress occurs at the end point of arm cocking, when the humerus is in maxER (5). The average amount of valgus force at the elbow has been estimated to be around 35Nm (27). A varus torque is being produced at this time to resist the valgus angulation of the forearm. This torque ranges from 64Nm when the pitcher strides with his lead foot to a peak value of approximately 120Nm just before maxER is reached and the medial force causing these torques has been measured around 300Nm (30). At this point, the arm could be externally rotated as much as 180 degrees (11). The extreme ER that appears problematic in the early cocking phase is now, as mentioned above, necessary in order to increase ball velocity because it allows the arm to accelerate through a greater range of motion (5). Studies have shown a positive correlation between the amount of external rotation at the end of arm cocking and ball velocity at the time of release (37).

It has been suggested that experienced pitchers attain a "proprioceptive sense" of where the arm needs to be in order to attain the optimal amount of ER and subsequently optimal ball velocity. The authors refer to this as the ER "set point" (4). The late cocking phase is a time during which the pitcher can make a mistake affecting both glenohumeral stability and valgus stress on the elbow. The pitcher's act of turning his body towards home plate is termed "opening up" to the batter. If a pitcher opens up too soon, the humerus is too far abducted and externally rotated. This puts added stress on the anterior capsule by the humeral head. This same mistake increases valgus load at the elbow because the forearm lags behind the torso and humerus thus increasing tension on the medial elbow (28).

Anytime a portion of the pitching motion is performed in such a way that increases valgus stress on the elbow, the structures of the medial elbow must create a greater torque to compensate for the increased load. Another component to the valgus torque is the force produced by the ball. This force can be estimated by knowing the mass of the ball and the rate at which the pitcher's hand is accelerating.

A previous study measured just how much of an increase in medial elbow force was related to increased arm ER and discovered a relationship of 0.7N of force per 1° of rotation (37). A study by Werner, et al was able to determine several kinematic parameters of pitching that contribute to elbow valgus stress. In fact, over 97% of the variance in valgus stress can be explained through: shoulder abduction angle at stride foot contact, max shoulder horizontal adduction angular velocity, elbow angle at instant of peak valgus torque, and max shoulder ER torque (36). To clarify the significance of the elbow angle at peak valgus torque; it was found that greater extension was associated with greater valgus stress (36).

Another study was done which compared both kinematic and kinetic variables among youth, high school, college, and professional pitchers. The kinetic variables included forces and torques at the elbow and shoulder. The kinematic variables were angle measurements and velocities at the elbow and shoulder. It was found that kinetics did not vary significantly across levels. However, there was a significant difference in the kinematics. Greater forces were produced by pitchers at the higher levels. The authors felt that these data suggested similarities in the technique and mechanics of these pitchers, with the different forces caused by the greater mass and strength of the older pitchers (10). These data may also suggest a continued need for attention to variables such as fatigue and pitch count as pitchers age, because with increased strength, their body begins to naturally undergo greater stress.

Dun et al. looked at just kinematic data in a sample of professional baseball pitchers ranging in age from 18.8-34.4 (7). They found a significant difference with age in 6of the 14 position variables measured. These variables were: stride length, lead foot position, pelvis orientation, upper trunk orientation, shoulder ER, lead knee flexion, elbow flexion, spine axial rotation, maximum shoulder ER, maximum elbow flexion, maximum shoulder IR velocity, lead knee flexion, trunk forward tilt from vertical, trunk sideways tilt from vertical, and lead hip flexion. The results of this study provide valuable information for clinicians working with baseball pitchers on injury prevention and rehabilitation. When assessing an injury and creating a plan of action, the pitcher's age and mechanics should be considered.

The authors of the study on age and kinematics felt that age was the greatest contributing factor because their subjects did not range widely in height, weight, or throwing velocity. They also suggested the possibility that older pitchers alter their mechanics to compensate for the loss of motion as they age. This possibility exists because the older group showed less maxER and less forward trunk tilt at ball release than the younger pitchers. These motions are usually associated with greater ball velocity, but this study did not find decreased velocity in these older pitchers. This suggests that these pitchers found some other way to compensate for the decrease in these motions and to maintain velocities, but the authors recommend further work is necessary to determine what these compensations might be (7).

Glenohumeral Internal Rotation Deficit

Glenohumeral Internal Rotation Deficit (GIRD) is considered a loss of internal rotation relative to the total range of motion available at the shoulder. An otherwise healthy non-athlete's shoulder typically presents with a total rotational range of 180 degrees. These 180 degrees are comprised of approximately 90 degrees of each internal and external rotation. Baseball pitchers tend to present with a shifted range of motion. This shift involves increased external rotation (ER) and decreased internal rotation (IR), but the total range of motion (TROM) is still approximately 180 degrees (20). More specifically, a difference between shoulders of more than 25 degrees of IR or one arm having less than 10% of the opposite shoulder's TROM would indicate GIRD (34). A study of 124 baseball pitchers ranging from high school to college to professional indicated that the average GIRD was 53 degrees ranging from 25 to 80 degrees (4).

Two types of GIRD have been described. The first occurs when the increased ER is proportional to the decrease in IR. This would be considered a physiological adaptation. This type would be an expected adaptation to the repeated extreme stress placed on a pitcher's shoulder. It has been documented that in order to properly perform the pitching motion, a thrower needs the increased ER (3, 37). It can be expected that a pitcher will gain increased ER, and it is not uncommon for a pitcher to present with less IR than would be seen in a non-throwing shoulder. The concurrent increase and decrease can still be considered healthy as long as the TROM remains near 180 degrees. It appears as though diminished IR balances the TROM and helps to maintain the integrity of the joint. A large increase in ER without a loss of IR would result in a TROM of more than 180 degrees and could result in an instability that would place the pitcher at risk for injuries such as joint subluxation. The statement has even been made that it would be considered pathological for a pitcher to not display increased ER and decreased IR (3). However, it would also be considered pathological for an excessive loss of IR greater than the gained ER leading to a TROM less than 180 degrees (4). This would be second type of GIRD, occurring when the loss of IR is greater than the gain in ER. This would be due to pathological soft tissue changes (20).

Unfortunately, not all literature on GIRD is in complete agreement. There is disagreement regarding what causes the loss in IR, whether or not the loss occurs after an increase ER, and whether it is necessary to the pitching motion or pathological.

Although the specific cause of GIRD is up for debate, the general consensus seems to be that it is indeed an adaptation to repetitive microtrauma (6, 20, 34, 4, 33, 26, 21). As mentioned in the Pitching Mechanics section, excessively abducting and externally rotating the humerus stresses the anterior capsule of the shoulder. Repetition of this position would loosen the anterior capsule and could account for an increased amount of passive external rotation upon clinical evaluation of a pitcher's ROM. Some of the studies regarding GIRD acknowledge that the cause may not be the same for every single pitcher. Still others claim that the decreased IR and increased ER could be attributed to multiple different events. Burkhart et al describe microtrauma to the anterior capsule as being responsible for the increased ER while adaptive tightening of the posterior capsule causes decreased IR. Because there are distractive forces of great magnitude applied to the joint, the posteroinferior capsule develops an adaptive contracture in an attempt to keep the humerus attached to the body (4). This same scenario is also reported in little league pitchers (23). A third explanation for the changed ROM is that the humerus adaptively changes its position so that the arm may achieve a greater degree of ER. This adaptive change to the humerus would be caused by the repetitive external rotation torque on the humeral head during the cocking and acceleration phases. This phenomenon is called humeral retroversion and is an anterior angulation of the humeral head (34). In order for the head of the humerus to remain in a more anterior position where the shaft of the bone is more posterior, or "retroverted," ligament and capsular structure must be altered. Retroversion is assessed by measuring the angle created by the axis of the anatomical neck and the axis of the epicondyles (26). For a pitcher, this may be desirable; however, it may also put them at greater risk of an anterior dislocation.

The literature is in better agreement over the issue of whether GIRD is always secondary to an increase in ER. The majority of articles on GIRD report that the increased ER occurs before the loss of IR (3, 6, 20, 4). A study done on a group of 85 professional pitchers even found that ER of the dominant arm can increase without a subsequent loss of IR (20). Just two articles report an opposing trend. Spigelman claims "that GIRD occurs before any other motion adaptation and is sometimes followed by associated gains in ER" (p. 32) and Nakamizo et al found GIRD in little league pitchers to "occur prior to development of the increased external rotation…" (p. 795).

The third factor on which research has yet to come to a conclusion is whether GIRD is a necessary adaptation or a pathological condition. In fact, the two camps are fairly evenly divided. Essentially it would appear that whether GIRD is considered to be helpful or harmful to pitching depends on with which of the two types of GIRD a pitcher presents. As mentioned previously, experienced pitchers become aware of the "set point" required amount of shoulder ER necessary to achieve their optimal ball velocity. Burkhart et al. explain that maximal ball velocity is effectively achieved through high degrees of ER in the late cocking phase of the pitch (4). Other authors agree that the increased ER can place the IR musculature in a more effective position to begin forward acceleration of the pitching arm (3, 20, 26). The negative consequences of the shifted ROM include anterior capsular instability and other conditions such as superior labrum anterior-posterior (SLAP) lesions (20, 34, 4, 23, 21). Although these sources mention that GIRD may contribute to shoulder pathologies, this author has not found any other source which confirms Starkey's claim that, "Inclusion of range of motion exercises for increasing internal rotation of the shoulder is often needed to balance the stresses at the medial elbow" (p. 511).

Recent studies (23, 21) have investigated whether GIRD is also present in the little league pitcher. Nakamizo et al. found that 10 of the 25 young pitchers studied had decreased internal rotation in their dominant arms. However, ER was not significantly different. The conclusion drawn by the researchers was that the lack of IR can occur earlier than the increase in ER which is commonly seen in adult pitchers (21). They hypothesized that, similar to adult throwers, GIRD in the young athlete is an effect of a tightened posterior capsule. This would explain why the young throwers presented with decreased IR without an increase in ER (23). Meister et al. investigated whether measured amounts of IR and ER varied with the age of the little league athlete. The authors found significant differences in both IR and ER when comparing 8-year-old and 16-year-old athletes (21). Their data showed that the 16-year-old throwers had less of both IR and ER. This did not support their hypothesis that ER would increase with age, leading to the eventual shift in TROM seen in adult throwers. However this does agree with Dun et al. on the relationship between age and kinematics in professional adult pitchers, which found older pitchers to have less rotational motion (7). The study on the adolescent pitchers attributed their findings to the natural anteversion that occurs during skeletal maturation. Anteversion would be the opposite of the previously described humeral retroversion. The head of the humerus would be positioned more posteriorly while the shaft of the bone is more forward, or "anteverted." However, the pitching motion may adaptively slow natural anteversion in a high level pitcher. If GIRD is indeed a condition that contributes to injury, it would be important to note that it can begin in young athletes. Knowing this prevention could begin at an early age (21).

<u>Ulnar Collateral Ligament Injury</u>

It has become accepted that injuries to the UCL most often occur due to accumulated microtrauma caused by throwing a high number of pitches on a regular basis over a long career (35). Microtrauma also affects the strength of the ligament so that a "seemingly trivial amount of stress" may deliver the final blow that ruptures a ligament (16). Microtrauma can be compounded by improper pitching mechanics, fatigue and overuse, and decreased flexibility. Any one of these factors can contribute to increased elbow valgus and thus increased stress on the UCL. When these problems continue, the UCL accumulates microtrauma leading to possible rupture (30).

Proper pitch mechanics are especially important during the late cocking phase of the pitch. Fleisig et al. indicated the end of the arm cocking phase as a "critical instant" in the throwing motion because it is the moment at which the UCL and flexor-pronator muscles must create the most varus torque. It is necessary for these structures to create this torque in order to counteract valgus torque occurring at the elbow at that moment. If the UCL and flexor-pronators are unable to produce the necessary amount of varus torque, the result would be medial tension, lateral compression or impingement injuries. Such injuries would include muscles tears, avulsion fractures, UCL spurs or ruptures, and ulnar nerve damage (9).

Some degree of medial tension and lateral compression will always occur, and the repetition of these forces leads to microtrauma. Microtrauma to the ligament can accumulate and contribute to the injury of the UCL (35). When microtrauma accumulates at a rate faster than that at which the body can heal itself, overuse injuries occur (16).

At the end of the arm cocking phase the elbow is in approximately 85-95 degrees of flexion. It is worth noting that less flexion at the elbow increases the amount of valgus instability. Sectioning of the anterior oblique portion of the UCL has shown that instability begins at approximately 30 degrees of elbow flexion, and maximum valgus instability happens around 70 degrees of flexion. The ligament is most taut at around 90 degrees of flexion (15). A greater angle of elbow flexion at the end of the arm cocking phase has been associated with lower amounts of maximum elbow valgus force (37).

At the end point of arm cocking, when the elbow is flexed between 85-95 degrees, the UCL is providing 54% of the varus torque necessary to counteract the valgus forces. This varus torque has been calculated at 64Nm. In cadaver studies, the UCL has been shown to produce a maximum varus torque of 29-41 Nm before failing

(9). The bony anatomy at this time is providing 33% of the varus torque. The remaining 10% is attributed to the joint capsule (8).

Fatigue can indirectly lead to UCL injury by affecting the pitcher's mechanics. If a pitcher continues to throw after his muscles begin to fatigue, he may be unable to maintain proper mechanics. For example, a 2001 study looked at the effect that fatigue had on kinetic and kinematic parameters in professional baseball players. One of their key findings was that ER in the late cocking phase decreased after pitchers threw for 5-6 innings. Other findings were that the distraction forces and torques on the shoulder and elbow decrease over the course of a game, perhaps owing to the decreased velocity with which the pitcher is throwing in the later innings (22).

It has been stated in the current literature (8, 9, 30) that decreased flexibility can adversely affect pitching mechanics and thus lead to UCL injury. Except for Starkey (35), these sources do not say which structures must retain ROM to prevent injury. The issues of flexibility in the internal and external rotator musculature were discussed in the section regarding GIRD.

UCL injuries are primarily seen in the skeletally mature athletes at the college or professional levels. It is uncommon for a young, skeletally immature athlete to have a purely isolated UCL injury. The very same mechanisms that contribute to UCL injury in the adult pitcher (repetitive motions and large forces) can cause medial epicondyle fragmentation, UCL strain, flexor muscle strains and traction ulnar neuritis in the pediatric athlete (12).

Bony growth in the arms is not complete until 19-25 years of age. This causes the pediatric pitcher's skeleton to react differently to the same pitching stresses. A force that may rupture an adult pitcher's UCL may instead pull the medial epicondyle from the humerus because the bone has not completely fused at that location. Physeal injuries are more common to children than ligamentous injuries. After the athlete's medial epicondyle has fused, UCL injury becomes more common. So, due to the span of years between which portions of the skeleton mature, children are more susceptible to different injuries at different ages (18).

The aforementioned elbow pathologies typical of the skeletally immature pitcher are often grouped together under the term "Little League Elbow." In addition to those problems already mentioned, little league pitchers may present with altered growth of the medial epicondyle, osteochondritis of the capitellum or radial head (due to compression on the radial side), or hypertrophy of the ulna.

Chapter III

GLENOHUMERAL INTERNAL ROTATION DEFICIT AND UCL INJURY: THE RELATIONSHIP BETWEEN GIRD AND UCL INJURY

It is evident that more work needs to be done in order to determine whether an actual relationship of any kind exists between GIRD and UCL injury. As was discussed in the section of this paper specifically addressing GIRD, a sample of 124 baseball pitchers showed an average GIRD of 53 degrees (4). What this study did not mention is whether these pitchers still had a healthy TROM or what portion of them ever sustained an elbow injury. This author believes that future research should investigate shoulder ROM of a large sample of pitchers as well as incidence of UCL injury in that same group.

Up to this point in time, any relationship between GIRD and UCL injury must be inferred or contradicted by what is known about the two conditions. It may also be beneficial to measure the other motions performed by the shoulder joints. The arm cocking and acceleration phases are not pure moments of ER and IR. The other shoulder motions being performed during these phases include abduction during cocking and horizontal flexion in acceleration. For this reason, it is difficult to say that increased elbow valgus force during acceleration is caused solely by GIRD.

Despite the contribution of other motions, shoulder rotational motion remains an important part of the deceleration and follow through phases of pitching. Lintner et al. refer to unpublished data from 2002 describing a "rotational unity rule" (20). This rule states that a pitcher will maintain normal throwing mechanics *"if the internal rotation deficit is less than or equal to the external rotational gain."* As mentioned previously, this is the type of GIRD that research shows is common in pitchers.

A study looking at the range of motion in major league pitchers found that even with diminished IR, the pitchers still demonstrated more that sufficient IR for follow through. These throwers presented with about 83-86 degrees of IR (3). Thus it would seem that if GIRD does indeed have any affect on UCL injury, it would be through altered mechanics due to a loss of TROM rather than just a loss of IR.

<u>Prevention of Gird</u>

For the purpose of this paper, it will be accepted that an equivalent gain of ER and loss of IR is a normal adaptation. Therefore, prevention and treatment efforts should focus on GIRD that is *not* accompanied by increased ER.

Clearly the best way to limit problems that may be exacerbated by GIRD is to maintain a healthy TROM. This would mean making sure that a pitcher's lost IR is not greater than the gained ER. It is this author's recommendation that teams having the ability to do so should measure ROM of the pitchers at the beginning of each season in order to monitor future changes. Maintenance of a healthy ROM could then be achieved through regular stretching of the posterior shoulder capsule and posterior musculature. The Houston Astros Major League Baseball Club performed a study on the efficacy of an internal rotation stretching program in preventing GIRD. They found that pitchers enrolled in the stretching program progressively increased their amount of ER with each year in the program (20). Based on the information presented, it is this author's recommendation that GIRD be addressed on a case by case basis with treatment determined by the type of symptoms the athlete is presenting with. If the TROM remains near 180 degrees and the athlete is asymptomatic, they likely would not benefit any further from a stretching program. If it is clear that a pitcher is experiencing pain, fatigue, or diminished performance due to an unequal change in rotational motion, s/he may benefit from stretching to reestablish a functional ROM.

Of course, as was mentioned previously, the early stages of GIRD can be found also in the little league pitcher. Prevention at that level would require teaching age appropriate strengthening exercises as well as stretching that can be continued throughout a pitcher's career.

Prevention of UCL Injury

The overhand baseball pitch is capable of producing injuries in athletes ranging from Little League all the way up to the Major Leagues. Although we have seen that the injury types may differ with age, the mechanism is the same. Thus if coaches, parents, and athletic trainers begin working on injury prevention with Little League pitchers, good habits can be formed that can possibly prevent injuries later in life as well.

As previously discussed, the most common contributing factors to UCL injury are improper mechanics, fatigue/overuse, and decreased flexibility. Thus prevention of injury to the UCL would require attention to all three factors. The current recommendations for treating Little League Elbow could very well also be used to help the young pitcher prevent future injury to his elbow. These recommendations focus on reducing the microtrauma through stressing proper pitching mechanics and limiting pitch counts. Young athletes can also be taught proper stretching, strengthening, and warm up exercises which will help him prevent future injury (24).

Proper pitching mechanics are the same regardless of age. A summary of the mechanics of the overhead pitch were discussed in the Pitching Mechanics section.

In order to prevent problems related to fatigue and overuse, most levels of competition have devised some system of monitoring the number of innings or pitches a pitcher has thrown. Prior to 2008, Little League Baseball relied on the total number of innings pitched to determine whether an athlete was eligible to pitch in a game. Now, based on information from research done by the American Sports Medicine Institute, Little League Baseball has published an official document limiting the number of pitches an athlete may throw in a given game, rather than the number of innings. These pitch totals increase with each year of age beginning with 50 pitches for 7-8 year olds and progressing up to 105 pitches for 17-18 year olds (41).

Little League Baseball has also taken a position on the number of rest days a pitcher requires after throwing a given number of pitches. If the young pitcher has already begun to experience pain, he may even need to stop pitching and start practicing another position until symptoms have cleared (18). However, he should not immediately return to full pitching status as soon as the pain subsides. A gradual return to throwing program including a strengthening component can prepare the young pitcher for competition again (17). It has been found by one study that every 10 pitches thrown by a little league pitcher per game lead to a 6% increase in risk for elbow pain (24). It is important to address all of these factors: mechanics of the pitch, and number thrown, and amount of rest all contribute to injury in young pitchers and these same variables can set them up for injury later in their career.

Such specific guidelines for limiting pitch count do not exist at the higher levels of competition. However, there are visible mechanical changes and quantifiable performance variables that collegiate and professional coaches can use to gauge a pitcher's level of fatigue. The mechanical changes include a "dropped elbow" (less shoulder abduction) and a straighter lead leg (22).

Chapter IV

CONCLUSIONS AND RECOMMENDATIONS

The intent of this paper was to review the current literature on both Glenohumeral Internal Rotation Deficit (GIRD) and Ulnar Collateral Ligament (UCL) injury in order to evaluate whether a relationship between the two conditions might exist. At this time, the literature does not support the statement that GIRD is a predisposing condition for UCL injury. It is more important that a pitcher maintain a functional, asymptomatic total range of motion (TROM) of 180 degrees instead of a "typical" non-thrower's arc of 90 degrees internal rotation (IR) and 90 degrees external rotation (ER).

The articles that have been written on GIRD support the assertion that GIRD is a cause for concern when the subsequent gain of ER does not equal the loss of IR or when a pitcher begins experiencing pain or decreased performance that can be directly related to their decreased IR. The common theme in most of these articles is that GIRD is an adaptation to repeated microtrauma, and that the loss of IR occurs secondary to a necessary increase in ER. Those factors contributing to UCL injury which are supported by the literature are overuse and poor mechanics due to fatigue. The claim that decreased ROM contributes to UCL injury was not well supported.

This author recommends that future research be done to confirm or disprove the theory of a relationship between GIRD and UCL injury. One possible study would be to simply assess the frequency with which pitchers presenting with GIRD sustain UCL injuries. Another would be to measure a pitcher's ROM, then utilize three-dimensional video analysis to determine whether greater forces are indeed imposed on the medial elbow. This could be done using the equation Net Force = Mass x Acceleration. Mass can be calculated and acceleration can be determined from the displacement data gathered during the motion analysis.

Further recommendations for athletes, coaches, and sports medicine professionals are that pitchers maintain a TROM of 180 degrees, and that the risk of UCL injury be reduced by using proper pitch mechanics throughout the career. Coaches of young athletes should follow the guidelines set force by Little League Baseball, and coaches of adult pitchers should utilize observable changes in pitching mechanics such as a dropped elbow as signs of fatigue. Performance indicators such as loss of control or decreased throwing velocity also indicate fatigue. Adherence to these guidelines can reduce the risk of injury to the UCL.

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