5-2022

Predictors of Peak Elbow Valgus Torque in Collegiate Baseball Pitchers

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Predictors of Peak Elbow Valgus Torque in Collegiate Baseball Pitchers

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Athletic Training

by

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Boise State University
Bachelor of Science in Kinesiology, 2020

May 2022
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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Abstract

Context: The incidence of UCL tears in baseball is at an all-time high. ATs are in the position to identify those at risk and potentially prevent injury to the UCL. In baseball, research has associated elbow valgus torque as a potential predictor of injury risk. However, markerless analysis has not assessed possible predictors of injury to the UCL in baseball players. **Objective:** Identify the kinematic factors that influence peak elbow valgus torque through the sequence of a fastball pitch. **Design:** Cross-sectional study. **Setting:** Field study performed in university's pitching development center. **Participants:** Division 1 collegiate baseball pitchers (N=21; 17RHP, 4LHP; 20 ± 1y, 190 ± 4cm, 98 ± 7kg). **Main Outcome Measure(s):** Using KinaTrax® markerless motion capture, Division 1 college baseball pitchers' kinematics and kinetics of a single fastball pitch were analyzed. Peak elbow valgus torque, maximum glenohumeral external rotation, maximum glenohumeral internal rotation, glenohumeral angular velocity at ball release, elbow flexion at stride foot contact, and maximum hip shoulder separation. **Results:** Average velocity of pitches analyzed was 89.4 ± 3.6mph. Peak elbow valgus torque was 137.2 ± 26.2Nm. Maximum glenohumeral external rotation explain 42.4% variance in peak elbow valgus torque (r= -.651; P=.001). No other variables were significantly correlated with peak elbow valgus torque (P>.949). **Conclusions:** Maximum glenohumeral external rotation during the pitching motion influences peak elbow valgus torque. The negative correlation, as described, is a result of the unique coordinate conventions used by KinaTrax®. Previous literature has identified that increases in maximum glenohumeral external rotation concomitantly increases fastball velocity. Because this variable can influence both velocity and elbow stress, further research is necessary to identify norms that allow for safe and effective play.

Key words: Elbow valgus, UCL, baseball

Acknowledgment

I would like to give thank to all of the people who helped and supported me throughout this project. This project started as an idea that was floated with no real direction and has become something that I am extremely passionate about, and a future career for me.

I want to thank all three of my committee members: Dr. Brendon McDermott, Dr. Abigail Carpenter Schmitt, and Dr. Bart Hammig. Thank you to Dr. McDermott for your guidance and support, as well as keeping me levelheaded through the entire process of this. Thank you to Dr. Schmitt for giving me such a gracious welcome to the world of biomechanics, and with all of your assistance day in and day out on this project. Thank you to Dr. Hammig for assisting in making this research project happen.

I would like to thank Corey Wood, Blaine Kinsley, Matt Hobbs, and everyone at Razorback Baseball for allowing me access to preseason screening data. Working in NCAA Division 1 athletics is not easy and allowing an outsider to gather data is no small feat.

Finally, I want to thank all of my family, friends, classmates, and professors who have been very supportive through this two year long project. Through all the changes, the ups, and the downs, I have felt great support from everyone around me, and it has made this process very enjoyable.

Dedication

I want to dedicate this paper to all of the athletes who have been told that they have a career ending injury by any sort of medical professional. The devastation that you feel is understandable. I hope that this research and future research is able to assist in cutting down on the life-changing discussions.

I want to also dedicate this to athletic trainers, who are on the front lines of these injuries, and often have to have those tough conversations with athletes. While those conversations may never get easier, I am hopeful that they become few and far between.

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Introduction

A baseball pitch is a complex, ballistic motion that occurs extremely rapidly, within seconds depending on the pitcher. In order for a pitch to have adequate velocity to be considered a "good" pitch and the lowest potential for injury, the unique kinetic sequence for each pitcher must be executed well. Any disruption in the kinetic sequence can lead to abnormal force distribution, and increased injury potential.

Ulnar Collateral Ligament (UCL) injuries have been rapidly increasing at all levels of baseball,[11,12] and researchers are attempting to identify why this is happening, and what can be done to mitigate the risk that occurs with pitching a baseball. One approach for identifying potential risk factors is through biomechanical analysis. During biomechanical analysis of a baseball pitch, kinetics and kinematics are identified for each pitch, and evaluated to determine what factors can influence injury.

For baseball pitchers, risk of elbow injury has been linked to high elbow valgus torque during the pitching sequence.[17,18] Because of this link between elbow valgus torque and elbow injuries, it is important to understand what factors influence elbow torque. Once these factors are identified, this information could be used by coaches to manipulated the pitching process in an effort to attempt to increase the performance of a pitcher, and decrease injury risk associated with the unique movement. This study aims to tackle the first part of the elbow injury prevention process and identify what variables are influence elbow valgus torque during a fastball pitch through biomechanical analysis.

The hypotheses of this study include:

a. An increase in maximum glenohumeral external rotation will increase peak elbow valgus torque.

b. A decrease in maximum glenohumeral internal rotation will increase peak elbow valgus torque.

c. An increase in maximum hip shoulder separation will increase peak elbow valgus torque.

d. An increase in elbow flexion at stride foot contact will decrease peak elbow valgus torque.

e. An increase in glenohumeral angular velocity at ball release will increase peak elbow valgus torque.

Literature Review

UCL Injury

The Ulnar Collateral Ligament (UCL) is a tri-bundled, ligamentous structure on the medial elbow that prevents valgus stresses to the joint. The three bundles (anterior, posterior, and transverse) all play a unique role in joint protection. The anterior bundle (which has an anterior and posterior band) has attachment sites on the inferior surface of the medial epicondyle and the medial aspect of the coronoid process and protects against valgus stresses through the entire range of motion of the elbow.[16] The anterior band of the anterior bundle resists valgus forces from extension until 90° of elbow flexion, while the posterior band of the anterior bundle resists valgus forces when the elbow is flexed more than 60° and is the portion of the UCL receiving the most stress during a baseball pitch. [16] The transverse bundle does not cross the elbow, and thus provides little to no support against valgus load. The posterior bundle only provides stability of the elbow when it is flexed beyond 90° and provides little stability if the anterior bundle is intact. However, if the anterior bundle is disrupted, the posterior bundle provides valgus support.[16]

Atwater[17] examined numerous overhead athletes' throwing motions, and how these motions led to injuries. She concluded that, in baseball, repetitive valgus force was linked to injuries of ligamentous, bony, and muscular structures on the medial elbow. Bullock et al[18] came to the same conclusion in a meta-analysis of baseball biomechanics and injuries. Results from the meta-analysis[18] concluded that previous injury can impact the mechanics of the throwing motion, forces at the elbow were related to elbow injuries, pitching through pain increased injury risk, changed mechanics, and increased forearm flexor muscle activity had a relationship with elbow injuries. This highlights how complex it can be to identify who may be at a higher risk for elbow injuries.

Specific studies have examined different components of overhead throwing and how these contribute to valgus stress at the elbow. Morrey et al[14] identified three categories of structures that provide stability against valgus force: osseous, soft tissue/capsule, and the UCL. The osseous restraint comes from the lateral aspect of the elbow, and the compressive forces between the radius and the humerus. The soft tissue is categorized as the anterior capsule, supporting ligamentous structures not including the UCL, and muscles that cross the elbow joint. Morrey et al[14] found that, in full extension, the elbow is stabilized almost equally between the three categories, with the anterior capsule accounting for 38% of overall stability, while the other two categories account for 31% each, respectively. However, at 90° elbow flexion, the distribution of forces varied dramatically. The stabilization forces that, while the elbow is extended, are typically placed on the anterior capsule, are redistributed to the UCL when the elbow is flexed. When the elbow is flexed at 90° the UCL accounted for 54% of stability, osseous barriers accounted for 33%, and soft tissue accounted for only 10% of stability. Because this study did not examine the stabilizing factors of the elbow during a pitching motion, it cannot be definitively stated that this is the distribution of stability for a pitch.[14] However, the elbow is typically between these two positions at any point during the baseball pitch, so it can be assumed that the stabilizing roles of each category fall somewhere between these percentages.[13] This study conveyed that medial elbow stability is fluid throughout dynamic movements, such as a baseball pitch.

The UCL is fragile in isolation,[15] but when working in a dynamic system with supporting structures, the elbow can handle an increased load without injury to the UCL. While evidence shows that the UCL alone can withstand 32Nm of force in vitro,[15] Fleisig et al[3] found that maximum elbow valgus forces can range anywhere from 64Nm to 120Nm, depending on the pitch, the level of the athlete, and other extraneous factors. When maximum effort pitches are made, forces going through the medial elbow are enough to tear the UCL, if it was not for the other supporting structures taking some of the force. The bony makeup of the elbow, the surrounding musculature,[14] in particular, the flexor carpi radialis,[18] play a role in safe dynamic movement.

Epidemiology

Injuries are a common part of sport, but it is important to know who is most susceptible to injuries in a particular activity. According to research on NCAA athletes, over half of the injuries in college baseball affect the upper extremity, with non-contact practice type injuries occurring most often.[10] A large number of practice injuries occur during preseason when there are no restrictions on athlete exposures or time during the week that an athlete can practice, condition, or lift weights. It is hypothesized that this is due to increased exposure in combination with decreased conditioning, leading to overuse injuries.[10] Although college baseball has a relatively low injury rate (1.85 injuries per 1000 athlete exposures during practice, and 5.78 injuries per 1000 athlete exposures during games) when compared to other NCAA sponsored sports, 25% of all injuries reported lead to a severe injury causing the athlete to miss 10 or more days of participation. Pitchers account for 20.9% of all baseball injuries, while injuries from the pitching motion are responsible for 15.3% of all baseball injuries. Upper extremity injuries accounted for 44.6% of injuries in all baseball players during games, while 46.4% of injuries occurred during practices.[10] Knowing that pitchers are at a high risk of non-contact injuries opens the door for researchers to identify predisposing factors that increase the likelihood of injury.

Along with the high injury rates in college baseball, the prevalence of UCL reconstruction surgery is rising. Hodges et al[11] investigated overall instances of UCL reconstruction surgeries in the state of New York between 2002-2011, and found there was a 193% increase in volume of the surgery. They found that the rate of surgeries per 100,000 general population is skyrocketing to 0.45 surgeries per 100,000 population. This increased rate of surgical intervention was found in all populations, regardless of sex or age, but the largest spike in volume of surgeries was observed in 17-20 year-old males. Researchers concluded that this is likely resulting from overuse injuries and the lack of education around these injuries in overhead athletes, primarily youth baseball players.[11]

In a study that was specific to baseball pitchers, Camp et al[12] found that injury trends among this small population were on a steady increase. There was a large jump of annual reconstructions that started around the 2005 season for Major League Baseball and Minor League Baseball pitchers, which more than doubled the annual cases of surgery. Levels of reconstruction surgery have not returned to levels prior to the 2005 season since this increase was seen. The average time until these athletes returned to competition at any level was over 400 days and returning to the level at which they were injured was over 500 days. These significant findings from the most robust epidemiology study of the baseball pitching population and UCL injuries establishes the need for identifying risk factors of UCL injuries.[12]

With the increase in UCL injuries, it is important to identify the factors that may predict this devastating event from occurring. Biomechanically, increased elbow valgus stresses have been able to help identify those who are most at risk for UCL injury.[3] Along with that, decreases in glenohumeral range of motion in all directions has been attributed to shoulder and elbow pain and injury in the throwing athlete. [5,18,21-23]

Glenohumeral External Rotation

It is well-documented that glenohumeral external rotation is correlated with valgus force during a baseball pitch at a variety of levels.[1-3] Aguinaldo and Chambers[1] discussed the impact that maximal external rotation had on elbow valgus torques. In sixty-nine adult baseball players throwing fastballs, researchers found that the more glenohumeral external rotation the player had, the higher their elbow valgus torques were, with the mean maximum external rotation being 169 ± 12°. Anz et al[2] found in a study of 23 professional baseball players that both maximum degrees of external rotation and maximal external rotation torque are positively correlation to elbow valgus torque during a fastball. Fleisig et al[3] identified that peak elbow valgus forces occur at, or near, the time in which the shoulder is in maximal external rotation. With the current evidence, it is fair to conclude that maximum degrees of external rotation and maximal external rotation torque have a positive correlation with peak elbow valgus torque, and occur at similar times during a pitch.

Glenohumeral Internal Rotation

Nicholson et al[4] took a machine learning approach to predict the kinetics of a baseball pitch. They were attempting to identify what variables, out of 18 selected through expert opinion and literature review, most significantly impacted stresses on the elbow. They ran all variables through regression models and 4 machine learning models to determine significance. In doing this, they found that maximum velocity of internal rotation was correlated with both elbow valgus load and shoulder distraction forces. It has been suggested by Wilk et al[5] that glenohumeral internal rotation deficits, and related forces, increase injury risk for the elbow and the shoulder. Identification of functional glenohumeral internal rotation deficits, and their relation to pain, injury, and kinetics of the elbow during the pitching motion has not been studied.

Elbow Flexion

Elbow flexion angle varies between pitchers, and between pitches, and given this variability, it is important to determine if there is any significance in the stresses through the elbow. Aguinaldo and Chambers[1] demonstrated that decreased elbow flexion at the point of peak valgus was associated with increased valgus forces in the elbow during the pitch; meaning, the straighter the elbow, the more medial elbow force. As noted in their conclusion, this was an important finding because, clinically, pitching coaches are often instructing baseball players to decrease their elbow flexion during the pitch.[1] During a pitch, the time that valgus load is increasing corresponds with the timeframe in which the elbow is rapidly extending. Werner et al[13] found that there was roughly 60° elbow extension within 0.01 seconds. With elbow flexion being such a dynamic aspect of the pitching motion, it should be further researched to determine if there is an optimal range that both protects against injury and allows for adequate performance.

Trunk Rotation

Aguinaldo and Chambers[1] found that an early initiation of trunk rotation was associated with increased elbow valgus torque. They described early trunk rotation initiation as trunk rotation beginning prior to the lead foot hitting the ground.[1] Aguinaldo and Escamilla found that trunk rotation time and power were both factors in predicting maximal elbow valgus. This study also found that these were the only two variables that predicted pitch velocity.[19] With both of those correlations, there must be a fine line between increasing trunk power and trunk rotation time.

An increase in trunk power with concomitant decreased trunk rotation time may be sought by the coaching staff to increase velocity, but this combination seems to contribute to the risk of increased elbow stress.

Arm Slot

Aguinaldo and Chambers[1] found that the combination of shoulder abduction, trunk lean, and elbow flexion (commonly defined as arm slot) was a predicting factor of elbow valgus torque. Specifically, those who were identified as “side arm” throwers, who have an ipsilateral trunk lean, a more extended elbow, and less shoulder abduction, showed significantly higher elbow valgus torque than throwers who have overhead and contralateral lean approach to throwing.[1] Because of this study, it is easy for a coach or athletic trainer to identify a pitcher as a sidearm thrower, and note that the pitcher may be at a higher risk of injury.

Front Foot

The pitching motion is one where even the most minute details are important in both the health and performance of the pitcher. This can be shown when discussing the relationship between the front foot of the pitcher and pitching elbow stresses. Seroyer et al[9] identified the result of numerous unique malalignments of the kinetic sequencing of a pitch. It was theorized that the stride foot landing in a closed (or internally rotated) position decreases force production through the body, including through the elbow. In contrast, landing with the front foot in an open (or externally rotated) position will cause premature pelvic rotation, which will uncouple the kinetic chain and cause an increase in forces placed through the upper extremity.[9] While often overlooked in a throwing motion, the position of the front foot at landing can have implications up the kinetic chain when generating force.

Glove Side Kinematics

Barfield et al[6] investigated the opposing side (glove side) mechanics and their impact on pitch kinetics and kinematics. This novel study concluded that there was a negative correlation between elbow flexion on the glove side at maximal external rotation and pitching arm elbow valgus force. This is theorized because the glove arm will have an impact on trunk rotation, thus making the sequencing sub-optimal, and increasing valgus load at the elbow. Furthermore, they identified an active glove arm, or one that has greater elbow extension and shoulder abduction, contributing to lower valgus loads on the throwing elbow, while an inactive glove side arm contributed to higher valgus loads on the pitching arm. [6]

Kinematic Sequencing

Scarborough et al[7] researched the different kinematic sequences found in throwing a fastball in baseball. They found that there were fourteen unique kinematic sequences amongst 30 pitchers in the baseball pitch. These fourteen sequences could be classified into four categories. The closest to a theoretical perfect pitch was proximal to distal sequencing. This sequencing is identified by movement starting from the pelvis, going through the trunk, through the arm, down the forearm, and finishing the pitch with motion in the wrist, almost creating a whip effect. The other categories describe what body segment was the first to deviate from the proximal to distal sequencing. Scarborough's research found that a kinematic sequence that had an initial deviation from the theoretical perfect pitch at the distal upper extremity was the most common and accounted for the largest mechanical stresses at the elbow.[7]

Velocity

There is varying information that results in unclear findings regarding a correlation between pitch velocity and valgus forces at the elbow. A study by Nicholson et al[4] used machine learning to predict elbow valgus and shoulder distraction forces. They found that out of over 15 variables, fastball velocity was the most influential variable used to predict elbow valgus forces in all models run for their population of high school pitchers. Conversely, a later study showed that there was no correlation in fastball velocity and elbow kinetics.[8] These conflicting studies leave great room for further research, which has clinical importance to ensure that velocity of the fastball can increase in a safe and effective manner.

Stride Phase

Tanaka et al[20] found that, during the stride phase, having increased wrist extension, elbow pronation, knee flexion on the leading leg, knee extension on the trailing leg at stride foot contact, and upward displacement of the bodies center of mass all had correlation to decreased elbow valgus toques. These five parameters, when combined, accounted for 38% of the variance in elbow valgus force. These variables could easily be measured with motion capture and could assist in the identification of athletes who may be at a greater risk for injury.

Summary and Research Gaps

Biomechanics has taken the world of baseball by storm and the literature surrounding it is starting to trickle in. Numerous parts of the body have been studied in an effort to identify specific factors that can influence medial elbow forces during a pitch. With the knowledge of how much force is going through a pitcher's elbow during a pitch, researchers and coaches should be able to identify who is at increased injury risk; all of which could benefit the sport. Multimodal preseason screenings that consist of a biomechanical analysis of the pitching motion, as well as passive range of motion assessment should be used to determine if a baseball player is at risk for a UCL injury.

While research in baseball biomechanics, specifically in predicting elbow valgus forces, is vast and developing rapidly, there are some key gaps. Some studies[1,19] use average elbow valgus forces over the duration of the pitch, while others[2,8] use peak elbow valgus in determining what could be correlated with elbow valgus forces. Also, few studies confirm predictors of elbow valgus with the exception of shoulder external rotation. In this paper, I am attempting to identify predictors of peak elbow valgus torque during a baseball pitch.

Methods and Materials

This research study received University of Arkansas IRB exempt approval (Protocol #2102318176) to gather deidentified data from routine performance screenings of baseball players.

Participants

Twenty-one adult pitchers (demographics in Table 1), who were all a part of one collegiate baseball team, were included in this study. All pitchers reported to their session and were considered healthy, with no significant injury at the time of collection. Data collection was performed at the pitcher's home practice facility two weeks prior to the season start.

Table 1. Participant demographics (mean ± SD).

Age	20 ± 1 years
Height	190 ± 4 cm
Mass	98 ± 7 kg
Throwing Arm	17 right-handed, 4 left-handed
Pitch Velocity	89.4± 3.6 mph*

Note: Pitch velocity includes data from 20 pitchers - 1 was unavailable due to a data collection error.

Setup and Protocol

Motion capture was conducted using an eight camera, markerless KinaTrax (Boca Raton, FL) training setup. Markerless motion capture works by tracking body segments based on pattern recognition algorithms and solves for joint kinematics, as opposed to traditional motion capture with markers being placed on anatomical landmarks. The pattern recognition algorithms allow for each pitch to be analyzed, and the KinaTrax artificial intelligence to identify the landmarks used for measurements. All cameras were set to capture at a data sampling rate of 300Hz and were capturing at full resolution. Kinematic data was filtered using a 4th-order Butterworth Low-Pass Filter with a cutoff frequency of 15Hz. On the day of collection, each pitcher performed an individual warmup and stretching routine prior to their pitching session, prescribed by the team and independent of the research collection. Each pitcher was instructed to throw 15 total pitches of various pitch types, all at full intensity from a standard distance of 60 ft 6 in (18.4 m) from the plate. At least two fastballs were captured for each pitcher. For each pitcher, a randomly selected single fastball pitch was used for data analysis, consistent with other studies evaluating pitch mechanics.[13,24,25] A regulation baseball, with a 23 cm circumference and mass of .14 kg, was used for all pitches in this study. All pitches were thrown off a NewtForce (Little Rock, AR) pitcher's mound. Velocity, ball movement, and spin rate was measured using TrackMan (Scottsdale, AZ).

Data Extraction and Analysis

All raw kinematic, kinetic, and temporal data was accessed through KinaTrax software, including subsequent algorithms. KinaTrax processes raw motion capture data using Visual3D (C-Motion Inc, Germantown, MD) to generate the musculoskeletal time-series parameters during the pitch. Peak elbow valgus torque, hip shoulder separation, elbow flexion, glenohumeral rotation, glenohumeral angular velocity, beginning and end of kinematic sequence, time of foot contact, and time of ball release were extracted from KinaTrax software. Using custom MatLab (Mathworks, Natick MA) algorithms, discrete variables were extracted from raw KinaTrax data, including maximum glenohumeral external rotation, maximum glenohumeral internal rotation, maximum hip shoulder separation, elbow flexion angle at foot contact, glenohumeral angular velocity at ball release, and maximum elbow valgus torque.

Figure 1. Time series of elbow torque over the course of a fastball pitch.

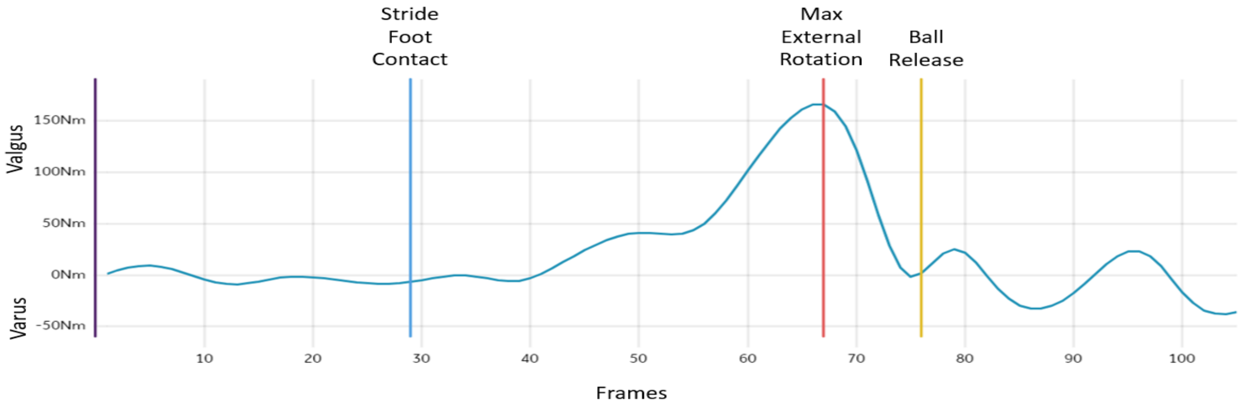
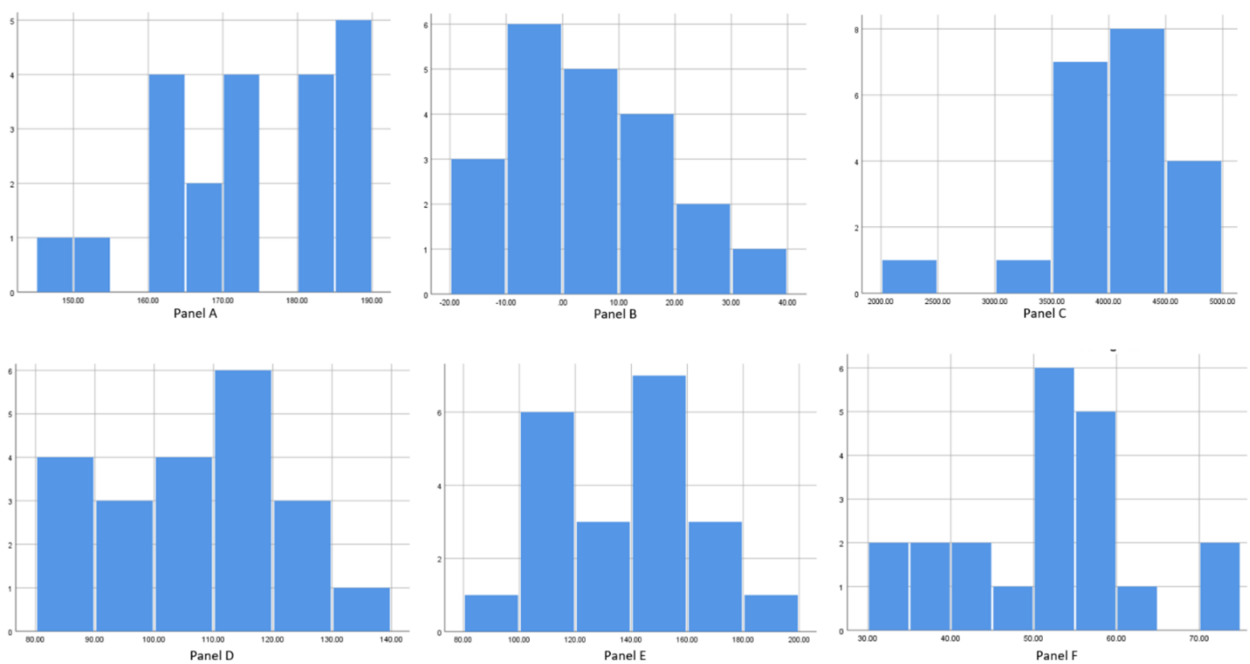


Figure 2. Histograms for each of the variables of interest.



Panel A: Maximum Glenohumeral External Rotation. Panel B: Maximum Glenohumeral Internal Rotation. Panel C: Glenohumeral Angular Velocity at Ball Release. Panel D: Elbow Flexion at Foot Contact. Panel E: Peak Elbow Valgus Torque. Panel F: Maximum Hip Shoulder Separation.

Using SPSS (SPSS Inc., IBM, Chicago, Illinois), the variables were analyzed with a bivariate Pearson Correlation Coefficients ($p < 0.05$). Assumptions for normality of distribution were forgone for this study's statistical analysis. Histograms showing distribution for each variable of interest are included in Figure 2.

Variables of Interest

Maximum glenohumeral external rotation is a variable of interest due to previous literature[1-3] supporting the claim that this measurement impacts elbow valgus torque. Maximum glenohumeral internal rotation is a variable of interest to further investigate if a functional glenohumeral internal rotation deficit has relation to high elbow valgus torque. Passive glenohumeral internal rotation range of motion deficits have been linked to pain and injury in the upper extremity of baseball pitchers,[5] so this study will help bridge the gap to determine if this is due to increased elbow valgus torque. Maximum hip shoulder separation is a variable of interest because of the relation in previous literature to fastball velocity.[27] This is an effort to identify if the variable is safe to attempt to manipulate for performance gains, or if an increase in peak valgus torque would be associated with the manipulation of this variable. Elbow flexion at stride foot contact is a variable of interest due to previous literature[1] suggesting that elbow flexion at other time points during a pitch relates to elbow valgus torque. Glenohumeral angular velocity at ball release is a variable of interest due to findings[27] that state that an increase angular velocity is related to increased fastball velocity.

Results

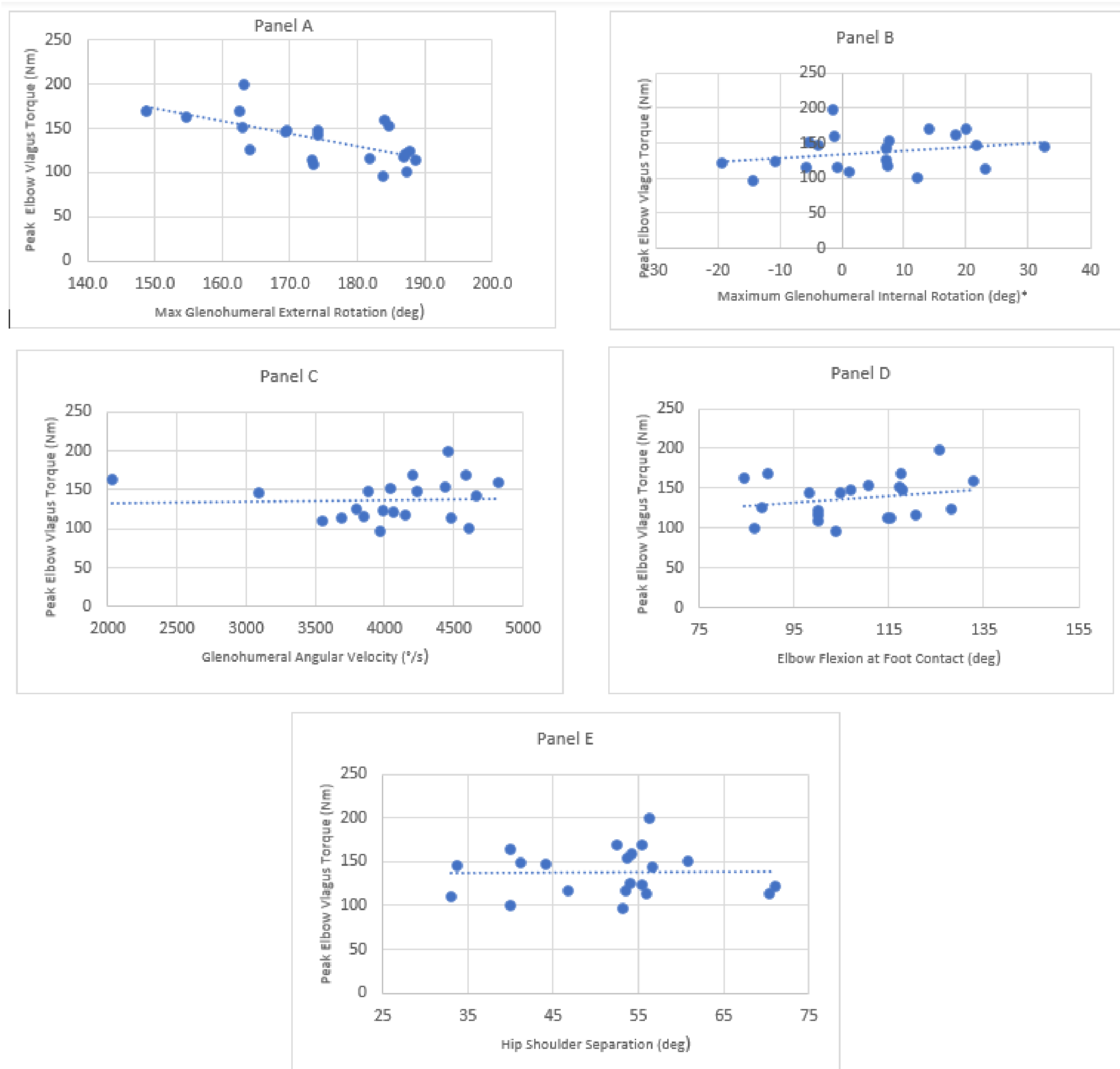
Maximum shoulder external rotation explained 42.4% of the variance in peak elbow valgus torque. In our cohort, peak elbow valgus torque was observed to be 137.2 ± 26.6 Nm. No other variables were significantly related to peak elbow valgus torque ($p \geq .240$). The results of the correlation analysis are presented in Table 2. Correlations of the variables of interest are shown in a scatter plot in Figure 3.

Table 2. Kinematic Variables and Their Correlation to Peak Elbow Valgus Torque

Parameter	Mean ± SD	r	r^2	p
Max Glenohumeral External Rotation	174.4° ± 11.8°	-.651*	.424*	.001*
Max Glenohumeral Internal Rotation	5.2° ± 13.3°	.268	.072	.240
Glenohumeral Angular Velocity at Ball Release	4030°/s ± 618°/s	.047	.002	.840
Elbow Flexion at Foot Contact	107.7° ± 14.0°	.231	.053	.314
Max Hip Shoulder Separation	51.1° ± 10.1°	.015	<.001	.949

*Denotes significance at p<.05.

Figure 3. Correlations of the Variables of Interest



Panel A: Maximum glenohumeral external rotation and peak elbow valgus torque.

Panel B: Maximum glenohumeral internal rotation and peak elbow valgus torque.

*Negative number represents internal rotation, positive represents external rotation.

Panel C: Glenohumeral angular velocity at ball release and peak elbow valgus torque.

Panel D: Elbow flexion at foot contact and peak elbow valgus torque.

Panel E: Maximum hip shoulder separation and peak elbow valgus torque.

Discussion

The purpose of this study to was investigate variables that influence peak elbow valgus torque during the pitching motion while throwing a fastball in college baseball players. The main findings from this study are that maximum glenohumeral external rotation was correlated with peak elbow valgus torque during the throwing motion. These findings are similar to previously published literature,[1,3,26] however, this study looked specifically at peak elbow valgus torque while the others listed identified mean elbow valgus torque throughout the pitching sequence. The peak valgus torque is important to identify, as it is a quantifiable amount of stress being placed on the elbow at any given time during the pitching motion. Clinically, this is relevant since maximum external rotation explains over 1/3 of the variance of peak elbow valgus torque. It has also been documented in previous literature[27] that maximum external rotation influences fastball velocity, with greater external rotation leading to greater fastball velocity. Because there is an increase in both velocity and peak valgus forces with increasing maximum external rotation, it is important to identify that there is a fine line between a performance increase and a potential injury when maximum external rotation increased. Further research is needed to identify if there is a cutoff point for maximum external rotation that both improves performance and limits injury risk.

Other findings from this study were that no other variables had a significant correlation to peak elbow valgus torque. Having no significant correlation between maximum internal rotation and peak elbow valgus torque identifies that peak elbow valgus torque may have no relevance when discussing the widely studied phenomenon of Glenohumeral Internal Rotation Deficit (GIRD), and the pain and injury associated with it.[5,28] Our findings show that there is no relation between glenohumeral angular velocity at ball release and peak elbow valgus torque. This is contrary to the findings of Nicholson et al[4] who found that peak angular velocity, when used in a machine learning model, had an impact on peak elbow valgus torque when normalized to body weight and height. These contradictory findings, along with angular velocities impact on fastball velocity,[27] require more research to determine if there is a meaningful relationship of peak elbow valgus torque and angular velocity, and at what point in that pitching motion this occurs. Aguinaldo and Chambers[1] also identified that elbow flexion at peak elbow valgus torque was associated with mean elbow valgus. They found that less elbow flexion at that time point increased the mean elbow valgus force. However, when looking at elbow flexion at foot contact, a timepoint that occurs moments before peak elbow valgus, it was found that elbow flexion had a negligible effect on peak elbow valgus torque. Elbow flexion at stride foot contact has been shown to have an impact on fastball velocity, with greater elbow flexion resulting in higher fastball velocity.[27] Although we did not explore the relationship between elbow flexion and velocity, we did not see a significant correlation between elbow angle at foot contact and peak elbow valgus torque. With the combination of having no impact on peak elbow valgus torque and having a positive influence on fastball velocity, elbow flexion at foot contact should be further investigated to determine if there is an optimal range for both safe and effective throwing. While trunk rotation power and timing have been shown to have an impact on peak elbow valgus,[19] this study concluded that the degrees of separation between transverse planes of which the shoulder and hips move (which is identified as hip-shoulder separation in the literature[3], in coaching and in this study) was not correlated to peak elbow valgus torque. Hip-shoulder separation has been shown to have a positive relationship with fastball velocity,[29,30] while no studies have identified an increase in peak elbow valgus torque, meaning this could be a safe and effective way to increase performance.

Maximum glenohumeral external rotation having an influence on elbow valgus stresses with the documented influence on velocity of a fastball puts coaches, athletic trainers, and other stakeholders concerned about both the performance and health of the pitchers in a difficult situation. On one hand, for external rotation to be optimized for performance, methods of increasing external rotation should be used. To limit elbow valgus stresses, and potential injuries, increases in external rotation should be limited. However, this study showed that other variables that influence velocity in a fastball are not significantly correlated to peak elbow valgus torque. Based on this information and the current findings, coaches and athletes should be attempting to maximize hip-shoulder separation and increase elbow flexion at foot contact to increase fastball velocity. Neither of these variables negatively impacted peak elbow valgus torque, and positively influence fastball velocity, according to other studies.[27,29,30] Coaches and athletes should be cautious in increasing maximum external rotation and shoulder angular velocity to improve performance. While both variables do have a positive impact on fastball velocity when increased, external rotation was shown in this study to have an impact on peak elbow valgus torque, and while the results of this study show no correlation between peak elbow valgus torque and shoulder angular velocity at ball release, this finding is not agreed upon in the literature.[4] Maximum glenohumeral internal rotation had no influence on peak elbow valgus torque, and has not been shown in the literature to be a variable that influences performance. This study suggests that maximum glenohumeral internal rotation may not be as relevant to elbow valgus as previously thought. There is still more research to be done on glenohumeral internal rotation deficit, and why there is such a high rate of pain and injury at the elbow associated with it.

This study is one of the first to use the KinaTrax motion capture technology in a research setting to analyze collegiate baseball pitching. This markerless system facilitates streamlined data collections by allowing pitchers to move promptly from their warmup to their recorded throws. This sequencing allows for more natural transitions from warmup to competition style throws than with traditional motion capture, by eliminating the time needed to place markers. KinaTrax uses custom Visual3D modeling to determine joint coordinates, as opposed to ISB standards used in previous literature,[1,3,19,24] which explains the negative correlation for maximum external rotation and peak elbow valgus. While there are slight differences in the sign conventions used, KinaTrax offers a user-friendly experience that enables pitchers' biomechanics to be analyzed on a more regular basis than in a traditional lab. This technology opens doors for further research into season-long changes in kinematics and kinetics of a pitch.

Limitations of this study include the number of participants, the participants receiving the same coaching, only analyzing data on fastballs, and the use of new technology. With only 21 participants, this study would need to be replicated with a larger population in order to validate findings. The participants in this study were all coached by the same coaching staff, meaning that there could be nuances in this cohort that may not be seen in a group coached by a different staff. This study also focused solely on college baseball players. Additional studies are needed to identify similarities and differences between age and skill levels. For this study, we only analyzed fastballs. While the fastball is a common pitch type in baseball, there are other pitch types that may have different impacts on peak elbow valgus torque, that could put an athlete at a higher risk of injury. Finally, this study used the KinaTrax markerless motion capture system, and their musculoskeletal models to identify the kinetics and kinematics of each pitch. To my knowledge, there have been no publications citing the use, validation, or reliability of KinaTrax. Additional studies using the data that the KinaTrax system produces to validate the system are needed. These validity studies would allow for coaching staffs who have access to motion capture and the KinaTrax software to use the findings for each pitcher to make adjustments based on other published biomechanics data.

Conclusion

Maximum glenohumeral external rotation was the only variable tested that had a significant correlation to peak elbow valgus torque. Maximum external rotation accounted for 42.4% of variance in peak elbow valgus torque. Therefore, additional factors not tested in this study may have a significant impact on peak elbow valgus torques and should be examined. This study represents a first step in identifying UCL injury risk. Future studies should confirm these findings before researchers and healthcare professionals use them in injury reduction protocols, to create and validate screening protocols, and use the results of the screenings, in combination with therapeutic exercise, to reduce predisposition to injury. Further studies are needed to identify what variables influence peak elbow valgus torques in college baseball pitchers throwing fastballs and what variables have no influence on peak elbow valgus torque, but have an influence on fastball velocity. Finally, further studies are needed to validate the KinaTrax software for biomechanical analysis of baseball pitching.

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