ANTHROPOMETRIC MEASUREMENTS AS PREDICTORS OF THE DEGREE OF CARRYING ANGLE IN COLLEGE BASEBALL PLAYERS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In baseball, a pitcher can single handedly win or lose a game based on skill, fatigue level, or musculoskeletal health. Injuries to these athletes can affect the players health, productivity, finances, and the team's record. Investigators have shown that the throwing mechanism places great stress on the glenohumeral (GH) joint, as well as the elbow [1,2,3,4]. Additionally, when compared to other positions, pitchers produce greater mean and peak torque values through the throwing motion. So it is no surprise that the shoulder and elbow are the two most common joints injured in throwing athletes [5]. Some research has suggested that experienced pitchers may develop increased retroversion of the humeral head over time due to the aforementioned torque levels. This adaptation does not increase overall range of motion, but decreases the amount of internal rotation while increasing external rotation [5,6,7]. Wilk proposed the total motion concept, suggesting that if total motion is equal bilaterally, any change in the arc of motion is due to humeral retroversion [8]. On the contrary, most other researchers and practitioners believe that the increase in GH external rotation is due to adaptive changes to the surrounding tissue structures (ie. posterior capsule, anteroinferior GH ligament and capsule). These researchers recognize GIRD (glenohumeral internal rotation deficit) as a source of limited scapular motion or dyskinesia, and labral and rotator cuff injuries [5,9,10]. With respect to the elbow, these maximal torque values create a phenomena called "Valgus Extension Overload" (VEO), which produces lateral tensile and medial compressive forces on the elbow. Investigating this further, VEO has been the culprit for injury to the ulnar nerve, ulnar collateral ligament, common flexor tendon, common extensor tendon, and osteochondritis dessicans of the capitullum, and osteochondral chip fractures[11]. Unlike the shoulder, no anatomical alignment adaptations have been proposed in the literature for the elbow with respect to pitching. It is reasonable to assume the possibility of adaptive changes occurring to the degree of elbow carrying angle which is the result of the frequent lateral tensile and medial compressive forces occurring through the throwing motion.

The carrying angle is defined as the clinical measurement of the varus-valgus angulation of the arm with elbow fully extended and forearm fully supinated [12]. The Carrying Angle may also be described as the angulation due to configuration of the articulation of joint surfaces which produces a natural valgus angulation of the forearm in relation to the humerus [13]. The angle can be measured statically through radiographs, digital electrogoniometer [14], and most simply a single hinge manual goniometer with 35 mm arms. The manual goniometer requires measurement of 3 points or landmarks across the forearm, elbow, and arm [15]. The normal carrying angle for men and women is 5 degrees and 10 to 15 degrees, respectively [13]. Some studies have suggested that there is not as much variation between males and females (10.97 degrees +/- 4.27 in men and 15.07 degrees +/- 4.95 in women [7]. Dynamically, the elbow carrying angle changes from the varus position in full flexion to it's previously stated valgus angle in complete extension. In other words, the carrying angle increases as the elbow approaches full extension [14]. Research has suggested that the carrying angle is greater in women versus men, dominant versus non-dominant elbows [16,17], shorter versus taller persons [18], and (although controversial) larger greater trochanteric versus smaller greater trochanteric circumference [18,19]. The significance of having a larger valgus angle may be the potential for non-traumatic neuropathy due to decreased conduction of the ulnar nerve. In explanation, some research suggests that there is an inverse relationship between carrying angle and nerve conduction velocities of the distal ulnar nerve [20]. Although not in the literature, the reciprocal biomechanical effects of the shoulder, and shoulder width on carrying angle have yet to be studied.

Stability of the elbow is achieved through the osseus structures, ligaments, and surrounding soft tissue structures [21,22,23]. Primary stability of the elbow from 20 degrees to about 120 degrees of flexion is due to the olecranon fossa articulation. With respect to pitchers' active range of motion between 20 and 120 degrees, the stability is mostly due to soft tissue structures. Consequently, pitchers are more susceptible to soft tissue injuries [21,22,23].

As mentioned previously, pitchers produce greater mean and maximal torque values at the elbow and shoulder than any of the position players [1,2,3,4]. The pitching motion is divided into specific phases which vary in the amount of torque in the elbow: wind-up, arm-cocking, acceleration, and deceleration.

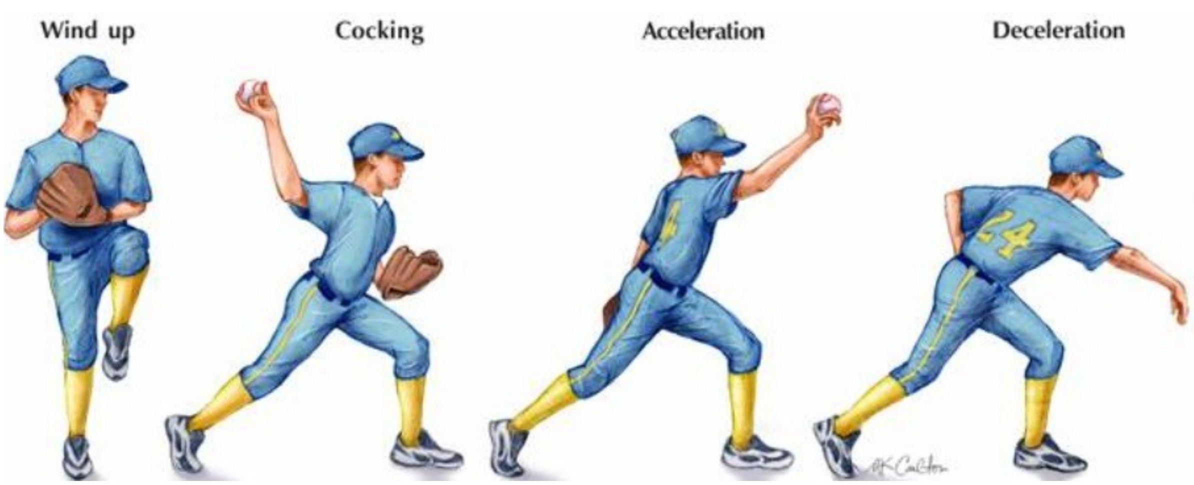

Figure 1. Four phases of pitching motion. Assessed: www.kineticintegrations.com/kinetic-integrations-2/injury-and-pain/throwing-shoulder-pain/

Wind-up is the initial counter movement of the upper extremity and torso, were the body's overall center of gravity is first raised [24,25]. In this phase, there is very little shoulder and elbow torque. The shoulder moves from a position of horizontal adduction to 90 degrees of shoulder external rotation and abduction and the elbow approaches 90 degrees of flexion into the cocking phase.

Arm cocking is the phase that begins to produce torque values in the elbow and shoulder. The shoulder arrives at 90 degrees of abduction and external rotation and the elbow flexion begins at 90 degrees. This produces an average flexion torque of 32 Nm and an average varus torque of 64 Nm on the elbow in the early cocking phase [24,25,26]. Additionally, during the late cocking phase the shoulder begins to internally rotate and horizontally adduct which causes an anterior force of near 400N, and an average internal rotation torque of 67 Nm (equivalent to pulling 40lbs down with hand [27]). At the same time the elbow absorbs an average valgus torque of 64 Nm and produces compressive forces of around 500 N at the lateral radiocapitellar joint. While shifting from the cocking to the acceleration phase the elbow must be stabilized by contraction of the flexor-pronator mass to counteract the large tensile forces produced on the medial aspect of the elbow. The elbow torque is greatest in maximally cocked position [27]. The late cocking phase has been reported to be one of the crucial periods of the pitching motion, where higher levels of torque at the shoulder and elbow can increase risk of injury [24].

Arm acceleration comes after the arm cocking phase. This phase is the shortest of all of aforementioned phases and may last less than 0.1 seconds. The elbow moves from the 90 degree position to full extension. This is the most intense phase for the shoulder and elbow. The shoulder will internally rotate at approximately 7500 degrees per second and the elbow will extend at a rate of approximately 2100-2700 degrees per second depending on pitch [24,25,26,27]. Maximal elbow angular velocity is similar for the fastball, slider, and curveball- but noticeably less for the change-up. As the elbow extends and the upper torso continues through rotation, a maximal elbow proximal force around 800 N to 1000 N is produced at ball release. The proximal force occurs to prevent elbow distraction due to centripital forces acting on the forearm. Additionally, elbow flexors add joint stability by contracting throughout the whole phase and by contracting eccentrically to control the forearm during the rapid extension. It is in this phase that a great degree of valgus torque occurs [24]. Some authors have suggested that the rapid extension in this phase has little to do with the elbow extensors [28]. Roberts, reported that a pitcher with a selected nerve block for the triceps was able to accomplish 80% of ball speed [28]. The deceleration and follow-through phases exhibit rapid decreases in all torque to resting state. Deceleration is initiated at ball release and completed at the instant when the shoulder reaches maximal internal rotation. The role of the body at this point is to decelerate the rapidly moving arm and dissipate energy of the shoulder and elbow. This phase requires the posterior rotator cuff muscles to contract to prevent distraction of the humeral head. Follow through is initiated at maximal shoulder internal rotation and concludes when the pitcher reaches a balanced fielding position. Finally, the elbow is now in a comfortable flexed position [24].

The acceleration phase of pitching produces a combination of elbow extension and valgus torque which is sometimes described as valgus extension overload by Wilson [25,29]. The greater valgus forces occur during rapid extension of the elbow causing shear forces. Valgus extension overload gives rise to high distraction stress at the medial compartment causing injury to soft tissue restraining structures. On the other hand the valgus stress also causes compressive types of injuries [25]. This phenomena has been associated with various injuries to the throwing elbow. Medial epicondylitis, cubital tunnel syndrome [28], ulnar nerve injuries, UCL sprains and rupture, and flexor/extensor common tendon strains are all valgus mechanism injuries due VEO. Compressive mechanism injuries occur between the radius and humerus at the end of the acceleration phase and consists of: posterior impingement, avascular necrosis (AVN) of joint surface, osteochondritis dessicans of the capitullum, and osteochondral chip fractures [30]. The mechanism through which the injuries occur tells us biomechanically how the aforementioned structures are damaged, but it is the accumulation of micro-trauma over time that seems to be the major factor. The threshold through which the structures of the elbow can be tolerated are predicated on several factors outside of the actual mechanism of injury.

Age of the pitcher is a significant factor because of the musculoskeletal maturity of the thrower. Pre-adolescent pitchers may not have full closure of epiphyseal plates which are weaker than surrounding ligaments and tendons- predisposing them to epiphyseal plate injuries. Post pubescent or skeletally mature athletes are more prone to tendinous or ligamentous injuries [31].

Another factor, which probably plays the greatest role in whether a pitcher will develop an injury is the number of pitches thrown [32]. The number of pitches in a game and a season correlate to the amount of fatigue and potential structural failure that may occur. Adolescents who competitively throw more than 85 pitches per game, more than 8 months out of the year, or with arm fatigue are several times more likely to require elbow surgery [31].

Throwing mechanics also play a major role in the health of the pitching elbow. Investigators have suggested that the throwing angle may also have an influence on level of fatigue, which can expedite structural failure. For example, the side arm pitch places greater stress on the throwing shoulder and elbow than overhand pitch. [33,34] Increased valgus torque at the elbow has also been associated with a condition of late trunk rotation, reduced shoulder external rotation, and increased elbow flexion [34].

Type of pitch thrown is also a piece of the puzzle with regards to susceptibility of injury and torque in the elbow. The fastball, slider, and curveball all have similar high load patterns, whereas the change-up has the least load (25, 26). As expected, the fastball has the greatest overall load for the shoulder and elbow due to the velocity vector (25, 26).

To date, there is no examination of the carrying angle of baseball pitchers by years of experience. Similar to the arguable changes that occur to the experienced pitcher's shoulder, it would be reasonable to assume that anatomical differences could be present in the elbow by anthropometric predictors (height, shoulder range of motion, hip width, shoulder width), and valgus extension overload. These differences would most likely be accompanied with an increased carrying angle. The significance of investigating these anatomical changes in baseball players would provide strength and conditioning coaches, athletic trainers, and position coaches with more information on the causes of elbow injuries, and ways through strength training, stretching, or even bracing to prevent such injuries.

Purpose of the Study

The purpose of this study was to investigate whether height, shoulder range of motion, hip width, and shoulder width in pitchers are predictors for increased carrying angle degree. Valgus extension overload may produce injuries to the ulnar collateral ligament, ulnar nerve, and to the flexor/extensor muscle mass. Due to the mechanism of the injuries, valgus effects on medial elbow and compressive on the lateral elbow, it may be assumed that anatomical changes occur over time to the carrying angle. The question this research will attempt to answer: "Does pitching experience, and/or anthropometric differences indicate a predictor of carrying angle of the pitchers throwing side?" With this question in mind the purpose of the study will be to determine if there is a correlation between anthropometric measurements of the pitchers and the carrying angles of pitchers throwing elbows to that of the non-throwing arm.

Operational Definitions

- **Carrying Angle**: The intersection of the line along the mid-axis of the upper arm the line along the mid-axis of the forearm defines this angle (Figure 2).
- **Hinged Joint Goniometer**: Manual device with two 35mm arms and 360 degrees measurement.
- Large carrying angle for males > 5 degrees.
- ¾ **Throwing Angle**= Abduction of the shoulder 45 degrees from transverse plane.
- **Bi-Acromial**- area measured from right acromion process to the left acromion.
- **Intertrochanteric Diameter**- Circumferential distance from the left trochanter to the right trochanter.

Figure 2. Carrying angle of the elbow. Accessed: www.chestofbooks.com/health/anatomy/Human-Body-Construction/Elbow-joint.html

Limitations

- Small sample of convenience- no more than 12 subjects total.
- Inter/Intra-rater reliability- effectively finding all landmarks around elbow, then measuring the carrying angle properly.
- Previous injury (ie.Pitcher who has osteochondral defect of olecranon)

Assumptions

- Throwing extremity has greater elbow carrying angle than non-throwing.
- Pitchers have greater elbow carrying angle in throwing extremity versus non-throwing.
- Increased carrying angle is due to long-term effects of valgus extension overload.
- Increased carrying angle is indicative of previous or future injury.

Hypotheses

- *Ho:* Anthropometric measurements (Height, and hip and shoulder width), shoulder range of motion, and experience are <u>NOT</u> predictors for the degree of carrying angle of the throwing side in college baseball pitchers.
- *H1:* Anthropometric measurements (Height, and hip and shoulder width), shoulder range of motion, and experience are predictors for the degree of carrying angle of the throwing side in college baseball pitchers.

Chapter II

Literature Review

Goniometrical Measurement

Two articles were found specific to the measurement of the carrying angle of the elbow. As stated in the introduction, literature suggests that there are differences in the measurement of the angle across the two sexes. The first article was used to establish the method for goniometric measurement in this study due to time and cost effectiveness. The second article uses an electronic goniometer.

Twenty-eight right and left handed adults (15 men, and 13 women) were used to compare the electric goniometer to the 35 mm arm manual goniometer. Age range was 41-81 with the mean age being 59 +/- 10. Total of 88 measurements were made. Used the following landmarks for measurement: AH: gap between acromion and humerus.
EM: most caudal point on medial epicondyle of the humerus. EL: most caudal point on lateral epicondyle of humerus. US: Most caudal-medial point on the ulnar styloid. RS: Most caudal-medial point on the radial styloid. These landmarks were chosen due to the 2005 International Society of Biomechanics recommendations. The results of the study found the mean carrying angle of 12.42 +\- 4.06 degrees. Study showed neither sex nor arm side differences with the electrogoniometer or the standard goniometer. [14]

Some research shows no difference between males and females. Study consisting of 37 adults (17 men and 20 females) were measured. Patient age ranged from 41 to 81 years old. All participants were healthy with no signs or symptoms of pathology. 72 measurements made because right and left elbows were measured. Carrying angle was measured using the

Faro Arm Model Bronze digital electrogoniometer. Mean carrying angle was 12.7 +/- 3.8 degrees.[43]

The first article established the landmarks for measurement of the elbow carrying angle and also suggested that it was as effective as the electrical goniometer. This was important because it is necessary to utilize an efficient and cost effective method of measuring the carrying angle. Both articles found no differences in elbow carrying angle and the two sexes, as well as they did not record as much variability as the literature proposed previously. Both studies may be in question as both have less than 30 subjects.

Variation of Carrying Angle

In order to perform a study involving the carrying angle of the elbow it is necessary to examine the variability that exists. There were several articles that seemed to suggest variation of the degree of carrying angle in relation to trochanteric diameter, height, weight, sex, and dominant versus non-dominant sides. The following studies contradict the results of the previous two studies in that they find differences in the elbow carrying angles between women and men. Additionally, the following studies demonstrate a higher level of statistical power. The first examines hip diameter, and sex differences.

Although controversial, some studies have found a direct relationship between trochanteric diameter (hip width) and carrying angle and sex differences, others do not concur. In a retrospective study based on measurements carried out in students of the Medical Faculty of the Aristotelian University, Thessaloniki, Greece, and students of numerous high schools in Thessaloniki between 1998 and 2001. 600 subjects between 18-28 years old (320 men 280 women) were included in the study, while 35 were excluded due to elbow trauma. Researchers measured trans-trochanteric diameter with a classic pelvic-meter as used by obstetricians.

The measurements observed the medial outline of the arm and forearm against a horizontal board, and also measured on radiographs. The results found an inverse relationship in TD and carrying angle in women but not in men. Smallest carrying angles were found in slender participants and the greatest angles were found in obese participants.[18]

In a study of 600 students (320 men; 280 women) measured using a supplementary angle to that between the longitudinal axis of the arm and that of the forearm. The mean carrying angle was 12.88 degrees +/- 5.92: 10.97 degrees +/- 4.27 in men and 15.07 degrees +/- 4.95 in women. Also the article stated that the carrying angle was always greater on dominant side. They confirmed an inverse relationship between carrying angle and intertrochanteric diameter of females, but not males. The study also suggested that obese subjects had a greater carrying angle than those who were slender.[36]

This study measured the carrying angle of the elbow joint in full extension in 600 students, using the supplementary angle to that between the longitudinal axis of the arm and that of the forearm. The mean carrying angle was 12.88 degrees +/-5.92: 10.97 degrees +/-4.27 in men and 15.07 degrees +/-4.95 in women. The carrying angle changes with skeletal growth and maturity. The angle is always greater on the side of the dominant hand. We confirmed the inverse relationship between the carrying angle and the intertrochanteric diameter. Also, the type of constitution influences the value of the carrying angle, especially in women.[12]

The author of this study measured the carrying angle using a universal full-circle manual goniometer on the dominant and non-dominant extremity of the elbow in 1275 healthy volunteers (631 males, 644 females) with a mean age of 22.87+/-15.99 years (range: 2-91 years). In the subject right arm dominant group, right carrying angle was 11.25 degrees +/- 3.73 degrees and left carrying angle was 10.57 degrees +/- 3.63 degrees (P<.001). In the left arm dominant group, right carrying angle was 10.65 degrees +/- 3.99 degrees and left carrying angle was 12.93 degrees +/- 4.22 degrees (P<.001). They discovered the carrying angle of dominant arm was found to be significantly higher than the non-dominant arm in both sexes. The carrying angle of dominant and non-dominant arms were discovered to be significantly higher in patients aged >14 years than that of patients aged < or = 14 years; females ranked higher than males.[37]

Fifty-four radiographs were examined, and the carrying angle was measured using adult individuals and morphometry was measured on dry bones taking part in the formation of human elbow (on lower end of humerus-trochlear angle and inclination angle of olecranon fossa, on upper end of ulna-olecranon-coronoid angle and length and width of inferior medial trochlear notch). On radiographs, the difference between male and female carrying angle and difference between carrying angle of right and left limbs (in both sexes together as well as in same sex) was statistically not significant. All the morphometric parameters measured in this study did not show any significant sexual dimorphism or difference between right and left side except the inclination angle of olecranon fossa, which was significantly more on the right side. Different findings of carrying angle as reported by various authors could be due to racial difference or due to different methods used to measure carrying angle. Morphometric parameters were similar to the findings of radiographic method of measuring carrying angle. These factors should also be considered in construction of elbow prosthesis as well as use of carrying angle in identification of skeletal remains.[19]

This study was based on cadaveric experiments and accidentally amputated 8 upper limbs of children. The research examined the ulnae for presence and absence of non articular strip on the trochlear notch, measurements of carrying angle, length of forearm bones, pronation-supination, height and weight in 2250 infants, children and adults of various age groups and clinical observations on 800 cases of injuries around elbow many new facts have been observed about the development of the carrying angle and its significance in the etiopathogenesis of various types of fractures seen around the elbow. The carrying angle develops in response to pronation of the forearm and is dependent on length of the forearm bones. Lesser the length of forearm bones greater is the carrying angle. So the carrying angle is more in shorter persons as compared to taller persons. It is abduction at the shoulder and not the carrying angle which keeps the swinging upper limbs away from the side of the pelvis during walking. Carrying angle is not a secondary sex character. The type of fracture a child sustains after fall on outstretched hand is also determined by the value of the carrying angle. A new type of fracture not described in the literature, T-Y fracture of the distal humeral epiphysis is also reported.[17]

As of 2010, only one study compared carrying angle of dominant and non-dominant upper extremities. Some articles have empirically made the assumption that the carrying angle is larger in the throwing side of pitchers. Study comprised of 1275 healthy volunteers with an average age of 22.87 +/- 15.99. The carrying angle was measured with a clear plastic, full circle, manual goniometer with 35 cm long arms. Placed on the volar surface of the arm and aligned with the mid-axis of the humerus to the extended elbow and mid-axis of the fully supinated forearm. The results concluded the right and left elbow carrying angles of females with right arm dominance were found to be higher than the same carrying angles of males with right arm dominance. The same is true for right and left carrying angles of females with left arm dominance.[41]

Most literature points towards females having larger carrying angles. Most studies have females with larger carrying angles than males. A cross-sectional study measured the carrying angle in 2050 normal boys and girls of a different age from 0-20, using a goniometer. Height, weight, length of forearm, pronatio-supination movements and width of pelvis were also recorded.

First year of life the carrying angle was 13 degrees in both sexes. At age ten carrying angle decreases possibly due to adolescent growth spurts. Great variability exists throughout ages. This study suggests a significant relationships exists between length of forearm. (longer forearm, lesser was carrying angle.) Increased length had a direct relationship in supination/pronation motion. Greater length of ulna seemed to associate with lesser or absent carrying angle. Most persons kept their upper limbs pronated and slightly flexed at the elbow. While walking there didn't appear to be a valgus angle. Abduction of the shoulder at the shoulder, rather than carrying angle, which helped in clearing the limb from the side of the pelvis. The study found that carrying angle is not related to greater trochanteric width of pelvis and is not a secondary sex characteristic as previously thought.[42]

In conclusion, most of the aforementioned articles demonstrated a high level of statistical power by having a large subject pool. Review of literature in this area reveals that there are no morphological characteristics that relate to the degree of carrying angle of the elbow without some argument to the contrary. Investigating this further, if the level of statistical power is including as weight to the value of each study then one may lightly consider several characteristics to be important. The first is that carrying angle of males is generally less than females. Next, the trochanteric diameter may have an inverse relationship with the carrying angle in females, but not males. Thirdly, slender individuals have less of a measured degree of carrying angle then those who are obese. Lastly, dominant side elbows may have a greater degree of carrying angle than the non-dominant side.

Carrying Angle and Biomechanics of the Elbow

The current study is predicated on the torque values present during the throwing motion which cause tensile and compressive forces at the elbow. One way to understand how those forces occur is to examine the biomechanics of the carrying angle during dynamic activities. One article that was discovered explains how the carrying angle changes throughout the sagittal plane motion of the elbow. Another article explains the mechanism of valgus extension overload and how it stresses the elbow.

The carrying angle of the elbow is usually assessed in full elbow extension, with a protractor goniometer, or derived from X-ray images. Substantial differences in carrying angle values have been reported, possibly explained by methodological differences. Carrying angles tend to show higher values in women than in men. The aim of this study was to confirm the previously described progressive decrease of the carrying angle as a function of increasing elbow flexion. After assessment of the carrying angle with a protractor goniometer and an electromagnetic tracking system (Flock of Birds) in extension, flexion-extension movements with the forearm held in supination were recorded by means of the latter system. Three recordings were averaged in both the left and the right elbows of 20 volunteers without a history of elbow pathology (10 males and 10 females; mean age 25 years). In extension, a mean (+/- SD) carrying angle of 11.6 +/- 3.2 degrees was found in the male and 16.7 +/- 2.6

degrees in the female subjects. The carrying angles progressively decreased with flexion, at the end changing into a mean (+/- SD) varus angle of 1.8 +/- 2.9 degrees in men and 1.6 +/- 2.3 degrees in women significant differences in carrying angles between the sexes were recorded in moving from 0 to 30 degrees of flexion.[40]

This article discusses how repetitive overhead throwing imparts high valgus and extension loads to the athlete's elbow, often leading to either acute or chronic injury or progressive structural change. The tensile force is applied to the medial stabilizing structures with compression on the lateral compartment and shear stress posteriorly. It further discusses that the common injuries encountered in the throwing elbow include ulnar collateral ligament tears, ulnar neuritis, flexor-pronator muscle strain or tendinitis, medial epicondyle apophysitis or avulsion, valgus extension overload syndrome with olecranon osteophytes, olecranon stress fractures, osteochondritis dissecans of the capitellum, and loose bodies. It goes on further by stating that knowledge of the anatomy and function of the elbow complex, along with an understanding of throwing biomechanics, is imperative to properly diagnose and treat the throwing athlete. Recent advantages in arthroscopic surgical techniques and ligament reconstruction in the elbow have improved the prognosis for return to competition for the highly motivated athlete. However, continued overhead throwing often results in subsequent injury and symptom recurrence in the competitive athlete.[38]

Both articles provide information, albeit indirectly, supporting each other. Biomechanically, the elbow increases the degree of carrying angle as extension occurs. Consequently, this would indicate that the elbow is moving in a lateral position with respect to the frontal plane. Valgus extension overload is the aforementioned biomechanics moving at a much faster rate. In conclusion, the medial elbow receives tensile stress and the lateral elbow endures compressive forces which may cause injuries under certain circumstances- which will be discussed in the next section.

Pathologies in Baseball Pitchers

The previous section discussed the biomechanics of the elbow and the valgus extension overload phenomena. Valgus extension overload produce tensile stress on the elbow that in some cases may injure the ulnar collateral ligament, ulnar nerve, or the flexor muscle mass. Additionally, the compressive forces may cause osteophytes in the olecranon fossa, avasclar necrosis of the olecranon, olecranon stress fractures, and osteochondritis dessicans of the capitellum. Most of the previous injuries are not due to an acute incidence, they usually the result of chronic or repetitive injuries. The following studies examine pitch count, type of pitch, pitching mechanics, and age related factors to injury.

In this study the authors examined radiographs of elbows of the pitching arms of 79 professional baseball pitchers (mean age, 25.1 years; mean duration of professional career, 4.7 years). Then they noted the frequency and size of spurs, bone fragments,and intra-articular loose bodies according to site. In addition, the influence of duration of professional baseball career on these osteoarthritic changes was also investigated.

The results of the study concluded that the olecranon tip was the most frequent site of bone spurs (62/79; 78.5%), and fragmentation of the spur was detected in 17 joints. Also, the frequency of spurs was also high at the medial margin of the olecranon, the tip of the coronoid process, the medial margin of the sigmoid notch, the medial margin of the trochlea, and the olecranon fossa.

In Thirty-eight of the subjects, spurs were observed at the distal portion of the radial notch of the ulna. However, few pitchers had osteoarthritic changes in the humeral capitellum or radial head. Intra-articular loose bodies were detected in 4 of 79 joints (5.1%), and bone fragments were present below the medial humeral epicondyle in 25 of 79 joints (31.6%). The authors believe that the osteoarthritic changes in the elbow joint appeared to be attributable mainly to traction stress and impingement associated with extension and valgus strain. Most of the significant osteoarthritic changes were often found in professional pitchers whose careers exceeded 5 years.[45]

Fifty-seven asymptomatic MLB pitchers, with an average age of twenty-nine years, participated in the St. Louis Cardinals spring training camp underwent routine preseason radiographic screening of their dominant shoulder and elbow between 1986 and 1998. Radiographs were reviewed for osteophytes, cystic changes, joint space, and loose bodies. Findings were recorded as present or absent.(average 3 for shoulder, 7 for elbow.) No significant difference was found for those on the DL and active players for age, number of seasons pitched, number of innings pitched.[39]

This article discusses how to prevent elbow injuries and further explains the need for restrictions on pitch counts because fatigue is one of the major factors causing injury. Adolescents who competitively pitch more than 85 pitches per game, more than 8 months out of the year, or with arm fatigue are several times more likely to require elbow surgery.[31]

The objective of this study was to evaluate the association between pitch counts, pitch types, and pitching mechanics and shoulder and elbow in young pitchers. The design of the study was a prospective cohort.

Four hundred and seventy-six, ages 9-14, baseball pitchers were followed for one season. The data were collected from pre- and postseason questionnaires, injury and performance interviews after each game, pitch count logs, and video analysis of pitching mechanics. Generalized estimating and logistic regression analysis was used.

Results indicate those pitchers who threw sliders were 86% more likely to experience elbow pain during the season. Pitchers who threw curveballs were 56% more likely to experience shoulder pain during the season. On the other hand , pitchers throwing change-ups were 12% less likely to experience elbow pain and 29% less likely to experience shoulder pain**.** Study also found that as pitch count increased, the number of cases of shoulder and elbow pain also increased. At the 75-99 pitch count range, the risk of shoulder and elbow pain increased by 52% and 35% respectively.

Author's recommendations were that pitchers between 9 and 12 should limit themselves to throwing only fastballs and change-ups, and not throwing sliders or curveballs. Also limit number of pitches to 75 per game and 600 pitches per season or limit number of batters to 15 per game and 120 per year.[33]

Thirty-three adolescent baseball pitchers with a minimum of 2 years of pitching experience underwent 3-dimensional motion analysis using reflective marker aligned to bony landmarks. After a warm-up pitchers threw either a fastball or curveball, randomly assigned, from portable pitching mound until 3 appropriate trials were collected for each pitch technique. Kinematic and Kinetic data for the upper extremities, lower extremities, thorax, and pelvis were collected and computed for both pitch types.

Results indicate there were lower moments on the shoulder and elbow when throwing the curveball versus throwing the fastball (speed was different).[35]

Twenty-nine youth baseball pitchers (age, 12.5 +/- 1.7 years) pitched 5 fastballs, 5 curveballs, and 5 change-ups with maximum effort in an indoor laboratory setting. Data collected with a 3-dimensional motion analysis system. Kinetic, kinematic, and temporal parameters were compared among the 3 pitches. The study concluded, that the elbow and shoulder loads were the greatest in the fastball an least in the change-up. The clinical relevance assumes the number of pitches is more of a factor in injury than the type.[32]

The aforementioned articles describe several different injuries that occur to the medial, lateral, and posterior side of the elbow as a result of the stresses during the pitching motion. Ultimately the main factor contributing to the injuries is fatigue. The fatigue may be represented a high age related pitch count, muscular weakness, or poor biomechanics. Pitch counts combined with the type of pitch are directly related. According to the studies above the fast ball produces the highest mean torque values on the elbow. Consequently, the pitcher will fatigue faster because the active and passive structures will have to work more rigorously to stabilize the joint. Although the previous studies have a lower level of statistical power they seem to be pretty reasonable and in line with conventional wisdom on the topic.

Injuries and Nerve Conduction Velocities

Only one article examined the relationship between the ulnar nerve and conduction velocities, and the elbow carrying angle. Anatomically, a larger carrying angle may lengthen or stretch the ulnar nerve thus increasing the distance that the nerve impulse must travel. This is a significant piece because if pitchers have adaptive changes over time causing an increase in carrying angle, then the end result may have adverse effects on the ulnar nerve.

The purpose of this study was to determine if neurological injuries are related to an increased carrying angle. A study measured the carrying angles of the elbow in 36 patients with clinically and electro-physiologically confirmed diagnosis of non-traumatic ulnar neuropathy at the elbow. Control group consisted of 50 healthy control subjects. Correlation analysis was conducted between carrying angles and parameters of nerve conduction studies, including nerve conduction velocities and amplitudes of muscle and nerve action potentials. The results of the study found an inverse relationship between carrying angles and motor nerve conduction velocities at cross-elbow segments of the ulnar nerves with sensory nerve conduction velocities of the distal ulnar nerve. [20]

Although the study has a relatively low statistical power with only 36 subjects, it stands as the only one of it's kind. I don't believe that is should be considered the gold standard and further research should be performed in this area to delineate it further. However, I think that the results of the study follow a practical course. This study may help to explain ulnar nerve injuries in pitchers if they appear to have a greater degree of carrying angle.

Characteristics	Patients with ulnar neuropathy (n = 36)	Control subjects (n = 50)	P
Age (years)	42.6 ± 8.3	40.5 ± 6.2	0.343
Carrying angles (degrees)	15.2 ± 4.1	12.0 ± 3.8	0.021
NCS of ulnar nerves			
MNCV, cross-elbow (m/s)	44.8 ± 6.6	53.7 ± 5.4	0.023
SNCV, finger to wrist (m/s)	36.9 ± 5.8	44.5 ± 3.2	0.011
Mixed NCV, forearm (m/s)	48.9 ± 5.1	55.4 ± 3.7	0.033
CMAP amplitude (mV)	6.7 ± 3.1	8.5 ± 2.0	0.072
SNAP amplitude (μV)	5.5 ± 3.8	12.5 ± 2.2	0.002

Table 1. Conduction Velocities.

CHAPTER III

METHODS

Participants

Subjects consisted of healthy Division I Baseball pitchers from Oklahoma State University with a mean age of 20.3 +/- 3.5 years, height of 182.0 +/- 6.0 cm, and weight of 80.3 +/- 9.5 kg. The Oklahoma State Investigative Review Board approved the study in October, 2010 (See appendices p. 40) and the study was performed on November 18th, 2010. There were a total of 13 subjects that began the study. One subject was excluded because he was a sidearm thrower. Of the 12 subjects, only two were left handed throwers. These subjects were recruited through the athletic department on a volunteer basis only and did not receive any compensation for their participation.

All of the pitchers that chose to participate came to the baseball athletic training clinic at the allocated time, where they filled out a questionnaire that requested information about the length of their baseball career, and any previous orthopedic injuries. After each athlete finished the questionnaire an athletic trainer wrote each athlete's height, weight, and age on the data sheet from an official body composition form used in the athletic department. After all paperwork was finished the measurements were performed in the supine position for shoulder external rotation and internal rotation, elbow carrying angle, and in standing for bi-acromial, and inter-trochanteric width.

Equipment Set-up

Equipment that was used specifically for this study were: 1 Treatment table, 1 manual goniometer with 35mm arms, and 1 Kobalt 6" Metric Caliper, 1 blue ball point pen, and finally 1 anthropometric measuring tape.

The only calibration required before performing the study was with the Kobalt 6" metric caliper. It has an accuracy of up to .001 in. and after each participant measure had to be "zeroed out"

Figure 3. Marked points.

Figure 4. Goniometer placement.

in order to ensure accuracy for each additional measurement.

With the athlete in the supine position, the digital calipers were used to determine the middle axis of the arm, which is defined distally as the midpoint between the medial and lateral epicondyles of the humerus and proximally at the lateral border of the cranial surface of the acromion. The axis of the forearm was defined distally at the midpoint between the distal radial and ulnar styloid processes and proximally at the midpoint between the medial and lateral epicondyles of the humerus. (Figure 3.) Once the middle points were established the carrying angle was measured using the manual goniometer. (Figure 4.) With the athlete in the supine position the carrying angle of both sides were measured using the 3 aforementioned points and with the shoulder in 0° flexion, 0° extension, 0° abduction, full extension of the elbow, and the forearm supinated .

Figure 5. External Rotation.

Additionally, while in the supine position the pitchers external and internal rotation were measured for both sides using the manual goniometer.

Once the athlete's carrying angle and shoulder motion were measured, they were instructed to stand. In this position the anthropometric measuring tape was used to measure the distance between each Acromion-even with the transverse plane. The most medial prominence of the acromion was used as the measuring points. Finally, the inter-trochanteric width was measured using the tape. Each greater trochanter was identified and then measured from the right to left- even with the transverse plane.

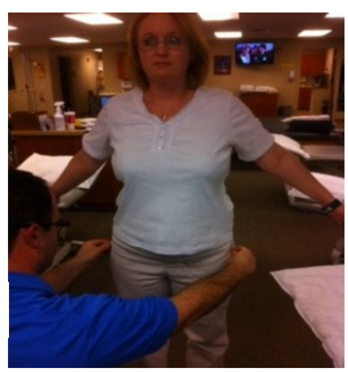

Figure 6. Trochanteric Width.

Statistical Analysis

A Pearson Correlation Coefficient was computed to assess the relationships amongst the anthropometric measurements and degrees of carrying angle of the pitchers throwing side. The 10 dependent variables examined were height, weight, hip width, shoulder width, left and right shoulder external rotation, years pitching, years playing baseball, left and right elbow carrying angle. Pursuing this further, a linear regression analysis was expected to be performed if a strong enough correlation (.7 or greater) could suggest any predictors of the degree of carrying angle on the throwing side.

CHAPTER IV

Findings

The Pearson Correlation Coefficient suggests that two of the anthropometric variables have a moderate correlation coefficient moment. In this case, a moderate correlation between the dominate (throwing) side carrying angle and hip width (r= -.532, N=12, p= .05), and dominate (throwing) side carrying angle and years pitched (r=-.499, N=12, p= .05) was discovered. A scatter plot summarizes the results (Figures 4 & 5).

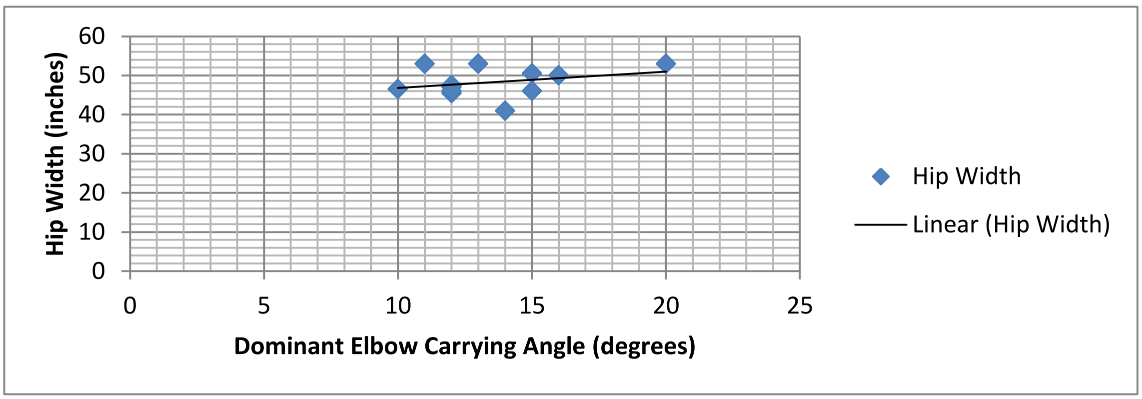

Figure 7. Hip Width v. Dominant Carrying Angle Scatter Plot.

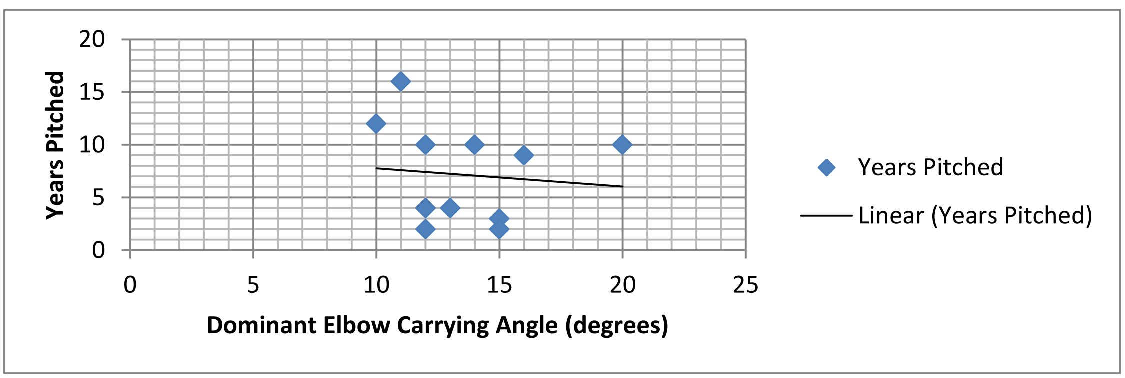

Figure 8. Years Pitched v. Dominant Elbow Carrying Angle Scatter Plot.

Means and standard deviations for the anthropometrics measurements and carrying angles are displayed in Table 2.

Anthropometric Measurement	Mean	Standard Deviation
Dominant Elbow Carrying Angle	12.1667	2.16725
Height	186.1083	4.67925
Weight	82.5108	6.63192
Hip Width	48.2500	3.70810
Shoulder Width	43.2917	1.77685
L SHLD ER	114.6667	5.80491
R SHLD ER	123.5000	12.04914
Years Played	15.6667	1.49747
Years Pitched	7.1667	4.56933

Table 2. Means and Standard Deviations

The following table represents the correlations of all the variables (Table 3.)

	Dominant CA	Height	Weight	Hip Width	Shoulder Width	L ER	R ER	Yrs Play	Yrs Pitched
Dominant CA	1								
Height	.041	1							
Weight	-.469	.485	1						
Hip Width	-.532	.425	.536	1					
Shoulder Width	.104	.357	.224	.050	1				
L Shoulder ER	-.219	.048	-.331	.057	-.289	1			
R Shoulder ER	-.212	.237	-.071	.552	-.470	.381	1		
Years Playing	.215	-.538	-.194	-.229	-.063	-.223	-.393	1	
Years Pitched	-.499	.244	.284	.209	-.012	.571	-.068	.075	1

Table 3. **Correlation Table.**

Following this further, it was expected that a linear regression analysis would be used if there was a strong correlation between the dominant (throwing) side carrying angle and hip width, and the number of years pitched. However, the current correlation strength (less than .70) did not indicate a regression model was necessary.

CHAPTER V

CONCLUSION

Summary

The goal of this study was to examine whether or not height, shoulder range of motion, hip width, and shoulder width in pitchers were predictors for increased carrying angle of the throwing side. Literature has suggested that valgus extension overload has the potential to cause injuries to the ulnar collateral ligament, ulnar nerve, and to the flexor/extensor muscle mass. The premise of the study is based on my theoretical assumption that valgus extension overload produces tensile strain on the medial side and compressive forces on the lateral side of the elbow that may produce anatomical changes over time to the thrower's degree of carrying angle. The question this research attempted to answer was: "Does pitching experience, and/or anthropometric differences indicate a predictor of carrying angle of the pitchers throwing side?" The importance of answering this question cannot be underestimated, as some studies have demonstrated that individuals who possess a larger degree of carrying angle have decreased conduction velocities of the ulnar nerve when compared to their non-injured counter parts in a normal population. Although no previous studies have examined the degree of carrying angle with respect to neurological injuries in throwing athletes, it is assumed that similar injuries parallel that of the normal population. The previous question was further delineated through the hypothesis which was: "Anthropometric and range of motion measurements are predictors of the degree of carrying angle on the throwing side of a pitcher."

Interpretation

The results of the Pearson Correlation Coefficient analysis suggests a moderate correlation between the dominant (throwing) side carrying angle in hip width, and dominant (throwing) side in years pitched. None of the literature up to this point has studied any of the previously mentioned variables as predictors of carrying angle, nor has any of the literature quantified possible differences in the carrying angle of pitchers or any throwing athletes.

As it stands, the null hypothesis is accepted since hip width and number of years pitched have a moderate correlation, which does not indicate possible predictability of the carrying angle of the throwing side. As suggested in the limitations section, the power of the study was compromised due to the quantity of subjects. Consequently, it is quite difficult to discern any solid conclusions from the data analysis presented.

Hip Width as Predictor of Carrying Angle

The Pearson Correlation Coefficient suggests a moderate correlation between the same variables. This is in line with current research which suggests that hip width has a direct relationship with the degree of carrying angle (12, 13). The scatter plot from Figure 4 demonstrates such a relationship. From a theoretical standpoint, these findings are more or less consistent with the current literature. As the literature review suggests, there may be a relationship between hip width and the carrying angle of the elbow.

Pitching Experience as a Predictor of Carrying Angle

There appears to be a moderate correlation between the number of years pitched and dominant (throwing) elbow carrying angle. No other research has examined these variables so there is no way to make any comparisons at this point. Theoretically, the degree of carrying angle may be directly related and predicted by the number of years that a player pitches. Examining the scatter plot from Figure 5 demonstrates this. Interpretation of the scatter plot suggests that there is a relationship between years pitched and degree of carrying angle. Admittedly, the relationship wasn't as strong as expected as the original theory included the idea that over time the valgus extension overload would cause an increase in carrying angle.

Limitations

It should be noted that the present study incurred several limitations. With only 12 total subjects there was loss of statistical power to determine predictability. Additionally, 6 of the 12 pitchers could not completely extend their elbows. As suggested before, full elbow extension is required to maximize the carrying angle.

Another limitation of the study is intra-rater reliability calculation errors. Although the greatest attempt was made to produce flawless calculations of the carrying angle, it was obvious during the study that the precision of finding the midpoint of the arm and forearm was difficult because the middle point had to be manually marked with a pen. Another potential for intra-rater reliability issues occurred when measuring each subjects lateral acromion. Like any palpatory procedure it is subject to inaccuracy when making an external marking. Lastly, there may be intra-rater reliability inaccuracies when using the anthropometric measuring tape for the shoulder and hip width measurements.

Recommendations

Admittedly, a large randomized population of NCAA Division I pitchers is optimal and would increase the power of the study. Although, the current study uses a sample of convenience the results are not definite and suggest the need to further examine the findings at a larger scale. Most researchers prefer a population of at least 100 subjects to have adequate statistical power. If the study were to be reproduced, the investigator should use several different college teams so that they may increase the power of the study.

Another area that should be addressed in future studies is the method through which the carrying angle is measured. The method used in this study had too many opportunities for inaccuracy. Palpating the acromion, and finding the midpoint of the arm and forearm is very difficult to calculate in a timely manner when there are a large number of subjects. One suggestion may be to measure the carrying angle from radiographs. The one problem with this method is that it would be difficult to perform a prospective study as most pitchers receiving radiographic examination may have an injury. Moreover, it may be difficult to find a large population of Division I pitchers willing to arbitrarily have an x-ray. Retrospective studies could be used, but once again the players would likely have an orthopedic pathology.

In final consideration, elbow extension should be observed for future studies of this kind because 6 of the 12 pitchers had deficits. This is a very significant finding as the carrying angle of the elbow is optimized in full extension. Clearly then, pitchers who have an extension lag will be difficult to measure and may have skewed carrying angles.

Practical Use

The value of understanding characteristics that contribute to anatomical differences such as a large carrying angle is appreciated if a pitcher can avoid an injury. Identifying such characteristics may give health care professionals and coaches a road map to follow in order to identify those pitchers more susceptible to injury.

REFERENCES

1. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. J Orthop Sports Phys Ther. 1993;18(2):402-408.

2. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sports Med. 1995;23(2):233-239

3. Jobe FW,MoynesDR, Tibone JE, Perry J. AnEMGanalysis of the shoulder in pitching: a second report. Am J Sports Med. 1984;12(3):218-220.

4. Jobe FW, Tibone JE, Perry J, Moynes D. The Role of the Sensorimotor System in the Athletic Shoulder., J Athl Train. 2000 Jul–Sep; 35(3): 351–363.

5. Stephen J Thomas; Kathleen A Swanik; Charles B Swanik; John D Kelly. Internal Rotation and Scapular Position Differences: A Comparison of Collegiate and High School Baseball Players. 2010;Journal of Athletic Training., Issue 42.

6. Chant CB, &Litchfield R, &Griffin S, &Thain LM., Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. 2007;J Orthop Sports Phys Ther. Sep; 37:9, pp 514-520.

7. Osbahr DC., &Cannon DL, &Speer KP., Retroversion of the humerus in the throwing Shoulder of College Baseball Pitchers. The American Journal of Sports Medicine., 2002; 30:3 pp 347-353.

8. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. Am J Sports Med. 2002;30(1):136-151.

9. Priscilla M Dwelly; Brady L Tripp; Patricia A Tripp; Lindsey E Eberman; Steven Gorin. Glenohumeral Rotational Range of Motion in Collegiate Overhead-Throwing Athletes During an Athletic Season., Journal of Athletic Training. 2009; Nov. 44(6)

10. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. Am J Sports Med. 1988;16(6):577-585.

11. O'Holleran JD, Altchek DW., Elbow arthroscopy: treatment of the thrower's elbow. Instr Course Lect. 2006;55, 95-107.

12. Paraskevas G, Papadopoulos A, Papaziogas B, Spanidou S, Argiriadou H, Gigis J Study of the carrying angle of the human elbow joint in full extension: a morphometric analysis. Surg Radiol Anat. 2004;26 (1), 19-23.

13. Levangie, P. K., & Norkin, C., Joint Structure and Function. Philadelphia, PA. 2001; 234-235.

14. Zampagni, ML., Casino, D., Martelli, S., Visani, A. MD., Maracci, Maurilio MD., Bolgna, I., A protocol for clinical evaluation of the carrying angle of the elbow by anatomic landmarks. Jan-Feb;17(1):106-12. Epub 2007 Nov 1.

15. Erhan, Y MD., Lokman, K MD., Oktay B MD., Mehmet Bulut, MD., Erhan S MD., Mustafa A MD., Variation of Carrying Angle with age, sex, and special reference to side. 2005; (28)11, 1360-63.

16. Erhan, Y MD., Lokman, K MD., Oktay B MD., Mehmet Bulut, MD., Erhan S MD., Mustafa A MD., Variation of Carrying Angle with age, sex, and special reference to side. 2005; (28)11, 1360-63.

17. Khare GN, Goel SC, Saraf SK, Singh G, Mohanty C. New observations on carrying angle. Indian J Med Sci. 1999; 53:61-67.

18. Keats TE, Teeslink R, Diamong AE, Williams JH. Normal axial relationship of the major joints. Radiol 1966; 87:904-908.

19. Kumar B., &Pai B., &Mishra S., &Pandey AK., Radiographic study of carrying angle and morphometry of skeletal elements of human elbow. Rom J Morphol Embryol. 2001; 51(3):521-6.

20. Chang, CW., Wang, YC., Chu, CH., MD., Increased Carrying Angle is a risk factor for nontraumatic Ulnar neuropathy at the elbow. Clin Orthop Relat Res 2008; 466:2190-2195.

21. Miller CD, Savoie FH 3rd. Valgus extension injuries of the elbow in the throwing athlete. J Am Acad Orthop Surg 1994; 2(5): 261–269.

22. Schwartz ML, al-Zahrani S, Morwessel RM, Andrews JR. Ulnar collateral ligament injury in the throwing athlete: evaluation with saline-enhanced MR arthrography. Radiology 1995; 197(1): 297–299.

23. Andrews JR. Bony injuries about the elbow in the throwing athlete. Instr Course Lect 1985; 34: 323–331.

24. Anz, A., W., MD & Bushnell, B., MD. & Griffin, L., MS. & Noonan, T.J., MD. & Torry, M., MD. & Hawkins, R.J., MD Correlation of Torque and Elbow Injury in Professional Baseball Pitchers. Published online before print April 16, 2010; doi: 10.1177/0363546510363402

25. Oullette, H., & Bredella, M., & Labis, J., & Palmer, W., & Torriani, M., MR imaging of the elbow in baseball pitcthers. Skeletal Radiol. 2008; 37:115-121.

26. Sabick MB, PhD., & Torry MR, PhD., & Lawton R, MD., PhD., Hawkins JH, MD., FRCS(C)., Valgus torque in youth baseball pitchers: a biomechanical study. J Shoulder Elbow Surg. 2004; 13(3) pp: 349-355.

27. American Sports Medicine Institute; 2004. Available at: www.asmi.org. Accessed at July 21, 2009.

28. Roberts EM. Cinematography in biomechanical investigation. Selected topics in biomechanics. In: Cooper JM, editor. CIC symposium on biomechanics. Chicago: The Athletic Institute; 1971. pp. 41-50) Grana W Clin Sports Med. 2001; 20 (3), 541-8.

29. Wilson FD., Valgus extension overload in the pitching elbow. Am J Sports Med 1983; 11:83-8.

30. Magra M, Caine D, Maffulli N., A review of epidemiology of Paediatric elbow injuries in sports. Sports Med. 2007; 37 (8), 717-35.

31. Fleisig GS, Weber A, Hassell N, Andrews JR., Prevention of elbow injuries in youth baseball pitchers. Curr Sports Med Rep. 2009; Sep-Oct:8 (^{n}), 250-4.

32. Dun S, Lotfice J, Fleisig GS, Kingsley D, Andrews JR., A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? Am J Sports Med. 2008; 36 (4), 686-92.

33. Lyman S. Fleisig GS, Andres JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. The American Journal of Sports Medicine., 2002; 30(4):463-468,
.
34. Aguinaldo, AL., Chambers, H., (2009) Correlation of Throwing Mechanics With Elbow Valgus Load in Adult Baseball Pitchers., American Journal of Sports Medicine. 2009; 37(10), 2043-2048.

35. Nissen CW, Westwell M, Ounpuu, S, Patel M, Solomito M, Tate J., A biomechanical comparison of the fastball and the curveball in adolescent baseball pitchers. Am J Sports Med. 2009; 37 (8), 1492-8.

36. Paraskevas P., &Papadopoulos A., &Papaziogas B., &Spanidou S., &Argiriadou H., &Gigis J., Study of the carrying angle of the human elbow joint in full extension: a morphometric analysis. Surg Radiol Anat. 2004; 26:19-23.

37. Yilmaz E., &Karakurt L., &Belhan O., &Bulut M., &Serin E., &Avci M., Variation of carrying angle with age, sex, and special reference to side. Orthopedics. 2005; Nov;28(11):1360-3

38. Cain El JR, Dugas JR, Wolf RS, Andrews JR. Elbow injuries in throwing athletes: a current concepts review. Am J Sports Med 2003; 31:621-35. AND King JW., Brelsford HJ, Tullos HS. Analysis of the pitching arm of the professional baseball pitcher. Clin Orthop 1969; 767:116-23.

39. Wright RW, Steger-May K, Klein SE., Radiographic findings in the shoulder and elbow of Major League Baseball pitchers. Am J Sports Med. 2007;35(11), 1839-43.

40. Van Roy P, Baeyens JP, Fauvart D, Lanssiers R, Clarijs JP., 2005; Sep 15-Nov 15 Ergonomics. 48 (11-14), 1645-56.

41. Yilmaz, E., & Karakurt, L., & Belhan, O., & Bulut, M., &Serin E., & Avci, M., Variation of carrying angle with age, sex, and special reference to side., Orthopedics., 2005; 28(11): pp. 1360-3.

42. Potter HP. The obliquity of the arm of the females in extension. J anat Physiol 1895:29:488-492., 2. Atkinson WD. Elfman H. The carrying angle of the human arm as, a secondary sex character. Anat Record 1945;91:49-53., 3.

43. Zampagni, ML., Casino, D., Zaffagini, S., Visani, AA., Marcacci, Maurillo., Estimating the Elbow carrying angle with an electrogoniometer: Acquisition of Data and Reliability of Data and Reliability of Measurements., Orthopedics. 2008; Apr. 31(4):370.

44. Werner, S L., & Murray, T A., & Hawkins, RJ., & Gill, T J, MD,. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers., J Shoulder Elbow Surg 2002;11:151-155.

45. Takeda, T., &Ishida, H., &Hortuchi, Y., &Nakao, Y., &Yutaka, Y., Radiographic study of osteoarthritic elbows in professional baseball pitchers. J Orthop Sci. 1997;2: 372-377.

VITA

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Scope and Method of Study: The purpose of this study was to determine if anthropometric differences (height, weight, bi-acromial distance, hip width, shoulder external rotation) could be predictors of the degree of carrying angle in the throwing elbow of college baseball pitchers, which may be an indicator of decreased conduction velocity of the ulnar nerve. Subjects consisted of healthy Division I Baseball pitchers from Oklahoma State University who have a mean age of 20.25 years. There were a total of 13 subjects that began the study. One subject was excluded because he was a sidearm thrower. These subjects were recruited through the athletic department on a volunteer basis only and did not receive any compensation for their participation.

All of the athletes that chose to participate came to the baseball training room at the allocated time, where they filled out a questionnaire that requested information about the type of pitches thrown, length of baseball career, and any previous orthopedic injuries. After each athlete finished the questionnaire an athletic trainer wrote each athlete's height, weight, and age on the data sheet from an official body composition form used in the athletic department. After all paperwork was finished the measurements were made in the supine position for shoulder external rotation and internal rotation, elbow carrying angle, and in standing for bi-acromial, and inter-trochanteric width.

Findings and Conclusions: Pearson Correlation Coefficient suggests a moderate correlation between the dominant (throwing) side and hip width, and years pitched. The correlations were not high enough to use in linear regression analysis.

ADVISER'S APPROVAL: Dr. Doug Smith