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Kinetic and Kinematic Variables Related to Medial Elbow Joint Space in Collegiate Baseball Pitchers

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KINETIC AND KINEMATIC VARIABLES RELATED TO MEDIAL ELBOW JOINT SPACE IN COLLEGIATE BASEBALL PITCHERS

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ABSTRACT

The ulnar collateral ligament (UCL) is a prime stabilizer in the elbow against valgus force. It is also a commonly injured structure in the overhead-throwing athlete. The majority of literature to date assesses the medial elbow by adding a valgus stress or evaluates the elbow after injury has occurred. The purpose of this dissertation is to explore static changes to the medial elbow and the relationship with the overhead throw. The first investigation sought to determine if there was a bilateral difference in the medial joint space of the elbow in general population college-aged students. There was no significant difference bilaterally; suggesting that the magnitude of stress applied to the elbow by daily activities is not substantial enough to produce an anatomical change to the connective tissue. However, there was a significant gender effect with males exhibiting larger joint spaces. The second study investigated the bilateral difference in the medial joint space of the elbow in male and female overhead athletes with the same protocol from the previous study. In this study, there was a significant difference between the dominant and non-dominant arms. The third study measured the medial joint space of collegiate baseball pitchers before, after, and 48 hours following the throwing of a simulated game. This study also included measures of grip strength and ball kinematics, in order to investigate a relationship between kinetic and kinematic factors and the changes in the medial joint space. There were no significant changes in the medial joint space following pitching a simulated game, although interestingly, grip strength increased following pitching. Ball kinematics did not indicate a relationship with the changes in the medial elbow joint space.

CHAPTER 1
INTRODUCTION

Ulnar Collateral Ligament (UCL) ruptures often involve microtears in the anterior oblique band from repetitive valgus force on the UCL complex.[23,25,45] Eventually, the accumulation of trauma, along with fatigue of the assisting stabilizers, results in a rupture of the UCL by a single throw, or overhead motion.[28,41] This rupture is most often seen in athletes participating in events that require a significant portion of time producing high force in the overhead position, especially baseball, softball, tennis, and some track and field events.[7,25,46] Waris, in 1946, first documented and described the injury of the anterior oblique band of the UCL in 17 javelin throwers.[56] At the time, this condition was seen as rare, however, with an increase in the popularity of overhead sports, injury to the medial elbow has become a common occurrence. With the rise in prevalence of elbow injuries, sports medicine professionals have become proficient in the treatment and rehabilitation of UCL ruptures, as the majority of the literature focuses on surgical and rehabilitation interventions. However, significantly less attention has been paid to potential factors, aside from overuse, contributing to these injuries.

Overuse has been described as a primary risk factor for developing UCL insufficiency, however, few other risk factors have been determined, as well as no true definition of "overuse."[25,41] Pitch counts, pitch types, mechanics, among other elements, have been discussed as risk factors related to overuse,[41] although there have been few resources for developing appropriate protocols for overuse prevention or providing a clear definition of where overuse begins. In chronic injuries, there may be structural changes in the UCL detectable by imaging modalities, prior to symptomatic pathologies. Even in

asymptomatic pitchers, calcifications, joint gapping, and hypoechoic foci have been recognized. [9,38]

Over the previous 30 years, multiple studies have compared kinematic variables, including forearm and wrist actions, and stride length during different pitch types (i.e. fastball vs. curveball vs. changeup). Although there is seemingly a difference in pitch types, there is not consistent data among the literature. Studies have produced variable results including: increases in extensor carpi radialis brevis and longus activity in the curveball compared to the fastball,[47,49] while additional studies have shown a decrease in wrist extensor activity with an increase in the muscles of supination with the breaking pitches.[16]

Studies suggest that the elbow undergoes 64±12 Nm of varus torque,[18] which is at or near the maximum capacity of the UCL as indicated by cadaveric studies[13]. While there is anecdotal support indicating breaking pitches, generate higher valgus forces than others, which need to be countered,[20] current literature has found few kinetic differences between fastballs and curveballs, suggesting that one specific pitch type is not potentially more harmful than others, but considerable debate still exists. Still, there is a general consensus that change-ups are the safest due to low kinetics and reduced kinematics.[16, 20]

To date, there are limited studies linking kinetic, kinematic, and anatomic variables in the investigation of potential risk factors associated with elbow injury in the overhead athlete. Defining a link between the biomechanical and anatomic factors could aid the developing of a systematic and practical injury prevention protocol. Currently, the body of literature regarding measuring the medial elbow involves applying a mechanical stressor to the connective tissue supporting the humeroulnar joint. While this is imperative for diagnosis of a pathological elbow, applying a valgus stress on an athlete with an

asymptomatic elbow will not be highly regarded. Thus it is essential to determine if structural changes in an asymptomatic joint can be assessed in a static position in order to effectively trace these differences to potentially prevent significant injury.

The following three experiments in this dissertation investigate bilateral anatomical differences in the medial elbow. The purpose of experiment 1 was to test the hypothesis that in the general population of active individuals, there would be no anatomical difference between their dominant and non-dominant extremities in terms of the space in the medial elbow. Experiment 2 was conducted to test the hypothesis that in a population of male and female collegiate overhead athletes, there would be a bilateral difference of the medial elbow joint space. Lastly, the purpose of experiment 3 was to build on the findings of the first two experiments and determine anatomical changes in the medial elbow joint space in collegiate baseball pitchers after a pitching bout.

CHAPTER 2
EXPERIMENT 1: ULTRASOUND EVALUATION OF MEDIAL ELBOW JOINT SPACE IN RECREATIONALLY ACTIVE INDIVIDUALS

Damage to the Ulnar Collateral Ligament (UCL) is one of the most prevalent injuries in the upper body athlete, however, factors preventing this complicated elbow injury are not well established. The repetitive nature of the overhead movement creates a destabilizing force to the supporting structures of the elbow, in which the anterior bundle of the UCL acts as the primary stabilizer.[18,59] Accordingly, the UCL is the most commonly injured soft tissue structure and accounts for 97% of elbow complaints among pitchers.[38,53]

To date, the primary method of imaging the UCL, for diagnostic purposes, is Magnetic Resonance Imaging (MRI). MRI is considered the imaging gold standard for the diagnosis of UCL tears with sensitivities up to 100%.[12,35,38,52,53] However, the MRI is not an efficient and cost effective modality when compared to the Musculoskeletal Ultrasound (MSK US).

Recent advances in MSK US image quality, ease of use, and ability for static and dynamic imaging make the US an appealing modality. By placing the elbow under valgus stress, the stability of the ulnohumeral joint can be assessed,[53] which is not a viable option with the MRI modality. It is also valuable to note that the contralateral elbow can be imaged for comparison with the pathologic elbow,[32,53] which is also not a standard course of action with the MRI. Previous studies have shown MSK US to have high specificity, as well as being cost and time effective[35] when a tear in the UCL is suspected.

There is limited literature on the effectiveness of MSK US in the clinical setting in tracking the structures of the medial elbow prior to the occurrence of damage to the tissue. Ciccotti et al. (2014) assessed the anatomical changes in the UCL over a 10-year

longitudinal study showing the bilateral UCL was significantly thicker on the dominant arm, along with a presence of hypoechoic calcifications in the dominant arm. The stress US also showed increased laxity with a valgus force over time. These previous results were supported by Atanda et al. (2015), who found a positive relationship between years of pitching and UCL thickness, indicating structural changes in the connective tissue with continuing valgus stress. While thickness has been measured, UCL length has not often been taken into account. While MRI imaging is not appropriate for asymptomatic structures, MSK US could potentially be used to visualize the medial elbow structures in the clinical setting preceding an injury to the soft tissue.

Clinicians have limited knowledge on the use of MSK US due to more recent improvements in the technology. An MRI is often the first imaging modality ordered, however it is important for clinicians to consider MSK US as a first line of imaging, even prior to elbow pathology. Therefore the purpose of this study is to assess the bilateral medial elbow joint space in recreationally active college age students that are not participating in overhead activity in order to examine the feasibility of measuring the length of the UCL by locating the attachment sites for the anterior bundle of the ligament. We hypothesize that there will not be a significant difference in the medial joint spaces bilaterally.

METHODS AND MATERIALS

We recruited 32 healthy college students (age 20-27 years) from Louisiana State University School of Kinesiology. 12 males and 20 females participated in the study. Participant inclusion was based on no history of collegiate athletic participation and no

current elbow pathology. Information on history of upper body injury as well as athletic participation history and arm dominance was obtained via written questionnaire. Each participant signed an informed consent form approved by the University's Internal Review Board.

Instrumentation

We obtained all image sequences with a GE LOGIQ e MSK Ultrasound utilizing a 12L transducer (GE healthcare, Fairfield, CT). All images were measured using the GE Ultrasound measuring function. Images were saved to a Panasonic 2GB memory card.

Imaging protocol

The MSK images were obtained in a manner similar to that described by European Society of Musculoskeletal Radiology[4]. Participants were fully supported in a supine position with the shoulder abducted and externally rotated to 90° and the elbow flexed to 90° with the forearm supinated.[50] The US probe (transducer) was placed in the coronal plane with its cranial aspect placed distally over the medial epicondyle of the humerus, so that the hyperechoic bone of the medial epicondyle and ulnotrochlear articulation was apparent.[32] Three images were captured bilaterally by the same researcher.

Ultrasound Analysis

Using MSK ultrasound, the peak of the medial epicondyle of the humerus and the medial margin of the coronoid process of the ulna were detected with markers placed on both landmarks as shown in FIGURE 1. The measuring tool of the US was used to measure

the distance between the two landmarks to determine the joint space. One researcher (MRJ) performed all measurements. A family practice physician with a specialty in sports medicine reviewed and confirmed the measurements of 10 of the 32 subjects.

FIGURE 1. Sample image of medial elbow

STATISTICAL ANALYSIS

In order to determine test-retest reliability, an intra-class coefficient (ICC) model (2,1) was used, along with calculating the standard error of the measurement (SEM) to determine variability due to random error.[3,57] Test-retest reliability was established by comparing measured medial elbow joint space within participants on the right side (ICC=.912; Cronbach's Alpha=.969; SEM= .1 mm) and the left side (ICC= .919; Cronbach's Alpha=.971; SEM=.2mm).

To establish the relationships between the independent variables (history of injury, gender, history of sport performance, and arm dominance) and the independent variables

(medial elbow joint space) an analysis of variance was performed. The α level was set at .05. A paired t test was performed between dominant and non-dominant arm measurements with a post-hoc Bonferroni correction. Data analysis was accomplished with the following software packages: Excel (for Mac 2011; Microsoft Corp, Redmond, WA), and SPSS (version 24; SPSS inc, Chicago, IL).

RESULTS

Data were collected on 32 healthy, recreationally active college students, age 21.7 years ± 1.37. The mean medial joint space between DOM and NDOM limbs was not significantly different ($t(31)=1.047$, $p=.303$). However, there was a significant difference in the medial elbow joint space between males (2.734 cm) and females (2.455cm) ($p>.01$) indicating a significant gender affect illustrated in TABLE 1. This was further supported with gender being significantly correlated with both the means of the right and left limbs; $r=.622$, $p<.001$; $r=.605$, $p<.001$ respectively.

DISCUSSION

Results from the analysis of the medial elbow joint space indicate that there is not a bilateral difference in the static length of the ulnar collateral ligament in recreationally active college-age participants. Our findings of a significant gender effect indicate that body size may be a significant variable in the joint space opening of the medial elbow. This could indicate that males have an anatomical predisposition to an unstable joint, without the assistance of the other structures, such as the wrist flexors, which attach across the medial joint.[59]

A significant difference was not observed bilaterally in this population. However, this is not unexpected due to the lack of chronic elbow stress experienced by a general population of college age students.

TABLE 1. Descriptive statistics for gender differences in bilateral medial elbow joint space measurements.

Gender	Right	Left	Mean
Males (n=12)	2.715±.145mm	2.752±.170mm	2.734±.225mm*
Females (n=20)	2.468±.184mm	2.445±.194mm	2.455±.220mm*

*Indicates statistically significant difference p<.01

Chronic injuries are seen more often with overuse and repetitive stress of the medial elbow. The most common complaint in a chronic elbow injury is decreased velocity and a lack of command, or accuracy with an overhead throw,[22] that would not be seen in the currently tested population.

Short-term test-retest reliability analysis done during testing indicated excellent reliability between testing sessions performed on the same day. Based on the test-retest results we believe that MSK Ultrasound images can provide very reliable intra-subject analysis of static medial joint space at 90°, however caution should be exercised when comparing results in dynamic movements, differing elbow or shoulder angles, and when significant time exists between sessions.

We were able to observe the practicality of MSK US for diagnostic imaging. The efficiency at which we were able to take measurements greatly exceeded that of an MRI. The testing was completed in a clinical setting without a Radiologist present, with speed and accuracy, as indicated by the repeatability values. This could potentially be a modality

that could track risk factors for injury prior to a pathological ligament, instead of only being used as a diagnostic tool after the injury occurs. MSK US could be used in conjunction with manual special tests. The UCL stability can be tested with the elbow flexed to 25-30° and the forearm pronated.[7] A valgus stress can be applied on the flexed elbow joint to assess the integrity of the UCL. Excessive gaping compared to the contralateral elbow along with pain with the valgus stress indicates UCL instability.[1, 22] However, excessive gaping is considered 1mm to 2mm, a relatively small value, which as a result, the results are often misinterpreted.[7,22] This joint space could be measured with the dynamic valgus test with MSK US.

It is important to note that US should be viewed as an imaging method that complements MRI rather than one that competes with MRI in the evaluation of musculoskeletal abnormalities,[29] making it a viable first choice before administering the MRI. There are significant advantages to ultrasound over other imaging methods because of its resolution, the dynamic imaging ability, and the ability to image an entire extremity, safely, over a short period of time.

CONCLUSION

In conclusion, we found a significant gender effect in the medial elbow joint space with the shoulder flexed to 90° and externally rotated and the elbow at 90° in healthy, college-age students. The excellent ICC value indicates that the use of MSK US in collecting images of the medial elbow is a valid imagery tool. The medial elbow in different populations needs to be further investigated, along with finding relationships with elbow and shoulder position and the muscles articulating across the involved joints. More

research needs to be conducted using a population that experiences significant medial elbow forces on a regular basis, such as an overhead athlete in order to determine the validity of the bilateral measurement as a means of tracking injury progression.

CHAPTER 3
EXPERIMENT 2: ULTRASOUND EVALUATION OF MEDIAL ELBOW JOINT SPACE IN DIVISION I OVERHEAD ATHLETES

The ulnar collateral ligament (UCL) is composed of 3 bundles: anterior, posterior, and oblique [10,55] connecting the proximal ulna to the distal humerus. The UCL is the main stabilizer against valgus stress in the elbow,[36,58] which is experienced during the throwing motion. In the overhead athlete, the repetitive nature of the throwing-type motion creates a destabilizing force to the supporting structures of the medial elbow, potentially leading to significant injury. UCL ruptures tend to be associated with baseball pitchers; however, all overhead athletes such as those who participate in baseball, tennis, football, volleyball, field events, and water polo experience substantial valgus forces on the UCL.[45,46]

When UCL injury is suspected, magnetic resonance imaging (MRI) is considered the gold standard for the diagnosis of UCL tears with sensitivities up to 100%. [12,35,38,52,53] While MRI can detect a tear in the pathological elbow, severity is not easily determined due to the inability of the MRI to perform a dynamic test[12]. Furthermore, examining the asymptomatic contralateral elbow is not easily done. However, musculoskeletal ultrasound (MSK US) does have the advantage of a dynamic, bilateral assessment.[32,53,55] This advantage was demonstrated in Experiment 1, which obtained excellent reliability when using MSK US to measure the joint space of the medial elbow. These results support those of Ward et al. (2003) who found similar results of reliability.

The elbow joint is easily accessible to ultrasound (US) examination, because of its superficial position.[17] The anterior bundle of the UCL is generally the only portion of the UCL to be examined by MSK US due to this band being the most important functionally and the most readily visible and accessible via superficial imaging. It normally appears as a

hyperechoic, fibrillar structure, originating from the coronoid process of the distal ulna, and inserting onto the medial epicondyle of the humerus.[17,53,55]

Current literature employing US while applying a valgus force to the medial elbow has shown changes in the ligament thickness and an increase in joint space over time in overhead throwers.[2,9,38] Cicotti et al. (2014) saw a mean joint space increase of 2.0 mm when the anterior bundle is released. Narzarian et al. (2003) measured the medial joint space and ligament thickness of 26 professional pitchers at rest and with dynamic US. At rest, they found a significant difference in the mean thickness of the anterior band measured at 6.3 mm ± 1.1 in pitching arms and 5.3 mm ± 1.0 in non-pitching arms. A similar significant difference was found using dynamic US. While at rest, they did not find a significant difference in the medial joint space, however there was a significant difference in the bilateral measurements when a stress was applied.[38] Currently, the literature tends to be restricted to male overhead athletes or non-athletes. To our knowledge, precise US descriptions, techniques, and imaging parameters have not been thoroughly described, and there is no US standard of reference for the normal anterior bundle of the ulnar collateral ligament for the male and female overhead athlete.

Much of the literature related to the UCL has focused on pathological elbows, emphasizing the use of various imaging modalities or surgical and treatment interventions. Knowledge of the relationship between bilateral elbow measurements may affect clinical diagnoses, treatment, and possibly practice and game plans, especially in the overhead athletes who are at a higher risk for significant elbow pathologies.

The purpose of this study was to compare the medial elbow joint space bilaterally in overhead collegiate athletes using MSK US. Based on the results of experiment 1 and

previous literature, our hypothesis was that there would be a significant difference in the bilateral medial elbow joint space, with the dominant (DOM) limb exhibiting a significantly larger joint space compared to the contralateral, non-dominant (NDOM) limb. Additionally, it was anticipated, considering the results of experiment 1, that there would be a significant gender effect, with male athletes having a larger measured joint space.

METHODS AND MATERIALS

We recruited 43 healthy, NCAA division I overhead athletes (softball, baseball, volleyball, tennis, and field events) from Louisiana State University. 19 males and 24 females participated in the study. Participant inclusion was based on current collegiate athletic participation and no current elbow pathology. History of upper body injury as well as athletic participation history, anthropomorphic measures and arm dominance was obtained via written questionnaire. Each participant signed an informed consent form approved by the University's Internal Review Board.

Instrumentation

We obtained all image sequences with a GE LOGIQ e MSK Ultrasound with a 12MHz transducer (GE healthcare, Fairfield, CT). All images were measured using the GE Ultrasound measuring function. Images were saved to a Panasonic 2GB memory card.

Imaging Protocol

The MSK images were obtained in a manner similar to that described by European Society of Musculoskeletal Radiology.[4] Participants were fully supported in a supine

position with the shoulder abducted and externally rotated to 90° and the elbow flexed to 90° with the forearm supinated.[50] The US probe (transducer) was placed in the coronal plane with its cranial aspect placed distally over the medial epicondyle of the humerus, so that the hyperechoic bone of the medial epicondyle and ulnotrochlear articulation was apparent.[32] Three images were captured bilaterally by the same researcher. This protocol was selected to allow for comparisons with results from previously performed studies.

Ultrasound Analysis

Using the MSK US, the peak of the medial epicondyle of the humerus and the medial margin of the coronoid process of the ulna were detected with markers placed on both landmarks. The measuring tool of the US was used to obtain the distance between the two landmarks to determine the joint space. One researcher (MRJ) performed all measurements. 10% of the images were assessed and approved by a physician specializing in sports medicine for accuracy and consistency.

STATISTICAL ANALYSIS

Short-term reliability of the same protocol in experiment 1 was determined to be excellent. The same researcher collected the measurements in this subsequent study. A paired t test was performed between dominant and non-dominant arm measurements. A paired t-test was also performed between right and left arm measurement. Pearson bivariate correlation tests were used to assess the relationship between the dominant and non-dominant arm measurements with height, weight, gender, and arm dominance set as covariates. Data analysis was accomplished with the following software packages: Excel (for Mac 2011; Microsoft Corp, Redmond, WA), and SPSS (version 24; SPSS inc, Chicago, IL).

RESULTS

Data were collected from 43 healthy, division I collegiate overhead athletes: 24 Female, 19 Male. TABLE 2 and FIGURE 2 provide descriptive statistics for the anthropometric measures of the subjects and the medial elbow joint space in the DOM and NDOM limbs, respectively.

TABLE 2. Descriptive statistics for subjects' anthropometric measures.

Descriptor	**Male (Mean ± Std Dev) N=19**	**Female (Mean ± Std Dev) N=24**	**Total (Mean ± Std Dev) N=43**
Height (in)	73.63±2.83	66.79±2.86	69.81± 4.44
Weight (lbs)	197.37±17.43	160.04±24.39	176.53±28.42
Age (years)	20.95±1.7	21.25±1.57	21.12±1.62

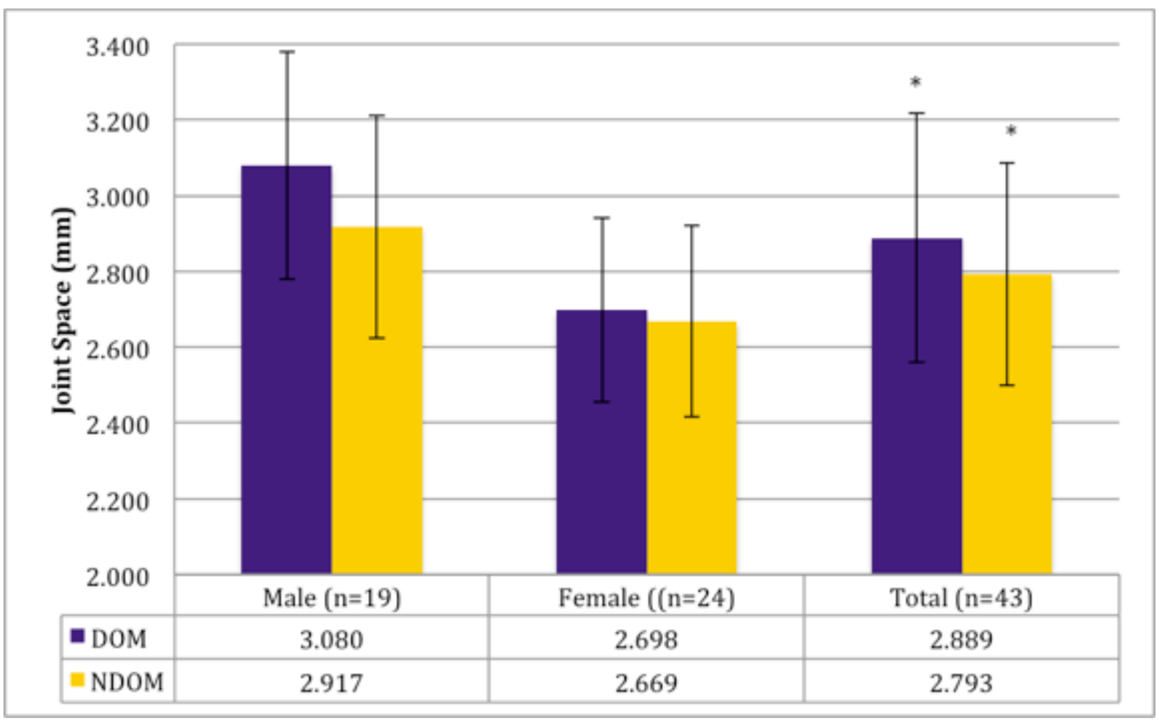

FIGURE 2. Descriptive statistics for elbow joint space in males and females.
*indicates significance at p<.05

A Paired t-test for dominant and non-dominant medial elbow measurements revealed a significant correlation ($\alpha = .05$). A bivariate correlation also indicated a positive correlation of r=.664 at the .01 level. The paired t-test also indicated a significant difference between the dominant and non-dominant arm measurements, $t(42) = 2.244$, $p=.03$,. Dominant means measured at 2.8665±.328 compared to the non-dominant at 2.778±.045. A difference of .088±.257, which was statically significant at $p< .05$. A paired t-test between the right and left arm also indicated significant correlation, however, there was not a significant difference between the means $t(42)=1.572$, $p=.124$.

A MANOVA multivariate test was completed with Gender as the fixed variable and the medial elbow measures (DOM and NDOM) as dependent variables. Post hoc analysis was not done, as there were only 2 levels of independent variables. There was a statistically significant difference in the medial elbow measurements based upon the subject's gender, $F(2, 40)= 10.5$; $p<.0005$; Wilk's $\Lambda=.656$, partial $\eta^2=.34$. When analyzing between-subjects effects, Gender had a significant effect on both DOM and NDOM medial elbow variables at $F(1, 41)= 21.32$; $p<.0005$; partial $\eta^2=.389$; and $F(1, 41)= 8.90$; $p<.0005$; partial $\eta^2= .178$, respectively.

Body size does moderately affect medial joint space. Weight and joint space were moderately positively correlated with the DOM and NDOM limbs, respectively (r=.416, p=.001); (r=.549, p=.001). Height and joint space was also moderately positively correlated (r=.450, p=.001); (r=.613, p=.001) indicating body size does slightly affect the medial joint size. Larger body sizes tended to have larger joint spaces, which is to be expected.

DISCUSSION

Results from the analysis of the medial elbow joint in the DOM and NDOM in overhead athletes, indicate a significant difference bilaterally, with the dominant arm joint space being significantly larger. When limbs are compared (right and left) there is no significant difference in the joint space, however, when dominance is taken into consideration, this difference is significant. This supports previous findings showing the medial joint space was significantly wider on the throwing side than it was on the contralateral side in baseball players.[48]

To our knowledge, few MSK US studies have measured the anterior bundle of the UCL. One study by Ward et al. (2003) was identified that investigated the normal anterior bundle of the medial collateral ligament to establish a standard of reference that could be used when comparing a normal ligament with an injured ligament. et al. (2003) measured the joint space of similarly aged individuals (21-34 years) at 2.6 ± 0.31mm and 2.6 ± 0.36. The mean measurements for this study for the right and left limbs were measured at 2.85±.336 mm and 2.79±.290 mm. respectively. While Ward et al. (2003) showed smaller mean values and no significant difference between DOM and NDOM limbs, their subject pool was not limited to overhead athletes. Eight of their subjects were identified as collegiate athletes, however which sport was not included. This indicates that being involved in repetitive overhead motion may increase the resting joint space length, giving overhead athletes a value larger than the norm established by Ward et al. (2003). Nazarian et al. (2003) used 26 major league pitchers to measure the resting length of the medial elbow joint space. They recorded the joint space width at rest as 2.8 mm ± 1.0 in the pitching arms and 2.5 mm ± 0.7 in the non-pitching arms, which is similar to the values

obtained in this study, however, only male, baseball pitchers were used. This current study may give more accurate normative values for the overhead athlete. This also shows the importance of MSK US in order to track such values. As previously discussed and supported by Ward et al. (2003), MSK US provides a consistent and reliable measurement of the medial elbow, which is a valuable tool for a practitioner treating overhead athletes. Knowing that overhead athletes may have a larger joint space, even without a pathological elbow, can be helpful when identifying potential injury risks. If the joint space is tracked throughout an athlete's playing career, noticeable changes in the joint space may allow for the sports medicine staff to provide care prior to a significant pathology. This may assist in preventing serious, season or career-ending elbow injury.

The results of the MANOVA indicate that there is a gender effect, meaning the measurements of the medial elbow are influenced by the individual's gender. However, this is to be expected due to body size, which was positively correlated with joint size, more than sex characteristics. Interestingly, no research related to UCL injury has been reported in female athletes.

No subjects complained of any pain or numbness in the elbow, either during testing or throughout normal and athletic activity. However, when compared to images obtained in Experiment 1, there are noticeable differences in the anatomical structures in the medial elbow in many of the overhead athletes, such as the smoothness of the bony structures, as shown in FIGURE 3.

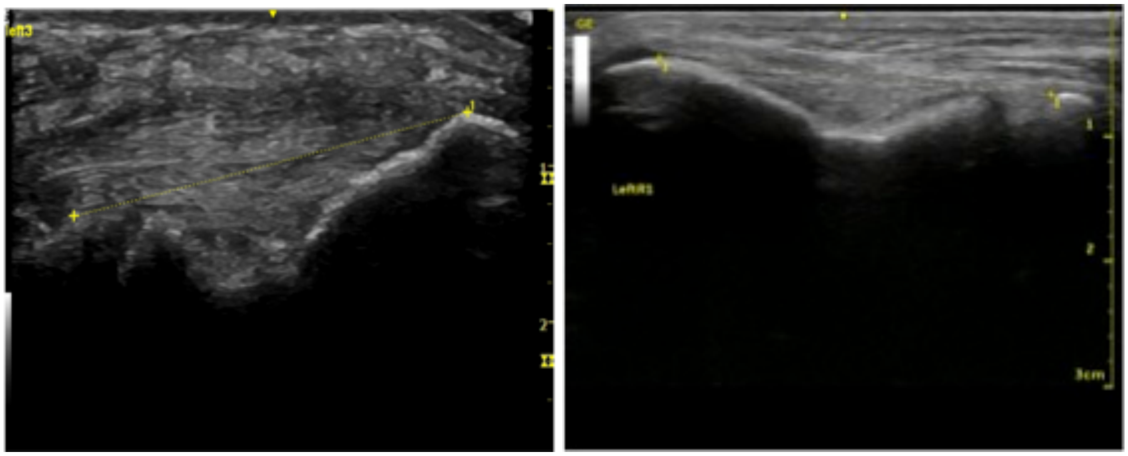

FIGURE 3. Medial elbow of a collegiate baseball pitcher (L) vs. Non-athlete (R).

As a practitioner, these differences should be noted, and may be a qualitative measure of tracking structural differences over a period of time (i.e. a playing season). This image also helps support the use of MSK US as a modality, as an MRI would not be as efficient in this manner, as well as exposing the athlete to unnecessary testing and contrast.

We acknowledge several limitations within our study. An advantage of MSK US is the ability to take measurements dynamically. There have been multiple studies using a Telos radiographic stress device (Austin and Associates, Fallston, MD) in order to consistently stress the medial elbow.[14,42,43] This device was unavailable during our study, furthermore our purpose was to determine static values. Ellenbecker et al. (1998) was not able to see a significant difference in DOM and NDOM medial elbows of professional pitchers, however, when a 15-daN valgus stress was applied there was a bilateral significant difference of 0.32 +/- 0.42 mm in the dominant arm, indicating an increase in medial laxity. This study was further supported by Popovic et al. (2001) who subsequently found a bilateral difference in the stressed elbows of professional handball players. The results of these studies are useful additions to the body of knowledge on the reliability and

validity of MSK US as an imaging modality. This current study further supports its usage in the sports medicine field.

CONCLUSION

In summary, we observed that MSK US has the potential to be used as a quick, noninvasive, and economical addition to traditional MRI imaging when examining the anterior bundle of the UCL. Our study found a significant difference between DOM and NDOM limbs indicting the forces imposed on the medial supportive structures of the elbow may lead to a larger joint space opening at rest. Furthermore, we observed larger joint spaces among overhead athletes when compared to the mean space established in other populations. We recommend that clinicians in the sports medicine field include bilateral baseline measurements in the current pre-participation physical exam. While there was a bilateral significant difference, it is unknown if the larger joint space contributes to injury in the overhead athlete, however, if the elbow space is tracked throughout a playing career, noticeable structural changes can be addressed prior to significant injury. Further research is necessary to determine if the joint space leads to an unstable joint. Additionally, further research is needed to establish additional factors involved in the medial elbow injury including the muscular strength and fatigue, volume of overhead throws, and magnitude of the force of the throws completed.

CHAPTER 4
EXPERIMENT 3: KINETIC AND KINEMATIC VARIABLES RELATED TO MEDIAL ELBOW JOINT SPACE IN COLLEGIATE BASEBALL PITCHERS

Ulnar Collateral Ligament (UCL) ruptures often evolve from microtears in the anterior oblique band from repetitive valgus force on the UCL complex.[23,25,45] Eventually, the accumulation of trauma, along with fatigue of the assisting stabilizers, results in a rupture of the UCL by a single throw, or overhead motion due to a progressive increase in elbow instability. [28,38,41] This rupture most often presents in athletes participating in activities that require a significant portion of time producing high force in the overhead position, specifically; baseball pitchers.[7,25] With the constant, repetitive force exhibited through multitudes of inning pitched, the UCL is the most commonly injured soft tissue structure and accounts for 97% of elbow complaints among pitchers.[38,53] Knowledge of changes to the medial elbow from repetitive overhead motion is important for clinicians in regards to best practices for treatment and potentially, preventing a significant elbow injury.

Currently, the shoulder is the main focus of literature involving baseball pitchers due to the high velocity forces at the glenohumeral joint. However, these high forces, that can be equal to 1-1.5 times the body mass of the thrower[18,19] at an angular velocity that can exceed 7,000° per second,[60] leading to a substantial valgus force at the elbow joint. Our previous work in Experiment 2 provided evidence of a significantly different joint space in the elbow bilaterally in overhead athletes, implying the constant valgus stress on the medial elbow may lead to joint gapping in the dominant extremity. These results differ from Experiment 1, which showed no bilateral difference among non-overhead athletes, suggesting the difference exhibited in Experiment 2 was not solely based on daily activities

with the dominant extremity, but was likely due to the repetitive stresses resulting from the consistent valgus forces accompanying the overhead motion.

Previous studies have found that the elbow undergoes up to 64±12 Nm of varus torque, during the overhead throw[18] which is at or near the maximum capacity of the UCL as indicated by cadaveric studies.[13,59] According to Werner et al. (1993), in cadaver studies, the ulnar collateral ligament fails under less stress than what occurs during pitching, suggesting other structures, such as the wrist flexors, must provide some assistance. The wrist flexors: flexor carpi radialis, flexor carpi ulnaris, palmaris longus, and flexor digitorum superficialis, originate on the medial epicondyle of the humerus and run along the anterior forearm to the palm of the hand and fingers.[11] By crossing over the UCL, they provide structural support during extension, when most of the stress is applied to the anterior band of the UCL.[45] However, much of the current research is focused changes in the muscle supporting the shoulder, without considering the strength changes involving the forearm musculature. When the muscles supporting the medial elbow begin to fatigue throughout a long pitching session, it may necessitate the UCL taking on more valgus force, leading to an increasingly unstable medial elbow joint. Fortenbaugh et al. (2009) reported that as pitchers reported feeling fatigued, kinetic values remained constant, but increases in arm pain were described. Therefore, pitchers were throwing with the same force, but potentially experiencing less joint stability, resulting in arm pain, which could lead to long-term injury. Similarly, Escamilla et al. (2007) found no increase in elbow torque as pitchers fatigued after pitching 105-135 pitches, but also reported that, arm pain was not indicated as the players reached fatigue. This supports the idea that pitch count cannot serve as the only potential risk factor to upper extremity injury.

Kinematic variables have been shown to change throughout a single pitching bout, which may imply that muscular fatigue is occurring. Murray et al. (2001) found decreases in maximum external rotation of the shoulder, knee angle at ball release, and ball velocity with a decrease in 5mph in fastballs over a complete game. This demonstrated the ability to track pitch velocity over the course of a pitching outing to observe decreases in overall pitch velocity, allowing the clinician to limit fatigue and potentially limit the overuse injury.

To date, there are limited studies linking kinetic, kinematic, and anatomic variables in the investigation of factors related to injury prevention in the overhead athlete. Characterizing the link between the biomechanical and anatomic factors could provide additional insight into the physical changes occurring while throwing leading to developing a systematic and practical injury prevention protocol.

Therefore, the purpose of the present study was to investigate kinetic and kinematic variables of overhead pitching as they relate to anatomical changes in the medial elbow joint space in collegiate baseball pitchers. We hypothesized that pitchers would demonstrate a decrease in isometric grip strength along with an increase in medial elbow joint space after pitching a simulated game. These changes will continue to be evident 48 hours after the simulated game.

METHODS AND MATERIALS

We recruited 12 healthy, male Division I collegiate baseball pitchers. Participation inclusion was based on no current shoulder or elbow pathology and they must be actively participating in baseball practice. To ensure participants were currently without upper extremity pathology, we consulted with the team's Certified Athletic Trainer. History of

upper body injury as well as athletic participation history, anthropomorphic measures and arm dominance was obtained via written questionnaire. Each participant signed an informed consent document approved by the University's Institutional Review Board.

Imaging Protocol

We obtained all image sequences with a GE LOGIQ e MSK Ultrasound with a 12MHz transducer (GE healthcare, Fairfield, CT). All images were measured using the GE Ultrasound measuring function. Images were saved to a Panasonic 2GB memory card.

The MSK images were obtained in a manner described by the European Society of Musculoskeletal Radiology.[4] Participants were fully supported in a supine position with the shoulder abducted and externally rotated to 90° and the elbow flexed to 90° with the forearm supinated.[50] The US probe (transducer) was placed in the coronal plane with its cranial aspect placed distally over the medial epicondyle of the humerus, so that the hyperechoic bone of the medial epicondyle and ulnotrochlear articulation was apparent.[32,51] This protocol was selected to allow for comparisons with results from previous studies.

Three images were collected, bilaterally, prior to a pitching outing in a simulated baseball game to live batters. Immediately following the conclusion of the pitching outing, three additional images were taken. Participants rested 48 hours and three subsequent images were bilaterally collected.

Ultrasound Analysis

Using MSK US, the peak of the medial epicondyle of the humerus and the medial margin of the coronoid process of the ulna were detected with markers placed on both landmarks. The measuring tool of the US was used to obtain the distance between the two landmarks to determine the joint space. One researcher (MRJ), performed all measurements. A physician with a specialization in Sports Medicine reviewed and evaluated 10% of images for accuracy.

Ball Tracking

Trackman, a three-dimensional Doppler radar tracking system currently used in the majority of Division I collegiate programs as well as professional programs tracked pitch count, pitch type, ball velocity, and spin rate for each pitch thrown in the simulated game.

Maximal Voluntary Isometric Contractions

Participants performed a series of warm-up exercises involving 20 repetitions using a Cando web hand exerciser. Participants were then seated with the elbow at 90° and bilaterally performed 2 sets of maximal voluntary isometric contractions (MVIC) for grip strength. Measurements were taken prior to pitching, immediately following pitching, and 48 hours after the participant's simulated game. The grip strength measurements were taken via a Jamar Hydraulic Hand Dynamometer (Patterson Medical, Warrenville, IL). Reliability studies of the Jamar Dynameter denote very high test-retest reliability and are consistently used in grip strength tests[44] although there is no standard protocol for the instrument's use. Mathiowetz et al. (1984) found lower correlations when only one trial

was used. However, Hamilton et al. (1994) found the Jamar to be equally reliable with one, two, and three measurements. Therefore, an average of two bilateral trials was used.

RESULTS

Data was collected from 12 healthy collegiate baseball pitchers. Age, weight, height, and number of years pitching values for the participants were 20.16± 1.33 years, 87.65± 8.13kgs, 1.88± .05m, and 9.0± 4.17 years respectively.

Grip Strength

When comparing the means of the DOM and the NDOM limbs for grip strength, there was a significant difference between the measures prior to pitching ($t(11)=3.08$, $p<.05$). However, there was not a significant difference between contralateral limb strength immediately following pitching and 48 hours later ($t(11)=1.233$, $p=.243$; $t(11)=1.985$, $p=.073$, respectively). TABLE 3 provides descriptive statistics for grip strength in both the dominant and non-dominant limb at 3 tested intervals.

TABLE 3. Descriptive statistics for grip strength prior to pitching, immediately following pitching, and 48 after pitching in collegiate pitchers (n=12).

	Dominant Limb Mean ± Std	Non-Dominant Limb Mean ± Std
Prior to Pitching	135.95±29.15lbs*	120.75±21.63lbs*
Following Pitching	142.66±31.42lbs	136.29±20.48lbs
48 Hours	141.70±24.22lbs	131.04±13.98lbs

*Indicates significant different (p<.05) between contralateral limbs prior to pitching

Differences between grip strength of the contralateral limbs are presented in FIGURE 4. Mauchley's test of sphericity indicated that the assumption of sphericity was not violated ($X^2(2)=4.774$, p=.092) , thus, no correction was applied to the degrees of freedom during ANOVA tests.

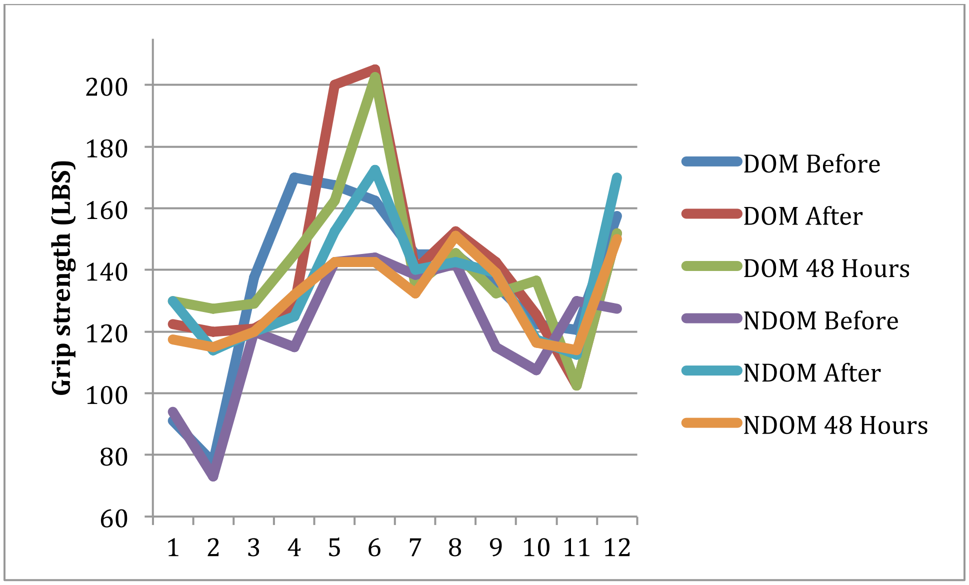

FIGURE 4. Graph of bilateral grip strength.

Throwing a simulated game did not have a significant effect on grip strength of the DOM limb ($F(2,22)=.638$, p=.538). Paired t tests comparing the means of DOM arm grip strength prior to pitching to after pitching; prior to pitching and 48 hours following the simulated game, and after pitching to 48 hours following pitching indicated that there were no significant differences between grip strengths at any time interval ($t(11)=.883$; p=.396; $t(11)=.813$; p=.433; $t(11)=.238$; p=.816, respectively).

Medial Elbow Joint Space

When comparing the means of the DOM and the NDOM limbs for changes in the medial elbow joint space, there were no significant differences between contralateral limbs

prior to pitching, following pitching, and 48 hours later ($t(11)=.468$, $p=.649$; $t(11)=1.056$, $p=.313$; $t(11)=.064$, $p=.950$, respectively). TABLE 4 provides descriptive statistics for the measured medial joint spaces in the DOM and NDOM limbs. Similarly, there were no significant differences between the joint spaces in the DOM limb in each of the testing conditions ($t(11)=2.187$, $p=.051$; $t(11)=.928$, $p=.373$; $t(11)=1.058$, $p=.313$).

TABLE 4. Descriptive statistics for the medial elbow joint space prior to pitching, immediately following pitching, and 48 after pitching in collegiate pitchers (n=12).

	Dominant Limb Mean ± Std	Non-Dominant Limb Mean ± Std
Prior to Pitching	2.84±.278 mm	2.88±.242 mm
Following Pitching	3.01±.239 mm	2.92±.199 mm
48 Hours	2.94±.292 mm	2.94± .215 mm

Mauchley's test of sphericity indicated that the assumption of sphericity was not violated ($X^2(2)=5.734$, $p=.057$) , thus, no correction was applied to the degrees of freedom during ANOVA tests. Throwing a simulated game did not have a significant effect on the medial elbow joint space of the DOM limb ($F(2,22)=1.969$, $p=1.63$). However, there is an interaction between the elbow joint space and the average ball spin rate the pitcher produces ($F= 6.374$; $p<.05$). The mean spin rate for all pitches thrown was 2282.83±161.31 rpm, with ranges from 2088.00 rpm to 2668.00 rpm. The differences between the DOM and NDOM medial elbow joint spaces are further demonstrated in FIGURE 5.

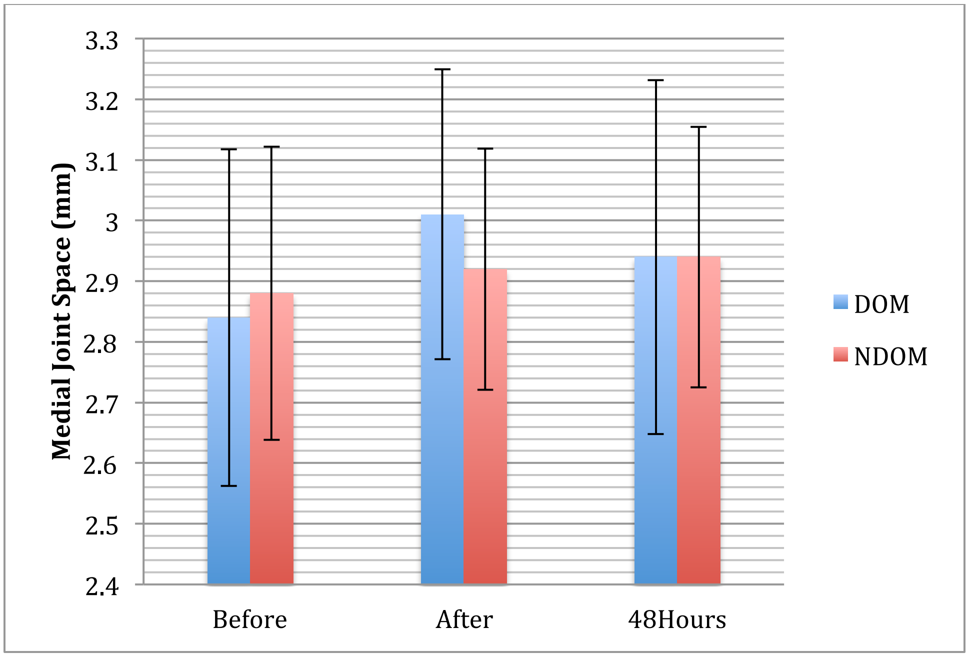

FIGURE 5. Graph of medial elbow joint space differences.

Ball Tracking

Number of pitches, as well as type of pitch thrown, ball spin rate, arm extension at ball release, along with ball velocities were recorded using the Trackman system. FIGURE 6 illustrates the total number of pitches thrown during the simulated game and each pitch type thrown.

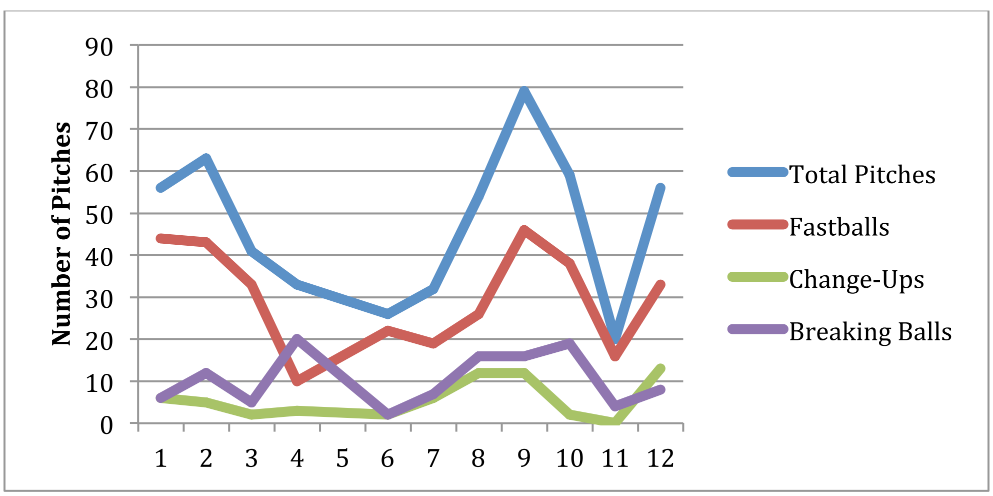

FIGURE 6. Graph of Pitch Types Thrown by Participant

There were a total of 526 pitches thrown, with 333 (63.31%) fastballs, 65 (12.35%) change-ups, and 117 (22.22%) other pitches including sliders, curveballs, and knuckleballs. Warm-up pitches thrown in the bullpen were not included in this value as well as any throws to a base such as when holding a runner on base.

Ball velocities of the pitches ranged in speed based on the type of pitch that was thrown. Fastballs were thrown with a mean of 88.42±2.45 mph compared to change-up with a mean of 73.79±23.35mph, and other pitches with a mean of 76.72±2.00mph. FIGURE 7 represents the mean velocities for each pitch type based on participant. Average ball spin rates ranged from 2088.0 RPM to 2668.0 RPM. Although this variable was not a focus of this study, ball spin rate is a factor that should be a concentration in future research related to elbow injury.

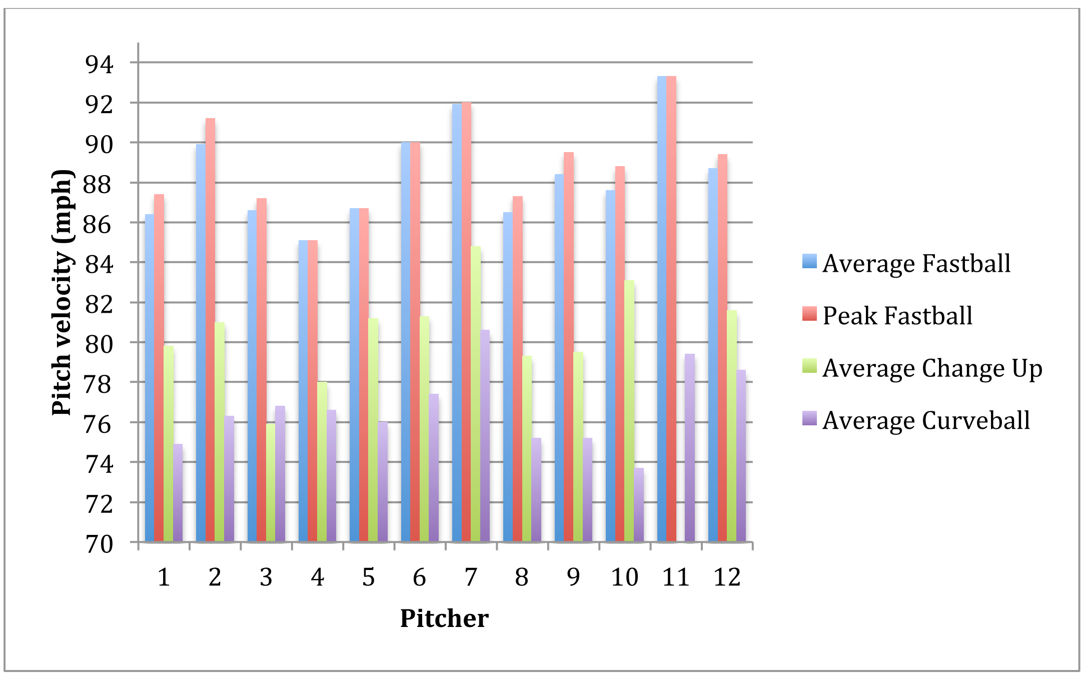

FIGURE 7. Graph of Pitch Velocity by Participant

Correlations

A Pearson product-moment correlation was run to explore the relationships among the kinetic and kinematic variables. Significant correlations were observed among participant age and grip strength measures ($p<.05$), as well as with grip strength and years the participant has pitched ($p<.05$). Arm dominance and the medial joint space before pitching were also positively correlated ($r=.683$, $p=.05$). A chart of the significant correlations can be found in Appendix A.

DISCUSSION

Our results indicate that there was no significant difference in the medial joint space from throwing a single simulated game, however, with a p value of .051, the difference between the mean joint space prior to pitching and immediately following pitching is trending to being significant. This supports previous studies examining the medial elbow space at rest.[38] Previous studies have indicated a difference between the joint space bilaterally, however, these studies apply a valgus force to the elbow, creating a stress sonography.[9,38] Ellenbecker et al. (1998) confirmed previous criterion that a contralateral difference of .5mm was indicative of an affected medial elbow when a stress was applied.[14,43] The mean difference in our ipsilateral measurement without a stressor was 0.17mm. Therefore, there was difference in the mean values, which may be exacerbated by applying a valgus stress. This is further supported by Sasaki et al. (2002) who applied a gravitational stress to the medial elbow and found the medial joint space was significantly wider on the throwing side than it was on the contralateral side (2.7 mm and 1.6 mm, respectively; $p<.01$). Sasaki et al. (2002) was also able to note structural changes in which

there was a lateral shift of the proximal ulna. Both the widening of the joint and the ulnar shift was significantly associated with participants indicating a history of medial elbow pain. This is important to note that the anatomical changes are associated with an increase in pain and a pathologic elbow.[9,38] We believe the absence of a significant difference in the bilateral values in our results is due to an unstressed ultrasound measure. However, in the practical setting players and coaches do not want their dominant elbow unnecessarily stressed, thus if we were able to note a difference in the measures without the stress, this would be important in terms of diagnostics and the tracking of changes in the static length of the UCL.

Nazarian et al. (2003) noted that 69% of participants imaged in their study of professional baseball pitchers showed indication of hypoechoic foci, or calcification of the UCL and surrounding tissues. Cicotti et al. (2014) saw similar calcifications in their subjects who were also professional pitchers. While echogenicity cannot be measured, it can be compared to normal or bilateral views of the same tissue. We were able to view differences in echogenicity in images of bilateral limbs, with notable differences in the bony tissue of the medial epicondyle. A bilateral comparison is shown in Figure 8. There is an apparent hypoechoic mass in the joint space of the medial elbow of the DOM throwing arm. While not currently experiencing an elbow pathology, this bilateral view is significant to indicate the obvious structural changes occurring in the tissue from repetitive overhead motion. Medial epicondylitis is a common condition affecting baseball pitchers and may be a contributing factor to UCL calcification or damage.[24,30,33] The medial epicondyle in the DOM image is rougher than the smooth articular surface of the NDOM limb, along with more inflammation in the soft tissue which can be visualized with the darkened spaces within the

soft tissue, superior to the joint. Although, no significant difference with indicated following a single simulated game, FIGURE 8 is indicative of the potential damage occurring in the structures from repetitive overhead motion which can be monitored by a practitioner throughout the training and the playing season.

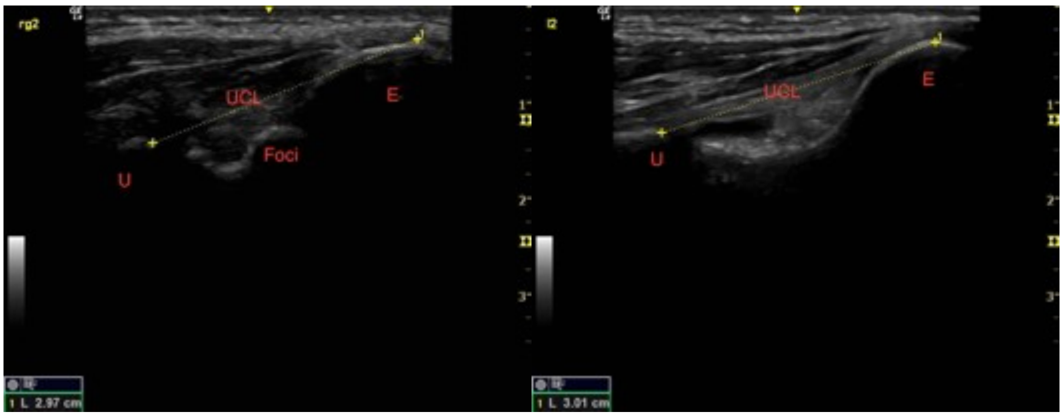

FIGURE 8. DOM Elbow Image (left) vs. NDOM Elbow Image (right). E denotes the medial epicondyle of the humerus with U indicating the coronoid process of the ulna

Previous studies have suggested that the demands placed on the UCL when it is subjected to valgus torque during throwing exceed its failure strength, which implies there is a necessary dynamic muscular contribution. Injury to the flexor-pronator mass is often concurrent with injury to the UCL.[39] The flexor carpi ulnaris muscle is the predominant muscle covering the UCL and, along with the flexor digitorum superficialis muscle, are the only significant musculotendinous contributors to medial elbow support.[40,54] The UCL is the primary stabilizer of the medial elbow with elbow flexion greater than 30°, as in pitching[11,40] and provides approximately 54% of the restraining force to valgus stress.[5,31] As the musculature fatigues, there is additional stress placed on the UCL. EMG studies have shown a decrease of muscle activation during the late cocking and early acceleration phases, when the UCL is stressed the most, with as much as 64 N-m of torque,[18] leading to

further injury.[23,27] With the flexor digitorum superficialis being the biggest contributor to stability,[40] as the muscle fatigues, we would likely observe a difference in the force output, or the grip strength. The flexor digitorum profundus muscle also provides assistance with wrist and finger flexion. Although the muscle belly is deep and thus is not conductive to EMG, it may contribute to force production during the terminal phases of the throw. While it is not a contributor to elbow stability due to its attachment sites, the activity of the flexor digitorum profundus may slow the fatigue of the muscles involved in the flexor-pronator mass. Thus, should not be ignored in strengthening protocols for pitchers. However, in this study no significant difference was recorded in the grip strength at any of the testing points. While it was hypothesized that the grip strength would decrease, our results indicated that the mean values increased from prior to pitching compared to after pitching. This may be due to the simulated game not being truly fatiguing, as starting pitchers are able to complete as many as double the pitches thrown in the simulated games, thus throwing approximately 50 pitches would act as more of a warm-up than a fatiguing activity. An interesting finding was each grip strength measure was positively correlated with age, supporting that as the players increase in age, their flexors increase in strength, potentially due to additional time working with collegiate strength and pitching coaches.

Kinematic and kinetic comparisons have been made among the various pitch type.[16,20] Studies have indicated that there are significant kinematic differences between the fastball and curveball but few kinetic differences, supporting the notion that one pitch is not more stressful or dangerous to a pitcher than others.[20,49] However, most pitchers are taught that a curveball is more dangerous. The majority of the pitches thrown in the simulated games were fastballs (63.31%). With breaking balls, curveballs and sliders, being

the next prevalent (22.12%). While the kinetics may not differ, the difference in the velocities between fastballs and curveballs was significantly different ($t(11)=23.013$; $p<.001$). Our findings show that the mean fastball velocity was 88.43mph, while the mean peak fastball velocity was 88.99mph. There is .638% difference between the mean and the peak velocities, indicating that most of the participants were throwing at or near their peak velocity for every fastball they threw. While this stress is not apparent in the medial joint space in this study, it is plausible that throwing an increased number of pitches at this velocity will not only fatigue the supporting musculature, but also allow for an increased opening of the medial joint space, further stressing the UCL. Studies have indicated that a tear of the UCL will potentially manifest itself as reduced ball velocity and control, and becomes evident during pitching.[5] Often pitch counted is noted, although has not been shown to correlate with the prevention of injury.[6] Ergo, the tracking of ball kinematics, such as ball velocity should be considered in addition to pitch count. Seeing as though there is no clear definition of the maximum number of pitches that should be thrown before significant structural damage has taken place, an objective measure such as changes in ball velocities can provide additional insight into any structural damage that is occurring. However, additional research needs to be conducted to determine at what magnitude of a decrease in ball speed is significant. Additionally, research is needed in the area of pitch type in collegiate and professional pitchers. Studies are abundant for youth and adolescent pitchers, with little information regarding collegiate and professional, where pitch counts, ball velocities, and the ability of the athlete to produce force is higher.

Several limitations exist in our current study; most are related to the population tested in this methodology. Due to our population currently competing in collegiate

athletics, the coaching staff controlled simulated games, including pitch count and pitch-type thrown. Therefore, games were concluded prior to muscular fatigue as was shown with the increase in grip strength immediately after pitching. However, when the number of pitches thrown was controlled for in this study, there was no significant difference in the medial elbow joint space, thus number of pitches thrown did not influence the medial joint space changes. We were also limited in population size due to the specialized nature of the group being tested. We measured isometric strength of the flexors however; the function of these muscles during throwing is isotonic. Further research should include more clinically relevant concentric strength measurements. Furthermore, our measures for medial elbow joint space were static, whereas current research indicates the use of dynamic movements for diagnostic purposes. Despite the present limitations, analysis of the UCL via MSK US enhances the understanding of the anatomical and structural changes occurring each time a pitcher throws. Future research should be conducted with the same parameters during a true competition where pitch counts are likely higher in order to add evidentiary support to the notion that structural changes in the elbow occur during pitching. Additionally, it would be prudent to continue these procedures throughout the course of a pitcher's season to record any changes in joint measurements and how they coincide with any fluctuations in ball velocities, forearm strength, as well as subjective measures such as pain. Long term evaluation of these variables and how they correspond with injury rates can provide substantial knowledge for practitioners and the development of practical injury prevention.

The goal of this study was to examine factors related to changes in the medial elbow joint space in collegiate baseball pitchers, thus our results might not be applicable outside

this specific population. The body of literature for the adolescent pitcher is copious, supporting the use of pitch counts and avoiding specific pitch types, however, the literature for collegiate pitchers is significantly lacking.

CONCLUSION

In conclusion, our study demonstrates that one bout of pitching does not significantly alter the medial elbow joint space, but anatomical and structural changes may take place over a longer period of time. Changes in the structure, along with kinetic variables, such as grip strength, and kinematic variables such as ball velocity may all be factors in shifting the stability in the medial elbow. Additional research is needed which tracks these factors over the course of a season or playing career.

As previously mentioned, mean grip strength increased following pitching and remained elevated 48 hours after pitching. However, the medial joint space increased, albeit, not significantly after pitching, yet did not return to the baseline measurement 48 hours later. There is continued controversy in the literature and a significant deficit of research to determine proper rest protocols for adult pitchers. To date, there have been no peer-reviewed studies of pitches thrown and the days of rest on the performance of adult baseball pitchers.

CHAPTER 5
SUMMARY AND CONCLUSIONS

The ulnar collateral ligament (UCL) is a significant contributor to elbow stability in the overhead throwing motion.[45] Valgus forces experienced by the medial elbow during throwing are primarily resisted by the anterior band of the UCL as it originates on the medial epicondyle of the distal humerus and attaches to the medial edge of the olecranon process of the ulna.[36] The wrist flexors: flexor carpi radialis, flexor carpi ulnaris, palmaris longus, and flexor digitorum superficialis, originate on the medial epicondyle of the humerus and run along the anterior forearm to the palm of the hand and fingers.[11,36] The wrist flexors provide additional support to the ligamentous structures of the medial elbow, especially necessary during the throwing motion when the anterior of band of the UCL experiences significant valgus force.[36,45] With repetitive motion, such as pitching, applying high, constant valgus force to the medial structures of the elbow, injury to these tissues can be extensive and common. Currently, musculoskeletal (MSK) ultrasound is used while applying dynamic valgus force to the medial humeroulnar joint for diagnosis of a pathologic elbow. The purpose of this dissertation was to determine if there were bilateral length differences in the UCL due to the overhead throwing motion when measured statically in participants without a pathologic elbow. This would make it possible to monitor structural changes in the medial elbow, and potentially circumvent injury without applying an additional mechanical stress to the elbow.

This dissertation contained a series of three experiments that examined variances in the length of the UCL by measuring the distance between the attachment sites on the humerus and ulna. The first experiment (chapter 2) investigated bilateral differences in UCL length in untrained, recreationally active males and females. This study suggested that

there is not a bilateral difference in the static length of the ulnar collateral ligament. However, this study also revealed a significant gender effect ($p<.01$), suggesting that body size may be a significant variable in the joint space opening of the medial elbow. A significant difference was not observed bilaterally in this population. However, this is not unanticipated due to the lack of chronic medial elbow stress experienced by a general population of college age students. This was an important step in transitioning to testing the overhead athlete and provided evidence that activities of daily living and recreational activities do not supply enough mechanical stress to cause a bilateral difference in the medial elbow. This study also assisted in establishing the validity of MSK US for measuring the medial elbow joint space, finding a high test-retest reliability, indicating that we were able to successfully capture consistent images.

In chapter 3, the participant pool included only collegiate overhead athletes. These participants were softball, baseball, tennis, and track and field athletes who engaged in throwing events. Weight and height were positively correlated with an increase in the medial joint space, however, this was to be expected, as there was also a significant gender effect, supporting the results found in chapter 2. Interestingly, there was a significant difference between the means of the dominant and non-dominant joint spaces, however no significant difference when only comparing right and left extremities without dominance taken into consideration. When relating to study 1, these results imply that repetitive overhead activity may lead to anatomical changes, such as lengthening the UCL, in the medial elbow.

Lastly, chapter 4 reported on a study, which examined anatomical changes in the medial elbow joint space before, immediately after, and 48 hours following a simulated

game thrown by collegiate pitchers. With the joint differences determined in chapter 3, additional variables, such as grip strength and ball velocities, were included in an attempt to find associated contributory factors to medial elbow injuries. In contrast with study 2, there was no observed bilateral difference in the medial joint space. Additionally, the mean grip strength increased following the simulated game. This suggested that a single simulated game by an elite pitcher may not provide enough mechanical stress to the show structural differences in the elbow statically. Additional research is needed to record the measurements of the elbow over a longer time interval to determine if a static difference can be observed. Observing the changes in the structure, along with recording factors, such as changes in ball velocities over a greater time interval may prove beneficial for clinicians, especially as MSK ultrasound becomes a more prominent modality.

In conclusion, this dissertation reported on a series of three experiments that provide insight into length changes of the UCL measured statically, in populations engaged in overhead activities. While there were no significant structural differences in the medial elbow following a solitary simulated game, this is meaningful as most research focuses on applying a valgus stress to the medial elbow as a diagnostic tool, not using ultrasound to monitor the static anatomical changes in the elbow. If changes to the UCL length can be shown statically throughout the course of a playing season, serious injuries to the UCL may be mitigated without applying a stressing force to the elbow. Although changes in the length of the tissue is not significantly different following one simulated game, as shown in chapter 3 between a thrower and a non-thrower and in chapter 4 between bilateral limbs, obvious and discernable structural changes occur in the medial elbow from prolonged overhead activity. After viewing the apparent hypoechoic masses in the dominant arm of a

pitcher, it can be recommended for clinicians treating and examining overhead athletes to note the presence of these structural abnormalities and monitor the progression of any irregularity throughout the course of a pitcher's season or career. Reducing the valgus stress imposed on the anterior band of the UCL, as well as the ulna and medial epicondyle, as deformities emerge may diminish significant injury and loss of playing time. By eliminating the need to apply a mechanical load to the elbow by measuring statically, athlete and coach efforts in monitoring is likely to increase.

Additionally, the flexor-pronator mass has been shown to contribute to dynamic valgus stability by providing a varus moment to unload force from the UCL.[40,54] While there was no decrease in grip strength following a simulated game, it is recommended that practitioners observe changes in grip strength and include strengthening exercises for the flexor group to allow the musculature to provide adequate dynamic assistance to the UCL during the throwing motion. Reducing valgus stresses associated with throwing as a reduction in strength in the flexor-pronator group is evident may diminish the damage observed in the UCL, thus reducing potential for long-term elbow injury.

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APPENDIX A: KINETIC AND KINEMATIC CORRELATIONS

GRIP STRENGTH

	age	yearspitch	dom arm	grip1dom	grip2dom	grip3dom	grip1ndom	grip2ndom	grip3ndom
Age				.778**	.630*		.782**	.579*	.760**
grip1dom	.778**				.625*	.592*	.813**	.621*	.732**
grip2dom	.630*	.717**		.625*		.906**	.601*	.844**	.713**
grip3dom				.592*	.906**			.815**	.815**
grip1ndom	.782**			0.813*	.601*			.603*	.665*
grip2ndom	.579*	.744**			.844**	.815**	.603*		.851**
grip3ndom	.760**	.713**		.732**	.731**	.815**	.665*	.851**	
DOMBP			.683*						
NDOMBP		.611*							
fastballs	-.782**			-.690*					

BALL TRACKING

	Pitches	fastballs	changeups	breaking	Avefb	Peakfb	Aveother	Ballspin	Releaseheight
Age		-.782**							
grip1dom		-.690*							
DOMBP			.664*						
NDOMBP									.659*
DOM48							-.594*		
Pitches		.907**	.658*	.597*					
fastballs	.907**								
changeups	.658*								
breaking	.597*								
Avefb						.977**	.706*		
Peakfb					.977**		.589*	.586*	
Aveother					.706*	.589*			
Ballspin						.586*			

MEDIAL JOINT SPACE

	age	yearspit	dom arm	DOMBP	NDOMBP	DOMAP	DOM48	NDOM48
Yearspitch					.611*		.592*	
dom arm				.683*				
grip1dom	.778**			0.813*				
grip2dom	.630*	.717**						
grip1ndom	.782**							
grip2ndom	.579*	.744**						
grip3ndom	.760**	.713**						
DOMBP			.683*					
NDOMBP		.611*						.838**
DOMAP							.655*	
DOM48						.655*		
NDOM48					.838**		.592*	
Pitches								
fastballs	-.782**							
changeups				.664*				
Aveother							-.594*	
Releaseheight					.659*			

APPENDIX B: REPETIVE MOTION AND MEDIAL ELBOW INJURIES IN THE OVERHEAD ATHLETE

A General Examination submitted to the Graduate Faculty of the
Louisiana State University and Agricultural and Mechanical College
In partial fulfillment of the requirements for the degree of
Doctor of Philosophy

In

The Department of Kinesiology

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INTRODUCTION

Injuries are pervasive in sport and at the collegiate level Athletic Trainers and the NCAA have developed significant protocols and formal legislation to protect athletes against various injuries. However, the majority of injuries addressed in these specific protocols are due to forceful contact, such as that of a concussion. Whereas, in a 16-year NCAA study, they found a high percentage of injuries sustained to be non-contact type injuries, especially during the athlete's practice time. These injuries primarily consisted of muscle strains and ligament sprains that, for the most part, cannot be effectively address by formal NCAA legislation. Most of these non-contact practice injuries are attended to by identification and modification of risk factors (Hootman et al., 2007). However, standards for distinguishing risk factors for musculoskeletal injury are currently inadequate.

One known risk factor for an upper body musculoskeletal injury is participation in a repetitive overhead activity, such as throwing. Baseball is the most common sport in the United States with a throwing motion, however, that motion is also found in softball, football, tennis, and some field events (Cain, et al., 2003). Injury to the upper body for an overhead athlete can lead to significant joint instability; potentially leading to a decrement in performance, chronic pain, and eventual surgical intervention. In the throwing athlete, the elbow complex is of particular concern in regards to stability of the humeroulnar joint, as throwing creates a significant valgus force to the medial elbow. The ulnar collateral ligament (UCL), particularly the anterior portion of the anterior oblique ligament, is the primary static contributor to elbow valgus stability and is most commonly injured in athletes participating in overhead sports (Hariri & Safran, 2010).

Most often the use of radiographic and magnetic resonance imaging (MRI) is reserved for affirming diagnosis following a physical examination warranting the use of further modalities. However, the use of imaging in the healthy athlete allows the practitioner to visualize changes in the soft tissue as chronic injury manifests over time. While the use of MRI imaging is not practical prior to indication of injury, the use of ultrasonography (US) is time and cost effective. US technology has been shown to identify morphological and functional UCL changes and may be helpful in predicting the injury to the UCL in an overhead athlete; functionally reducing the risk of injury (Ciccott et al., 2014).

Due to the use of musculoskeletal US not currently being a common practice in preventative medicine in the overhead athlete, the purpose of this literature review is to discuss its potential use compared to other diagnostic modalities. The functional anatomy of the elbow complex along with the pathophysiology of elbow injuries will be presented followed by biomechanical principles of the overhead throw influencing medial elbow injury. The following section will consist of current literature regarding the use of imagining techniques in the diagnosis of medial elbow injuries. Finally, the conclusive section will discuss the clinical applications of the literature findings, including invasive and non-invasive treatment protocols and present possible research questions.

1.0 ETIOLOGY AND EPIDEMIOLOGY OF MEDIAL ELBOW INJURY

In the overhead athlete the repetitive nature of the throwing-type movement creates an unstabilizing force to the supporting structures of the elbow, potentially leading to significant injury. Upper extremity injuries account for 67% of all injuries, 25% of those injuries being to the elbow in pitchers in Major League baseball (MLB), leading to an

accumulation of days on the disabled list, a decrease in performance, as well as potentially effecting an organization in wins and losses (Posner et al., 2011). While injuries to the elbow, particularly the ulnar collateral ligament (UCL), are widely discussed, the prevalence of UCL reconstructions in MLB athletes had not been documented until 2015. Conte et al. (2015) found that 25% of major league and 15% of minor league pitchers had a history of UCL reconstruction. Interestingly, the group also found major league pitchers were significantly older (28.8 ± 3.9 years) and 86% had their UCL reconstruction as professional pitchers, whereas minor league pitchers where younger (22.8 ± 3.0; $P < .001$) and the majority (61%) underwent their UCL reconstruction during high school and college (Conte et al., 2015).

However, this is not only an issue in Major League Baseball, elbow injuries are commonplace at the college, high school, and youth sport levels and is continuing to rise. Hodgins et al. (2016) reported a significant yearly increase from 2002 to 2011 in the number of UCL reconstructions performed in New York State, and in that time the overall increase was 193%. The American Sports Medicine Institute has suggested a significant increase in UCL tears in this younger population. Between 1994 and 1998, only 7% of UCL reconstructions were performed on this younger population; however, by 2004–2008, 26% of UCL reconstructions at their clinic were performed on high school aged or younger patients (Fleisig et al., 2009, Hibberd et al., 2015).

1.1 Elbow Complex Anatomy, Histology, and Structural Biomechanics

When discussing common pathologies related to the overhead motion, it is vital to have an anatomical understanding of the affected structures. While the entire body is

involved in the motion, the structural integrity of the elbow complex is a requirement for a successful motion. The elbow, an imperfect hinge, maintains two degrees of freedom allowing for flexion/extension, and pronation/supination. This seemingly small range of motion is due to the bony structures articulating in the elbow: the humerus, ulna, and radius (Figure 1).

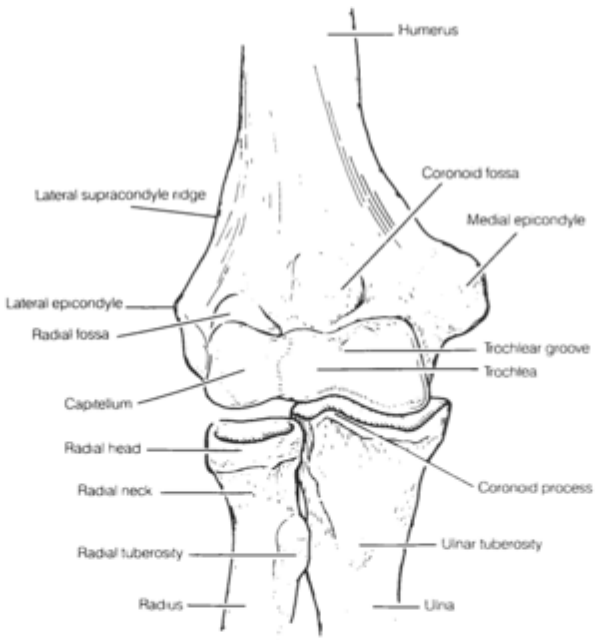

Figure 1 Osseous Structures of the Elbow. Stroyan and Wilk (1993)

The first of these structures is the humerus, the long bone of the arm. The distal portion of the humerus helps create the elbow joint and consists of 3 landmarks of note: 2 epicondyles, 2 processes (trochlea & capitellum), and 3 fossae (radial fossa, coronoid fossa, and olecranon fossa). The distal humerus flares to form the lateral and medial epicondyles that are directly superior to the capitellum and trochlea, respectively (Guerra & Timmerman, 1996). The humeral trochlea is the medial portion of the articular surface of the elbow joint which articulates with the trochlear notch on the ulna in the forearm. The trochlea has the medial epicondyle on its medial side and the capitellum located on its

lateral side. The capitellum is hemispherically shaped and predominantly faces anteriorly articulating with the head of the radius (Guerra & Timmerman, 1996).

Along with the processes, the distal humerus has three fossae that enable maximal flexion and extension. Anteriorly, the coronoid fossa accommodates the coronoid process of the humerus during terminal flexion. While the radial fossa, which lies above the capitellum, functions as a recess for the radial head. Posteriorly, the olecranon fossa houses the olecranon process of the ulna during terminal extension. Rotation occurs between the radial head and radial notch of the ulna as well as between the radial head and the capitellum of the distal humerus (Wells & Ablove, 2008). The cubital tunnel is located on the posterior humerus, medial to the trochlea. This fossa is of particular note, as the ulnar nerve, which is commonly affected in elbow pathologies, rests in the tunnel (Guerra & Timmerman, 1996).

Fitting into the humerus to allow for maximal range of motion is the ulna, the longer bone of the forearm. In the elbow complex, the proximal ulna is of importance. The shape of the proximal ulna enhances the stability and solidity of the elbow complex. The proximal ulna contains a 190° arced surface called the trochlear notch. The notch is bordered anteriorly by the coronoid process and posteriorly by the olecranon. The notch fits into the previously mentioned trochlea of the humerus. (Ablove et al., 2006; Brabston et al., 2009, Wells & Ablove, 2008). The coronoid process of the ulna resists posterior translation and acts as a varus stabilizer in extension likely due to the insertion point of the brachialis, anterior capsule, and medial ulnar collateral ligament (Hull et al., 2005; Wells & Ablove, 2008).

The third and smallest bone of the elbow complex is the radius. Throughout the

range of motion of the elbow, the radial head, which is primarily covered with cartilage, articulates with the capitellum of the humerus; anterior in flexion and inferior in full extension (Brabston et al., 2009). Although small, this joint is exceedingly strong and must accommodate 60% of axial loads during extension. The head of the radius articulates with the radial notch on the proximal ulna during pronation and supination movements (Guerra & Timmerman, 1996).

1.1.1 Muscles of the Elbow

While the bony anatomy of the elbow provides firm endpoint and static stability, the musculature crossing this joint provides mobility and dynamic stability (See appendix 1). Due to the hinge properties of the Humeroulnar joint, the involved muscles can be categorized into two groups: Flexors and Extensors. There are three primary elbow flexors: Brachialis, Brachioradialis, and Biceps Brachii.

The Brachialis, while important for strong movement, performs strictly elbow flexion. The anatomy of the brachialis has been disputed, however, Leonello et al. (2007) were able to clarify the description, which was later confirmed by Sanal et al. (2009) utilizing MRI technology. The brachialis has two heads, a larger, proximal head and a smaller, deep head. The muscle originates on the distal half of the humerus, near the insertion of the deltoid muscle. The tendon inserts distally to the coronoid process at the tuberosity of the ulna, along with the ulnar collateral ligament (Cage et al., 1995). The distal attachment of the large head has been described as fibers of the muscle belly converging to a thick, broad tendon, which is attached to the tuberosity of the ulna, whereas the smaller head attaches as an aponeurosis on the anterior aspect of the coronoid process. It is

innervated by branches of the musculocutaneous and radial nerves, (Frazer et al., 2007; Kamineni et al., 2015; Leonello et al., 2007; Sanal et al., 2009).

The Brachioradialis, located superficially on the radial (lateral) side of the forearm, takes on multiple roles as both an elbow flexor and pronator/supinator. It originates on the upper two thirds of the lateral supracondylar ridge of the humerus and attaches distally on the base of the styloid process of the radius and is innervated by the radial nerve (Gray, 1995 pg 369). Due to the distal attachment, the brachioradialis cannot develop high torque, therefore acts synergistically with the brachialis and biceps brachii to perform elbow flexion (Boland et al., 2008).

The biceps brachii, a two-headed muscle, is perhaps the most powerful of the elbow flexors, crossing both the shoulder and the elbow joints. The origin for the long head biceps brachii can vary among individuals. Vangsness et at (1994) found that the majority of individuals have an biceps origin from both the supraglenoid tubercle of the scapula and the glenoid labrum (Vangsness et al.,1994). The short head of the biceps originates from the apex of the coracoid process, along with the coracobrachialis (Gray, 1995). The two heads of the bicep remain separated until converging within approximately 3 inches of the elbow (Gray, 1995). The biceps brachii tendon also attaches in two locations: the Radial tuberosity and the bicipital aponeurosis, or the lacertus fibrosus. (Athwal et al., 2007). The biceps tendon rotates laterally prior to insertion, assisting the biceps brachii with performing supination of the forearm. The brachioradial bursa sits between the distal biceps tendon and the radius for protection of the structures (Brigido et al., 2009; Gray, 1995).

Elbow extension returns the forearm back to neutral position, where it has a bony

restriction due to the olecranon of the Ulna reaching the olecranon fossa of the humerus. The main elbow extender is the triceps brachii, minimally assisted by the anconeus. The triceps brachii is divided into three heads: long, medial, and lateral. The long head, crossing both the shoulder and elbow, arises from the infraglenoid tubercle of the scapula. It extends distally, anterior to the teres minor and posterior to the teres major. The medial head arises distally from the groove of the radial nerve; from the dorsal surface of the humerus. The medial head is mostly covered by the lateral and long heads, and is only visible distally on the humerus. The lateral head originates from the dorsal surface of the humerus, lateral and proximal to the groove of the radial nerve, from the greater tubercle down to the region of the lateral intermuscular septum. At the distal end of the humerus, the three heads converge to form a common muscle that inserts into the posterior surface of the olecranon. An insertion also exists by way of fibrous expansion into the deep fascia of the posterior forearm (Gray, 1995; Stroyan & Wilk, 1993).

Functionally, the anconeus can be considered a part of the long head of the triceps: it supports the elbow during abduction and extension (Boles et al., 2000). The anconeus' role is assisting the tricep in the extension of the elbow. While the anconeus is not a prime mover, its location, originating on the posterior surface of the lateral epicondyle of the humerus and inserting distally on the posterior surface of the ulna, allows for support of the elbow while in full extension.

Two muscles that cross the elbow accomplish the rotation of the forearm: the pronator teres and the supinator. The pronator teres crosses the elbow at an oblique angle from the medial epicondyle of the humerus to its insertion on the radius. When contracted, the pronator teres rotates the radius and forearm medially. Its antagonist, the supinator,

crosses the elbow obliquely at a right angle to the pronator teres and connects the lateral epicondyle of the humerus to the radius. Contraction of the supinator rotates the radius and forearm laterally (Stroyan & Wilk, 1993). In addition to the pronator teres and the supinator, the pronator quadratus is also a strong forearm pronator. The pronator teres consists of two heads, a superficial head that acts as the prime mover for forearm pronation, and the role of the deep head is a stabilizer for the distal forearm (Stuart, 1996). The pronator quadratus is a not part of the anatomy of the elbow complex, however, it is an important muscle to include due to the function affecting the motion at the elbow joint.

Muscle originating from the distal humerus, not only allows for elbow motion, but also are prime movers for wrist and digit motion. The wrist flexors: flexor carpi radialis, flexor carpi ulnaris, palmaris longus, and flexor digitorum superficialis, originate on the medial epicondyle of the humerus and run along the anterior forearm to the palm of the hand and fingers (Davidson et al., 1995). The wrist extensor group act as antagonists to the flexor group and originate on the opposing epicondyle of the humerus. This group includes: extensor carpi radialis longus, extensor carpi radialis brevis, and extensor digitorum, and originate on the lateral epicondyle of the humerus and run through the posterior forearm to the back of the hand and fingers (An et al., 1981).

1.1.2 Connective Tissue of the Elbow

As the elbow is primarily a hinge joint, two ligaments support the lateral stability of the joint: an ulnar collateral ligament (UCL) or medial collateral ligament and the radial collateral ligament complex. These ligaments blend with the joint capsule to provide structural integrity to the joint throughout abduction or adduction. The medial collateral or

ulnar collateral ligament (UCL) (Figure 2) is the main stabilizer against valgus stress (Morrey & An, 1985; Wells & Ablove, 2008). The UCL, located on the medial elbow comprises 3 portions, as seen in Figure: Anterior oblique, posterior oblique, and transverse (Cohen & Bruno, 2001). According to O'Driscoll et al. (1992), the anterior and posterior portions of the UCL originate from the anteroinferior surface of medial epicondyle and have no attachment to the condyle. The anterior band attaches to the medial edge of the coronoid process with the brachialis muscle, while the posterior band stretches from the medial epicondyle to the medial side of the olecranon, or the crista supinatoris (Cage et al., 1995, Morrey & An, 1985). Both the anterior and posterior portions act as a part of the joint capsule, however the anterior lies deep to the flexor carpi ulnaris and serves as partial origin to the flexor carpi superficialis muscle (Morrey & An, 1985; Safran & Baillargeon, 2005). The transverse ligament, also known as Cooper's Ligament, has little known function, as it attaches to two portions of the proximal ulna; the coronoid and the tip of the olecranon (Morry & An, 1985; Safran & Baillargeon, 2005).

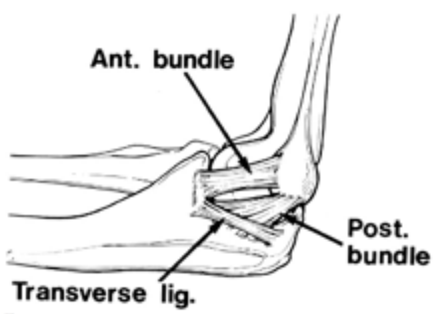

Figure 2. The UCL Jones et al. (2002)

The lateral, or radial collateral ligament complex is comprised of 4 separate ligaments: lateral radial collateral (RCL), annular ligament (AL), lateral ulnar collateral ligament (LUCL), and occasionally, the accessory lateral collateral ligament (King et al., 1993; Morrey & An, 1985) (Figure 3). The lateral ulnar collateral ligament (LUCL), is one of

the main stabilizers against varus and rotatory forces (Wells & Ablove, 2008). According to O'Driscoll et al. (2005), the LUCL originates on the lateral epicondyle, blends with the fibers of the annular ligament and the common extensor tendon and inserts on the tubercle of the supinator crest of the ulna. The AL encircles the radial head as it inserts and attaches on the anterior and posterior margins of the radial notch of the ulna (Safran & Baillargeon, 2005). The RCL inserts on the AL from an origin on the lateral epicondyle of the humerus, providing additional support to the AL during varus stresses (Cohen & Bruno, 2001).

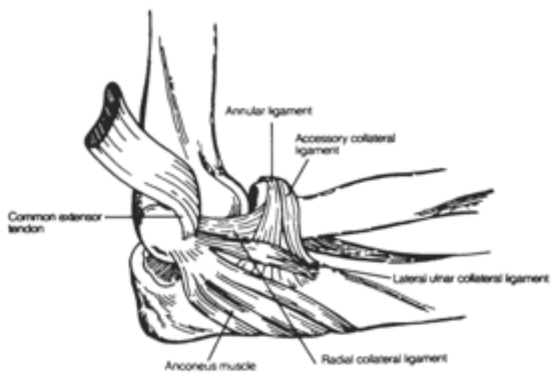

Figure 3. The Lateral ligaments of the elbow Stroyan & Wilk (1993).

The innervation of the elbow is a complex system stemming from three major sources from the brachial plexus. The three nerves that provide capsular innervation are the ulnar, median, and radial (Bekler et al., 2008). According to a cadaveric study by De Kesel et al. (2012), the ulnar nerve and some branches of medial antebrachial cutaneous nerve innervate the ulno-posterior part of the elbow; the radial-posterior part of the elbow is innervated exclusively by the radial nerve; the median nerve and the musculocutaneous nerve innervate the ulno-anterior part of the elbow and the radio-anterior part of the elbow is innervated by the radial nerve and the musculocutaneous nerve.

1.2 Pathophysiology of Elbow Complex Injury

The long lever of the upper extremity allows for substantial force, generally a valgus

force, to be applied to the complex anatomical structures of the elbow. With many overhead sports being repetitive in nature, this repeated application of force, results in microrupture of soft tissue such as ligament or tendon, to the tissues of the elbow can eventually lead to significant injury (Safran,1995). Injury to the Ulnar Collateral Ligament is a prevalent overuse injury among overhead athletes. Injuries to the elbow can also be a result of direct trauma as is the case in elbow dislocations and fractures.

1.2.1 UCL rupture

Ulnar Collateral Ligament ruptures tend to be thought of strictly in baseball pitchers, however, all overhead athletes such as those who participate in baseball, tennis, football, volleyball, hockey, and water polo subject themselves to major valgus forces stressing the UCL. (Safran, 2004; Safran et al., 2005). Hitting a ball, a tennis serve, or throwing side arm all creates a valgus force on the UCL complex (Safran et al., 2005), which is primarily resisted by the anterior oblique portion of the UCL, with assistance by the surrounding musculature (Hairi & Safran, 2010; Hibberd et al., 2015). This repeated trauma leads to an accumulation of microtears that creates a reduction in the tensile strength of the UCL. Eventually, enough cumulated trauma, along with fatigue of the assisting stabilizers, leads to a rupture by a single throw, or overhead motion, resulting in a popping or tearing sensation and medial elbow pain (Hibberd et al., 2015; Petty et al., 2004).

1.2.2 Dislocations

The elbow is a frequently dislocated joint, second only to the shoulder in adults, and is the joint most often dislocated in pediatrics (Cohen & Hastings, 1998; Kuhn & Ross, 2008). The most common mechanism of dislocation discussed is a fall on an outstretched hand or landing directly on the elbow (Cohen & Hastings, 1998; Ring et al., 2002), with 90% of dislocations occurring with posteriorolateral displacement of the forearm (Cohen & Hastings, 1998). Uncomplicated or simple dislocations are those that occur without fracture and usually can be managed with closed reduction and early range of motion protocols, although stability of the joint will be compromised following the dislocation (Hobgood et al., 2008; Mehlhoff et al., 1988; Sheps et al., 2004). According to Sheps et al. (2004), long-term results are usually good with non-surgical intervention having better results than a surgical procedure, allowing for a decreased immobilization period, however surgical intervention is rarely indicated (Cohen & Hastings, 1998). Additional damage to the soft tissue surrounding the elbow complex is seen and ligamentous rupture is common with a traumatic dislocation. Schreiber et al. (2014) assessed the MRIs of 16 acute dislocations. There were no partial or intact UCLs following the dislocation, only complete tears were seen in the affected elbows. O'Driscoll et al. (1992) used cadaver subjects to determine the disruption of the ligaments of the elbow to due to acute dislocation. They found that with dislocation, the lateral UCL is ruptured first, then if the force continues, the joint capsule will tear, and then finally the medial UCL. Interestingly, unless the patient is a throwing athlete, surgical intervention for ligament repair due to acute dislocation is not recommended (Hobgood et al., 2008; Josefsson, 1987).

2.0 STRESS TO THE MEDIAL ELBOW

Throwing is complex and complicated movement that requires coordination of muscle activation, neuromuscular efficiency, joint stability, and muscular strength and endurance. While the upper extremity appears to be the main focus of the overhead throw, the motion requires synchronization of the entire body for a successful and explosive movement. A breakdown of the movement at one segment of the body can create displaced forces at distal ends of the kinetic chain causing disruption in proper throwing mechanics. An understanding of the biomechanics of the overhead throw can help clinicians discover the disorder in the motion and reduce microtraumas that can lead to failure of the stabilizing tissue, such as the ulnar collateral ligament (UCL) of the elbow. However, the overhead motion itself, even while completed properly, can put the upper extremity in a vulnerable position for injury due to the high velocities and torques produced about the joints.

2.1 Biomechanics of overhead motion

The overhead throw has long been described as a 6-phase motion (Figure 4): wind-up, stride/early arm cocking, late arm cocking, arm acceleration, arm deceleration, and follow through (Dillman, Fleisig, and Andrews, 1993; Fleisig, Dillman, & Andrews, 1989; Reinhold et al., 2000; Seroyer et al., 2010; Werner et al., 1993). Of these phases, the former three create the highest magnitudes of force and torque about the shoulder and elbow joints (Fleisig et al., 1995; Oyama, 2012). The kinetic chain must act as a complete unit in order to have successful motion. As Putnam (1993) discussed, "segment motion sequences are dependent not only on a knowledge of the joint moments driving the system of linked segments, but on the way the segments interact as functions of their motions and

orientations."

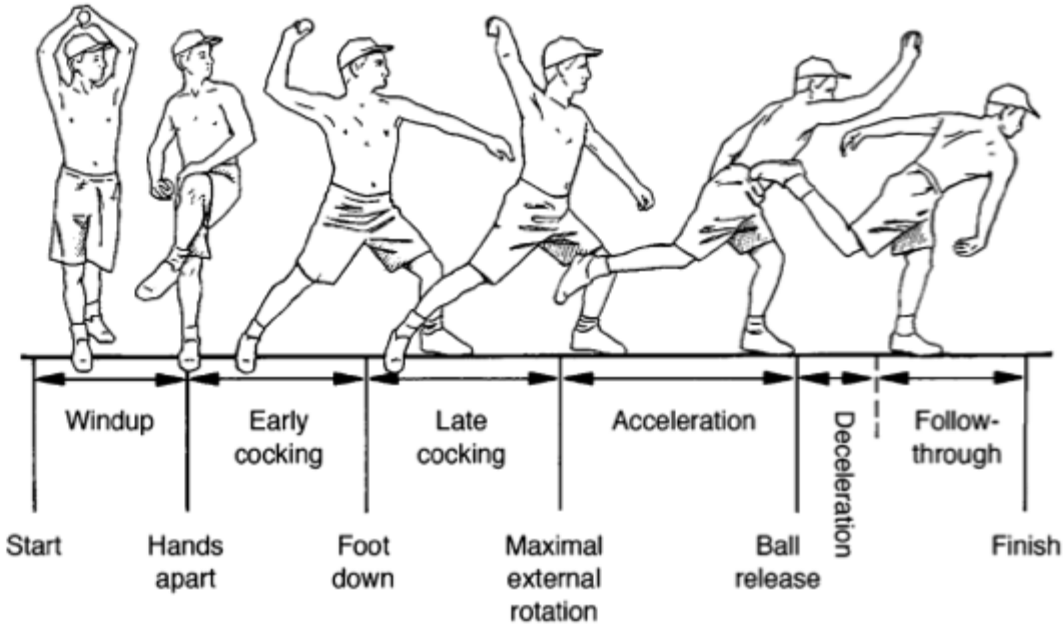

Figure 4. Six Stages of the Overhead throw. Diogiovine, Jobe, Perry (1992).

2.1.1 Wind-up

The windup acts as the preparatory phase to generate the force necessary to achieve a high velocity throughout the more dynamic phases of the movement. The windup begins with the initial movement of the contralateral lower extremity, and ends with elevation of lead leg to its highest point and with separation of the throwing hand from the glove (Meister, 2000; Seroyer et al., 2010; Werner et al., 1993). Maximal hip internal rotation of the stance leg is seen as it rotates 90° (McCulloch, et al., 2014). There is little risk of injury at this time due to minimal torque development (Werner et al., 1993), however improper positioning during this phase can cause the thrower to exhibit premature forward momentum, requiring greater force at the shoulder in order to achieve a high velocity (Seroyer et al., 2010).

2.1.2 Stride/Early Arm Cocking

The early cocking/stride phase begins once the lead leg reaches its maximum height and the ball is removed from the glove and it ends when the lead foot contacts the pitching mound or ground after a long step (Seroyer et al., 2010; Werner, et al., 1993), with hip external rotation of the stride leg in order to point the toes towards the target (Dillman et al., 1993; Laudner et al., 2010; McCulloch et al., 2014) The step increases energy production for transfer to the upper extremity (Dillman et al., 1993) as part of the kinetic chain. Knee and hip extension at this time allows for forward pelvic tilt, which can happen at a rotational velocity of 400 to 700 degrees per second (Seroyer et al., 2010) The forward tilt is countered eccentrically by the abdominal obliques while the stance leg gluteus maximus activates to provide pelvic and trunk stabilization during the flexion of the contralateral leg (Watkins et al., 1989).

Being an unstable joint due to the size differential between the humeral head and the glenoid fossa, much of the muscle actions at this time work to stabilize and position the head in the glenoid to assist in maintaining the integrity of the shoulder joint. The majority of the rotator cuff (supraspinatus, infraspinatus, and teres minor) externally rotates the humeral head on the glenoid fossa, while the scapula is retracted and upwardly rotated by the serratus anterior, middle trapezius, rhomboid, and levator scapulae (Gowan et al., 1987; Seroyer et al., 2010).

2.1.3 Arm-Cocking

The late cocking phase occurs between contact of the front or lead foot to the ground and the point of maximal external rotation of the throwing shoulder (Fleisig &

Escamilla, 1996; Seroyer et al., 2010; Werner et al., 1993). This is phase is more dynamic compared to the previous phases where stability and preparation for acceleration were the main objective. The objective of this phase is to transfer the forces generated in the lower body during the stride up the kinetic chain. This occurs in a rapid sequential rotation of the pelvis, as the lead knee extends, the upper torso, and the shoulder, which is moving into horizontal adduction due to contraction of the anterior deltoid and pectoralis major (Dillman et al., 1993; Oyama, 2012; Seroyer et al., 2010). The more rapid the pelvic and trunk rotation during this phase, the greater the ball velocity (Pappas et al., 1985) as it moves through the kinetic chain. The sequence of this force transfer causes the distal segments to lag behind the proximal segment. According to Putnam (1993), the subsequent forward acceleration of the elbow, or the distal segment is largely a result of the way the shoulder, or the proximal segment, interacts with the distal segment as a function of the shoulder's angular velocity. This lag of the elbow allows the proximal segment to reach a high angular velocity before initiation of distal segment rotation, which results in effective transfer of momentum to the distal segment (Oyama, 2012). This principle allows for higher efficiency in the movement and utilizing elastic energy, however, puts the joints in vulnerable positions.

The rapid accelerations imposed upon the structures require muscular stabilization to control the joint moments. Prior to maximal external rotation, the biceps muscle peaks in activity to act as a humeral head stabilizer (Rodosky et al., 1994). This peak puts significant stress on the long-head of the biceps origin on the labrum of the glenohumeral labrum, which can lead to significant injury in many overhead athletes (Oyama, 2012). As the arm rotates backwards, an eccentric internal rotation torque is needed to stop the arm

from externally rotating too far (Fleisig et al., 1989; Werner et al., 1993). However, it has been demonstrated that pitchers' shoulder external rotation angles reach as high as 170–190° at the instant of maximal shoulder external rotation, far exceeding average shoulder external rotation normative values (Dillman et al., 1993; Fleisig et al., 1999).

While the shoulder is rotating, a maximum valgus stress is placed on the elbow and countered with a varus stress from the wrist flexor-pronators (Fleisig & Escamilla, 1996; Seroyer et al., 2010; Werner, et al., 1993), and possibly assisted by the UCL (Werner et al., 1993). Before the shoulder reaches the maximal external rotation, the arm begins to extend. As previously discussed, the triceps brachii acts as an elbow extensor, however, Werner et al. (1993) found the tricep, while active, did not play a major role in generating high extension velocity, but that the bicep, the triceps' antagonist, activity was decreased, therefore allowing centrifugal force from the shoulder rotation to significantly contribute to elbow extension, without high force needed from the tricep, also allowing for more efficient movement.

Due to the decrease in the bicep activation, the rotator cuff musculature, specifically the teres minor and infraspinatus, provide 550N to 770N of compressive force to maintain the position of the humeral head (Fleisig et al., 1995; Meister, 2000). The subscapularis, serratus anterior, and the latissimus dorsi act to resist translation [which direction?] of the scapula, further stabilizing the joint while externally rotating during the arm-cocking phase (Gowen et al., 1987; Meister, 2000). According to Seroyer et al., "At termination of the late cocking phase, the arm is positioned in 95° of elbow flexion, 165° to 175° of external rotation, 90° to 95° degrees of abduction, and 10° to 20° degrees horizontal adduction (2010)."

2.1.4 Acceleration

Acceleration is generally described as the time between maximal external rotation of the shoulder and the release of the ball (Fleisig & Escamilla, 1996; Seroyer et al., 2010; Werner et al., 1993). There is a continuation of the centrifugal force, which attempts to cause distraction at the elbow while the trunk and arm are rotating (Fleisig & Escamilla, 1996; Werner et al., 1993). This distraction force can be as significant as a force equal to 1-1.5 times the body mass of the thrower (Fleisig et al., 1995; Fleisig et al., 1999). Activation of the triceps and anconeus (Werner et al., 1993) assist in providing compression to maintain the integrity of the joint, along with the elbow extensors, which also provide stability as they control the rate of elbow extension (Fleisig & Escamilla, 1996). As previously discussed during the arm-cocking phase, the tricep is not maximally activated as an elbow extensor. This was previously discussed by Roberts (1971) who found that a pitcher, when given a nerve block to paralyze the triceps, could throw at 80% of their top speed. So while the triceps are active through this phase, it is likely functioning as a stabilizer (Fleisig & Escamilla, 1996; Werner, 1993).

As the thrower approaches the release of the ball, the external rotation reverses course, and there s a rapid internal rotation. Approximately 30 msec before release, the arm internally rotates at least 80 degrees, due to contraction of the shoulder internal rotators and forward acceleration of forearm, reaching peak angular velocities near 7,000 °/s to 9,000 °/s (Dillman et al., 1993; Pappas et al., 1985; Seroyer et al., 2010). This has also been described by Pappas et al. (1985) as transitioning from as much as 175° of external rotation to 100° of internal rotation in 42 to 58 milliseconds. As the shoulder internal rotation velocity reaches this peak, momentum produced by the shoulder and upper torso

movement results in rapid elbow extension reaching as high as 2000°/s and moves from 90° to 120° of flexion, then rapidly extends to near 25° just before ball release (Fleisig et al., 1995; Fleisig et al., 1999; Oyama, 2012; Pappas et al., 1985). At the time of release, the task of the movement is changed from primarily concentric, to a high eccentric force.

The combination of the substantial valgus load due to the maximal external rotation of the shoulder in the late cocking phase to the rapid elbow extension in the acceleration phase generates high tensile forces in the medial aspect of the elbow complex, while compressive forces are placed on the lateral. This point of the overhead throw is where most medial elbow injury is developed and is often termed valgus extension overload syndrome (Langer et al., 2006; Wilson et al., 1983).

2.1.5 Deceleration

Deceleration of the movement is achieved by the eccentric work of the posterior shoulder, biceps, and the trunk musculatures. This phase occurs between ball release and maximum humeral internal rotation and elbow extension (Fleisig & Escamilla, 1996; Meister, 2000; Seroyer et al., 2010; Werner et al., 1993). The phase ends with completion of humeral rotation to 0°, shoulder abduction to 100°, and an increase in horizontal arm adduction to 35° (Meister, 2000). The shoulder rotation decelerates from 7000°/s of internal rotation velocity to a complete stop within this phase that lasts approximately 50 ms following the release of the ball (Pappas et al., 1985). The upper back and posterior shoulder, including the trapezius, rhomboids, serratus anterior, and teres minor are highly active to stabilize the shoulder girdle and humeral head during deceleration (Seroyer et al 2010).

The elbow flexors (biceps and brachialis) are highly active through this phase, acting in an eccentric manner (Dillman et al., 1993). An eccentric elbow flexion torque of approximately 10 to 35 nm is produced throughout the arm deceleration phase to decelerate elbow extension (Fleisig et al., 1995; Werner et al., 1993). According to Fleisig et al. (1995), a maximum elbow compressive force of 800 to 1,000 N occurs just after ball release to prevent elbow distraction. Pronator/supinator antagonists are simultaneously active as the pronator teres decelerates elbow extension and causes pronation, while the supinator and biceps, which is also controlling extension, work to control pronation (Fleisig & Escamilla, 1996). Elbow extension terminates when the elbow is flexed approximately 20° to 25° so as not to impinge upon the olecranon fossa (Fleisig et al., 1995; Werner et al., 1993). This phase transitions quickly to the final, follow-through phase of the throw.

2.1.6 Follow-Through

The follow-through phase begins at maximum shoulder internal rotation and ends as the body continues to move forward with the arm until motion is completed (Fleisig et al., 1989; Fleisig & Escamilla, 1996; Meister, 2000; Werner et al., 1993). Horizontal adduction of the shoulder increases to 60°, and muscle firing decreases in general (Meister, 2000). Forces and torques are significantly decreased as compared to during arm acceleration due to motion of the larger body parts, such as the trunk and lower extremities; help dissipate energy in the throwing arm during this phase (Fleisig & Escamilla, 1996). There is little stress imparted on the structures during this phase, therefore, little injury occurs throughout the follow-through.

2.2 **Elbow movements**

While most research focuses on the movement and torque at the shoulder joint during the overhead throw, the elbow joint moves through a large range of motion while experiencing substantial forces, having a significant impact on the throwing action. In analyzing the biomechanics of the throw, whether for performance or prevention of injury, it is vital for a clinician to be aware of the actions taking place at the elbow throughout the phases of the throwing movement.

The position of the elbow, leading the shoulder throughout the forward motion phases of the throw, imparts a valgus force, or tension, on the medial elbow and a compressive force, acting to resist distraction, on the lateral elbow (Werner et al., 1993; Werner et al., 2002). Extreme external rotation at the shoulder also results in high valgus moments at the elbow (Aguinaldo & Chambers, 2009; Fleisig et al., 1995; Oyama, 2012). In a study by Werner et al (1993), it was found the compression force gradually increased from the time of front foot contact until near the time of ball release. This position was supported by Stodden et al. (2005) who discussed that near the end of arm cocking, 64% of time from foot contact until ball release, maximum valgus torque is experienced at the elbow. Prior to the maximum external rotation of the shoulder, a valgus load of up to 120 Nm has been recorded (Feltner & Dapena, 1989; Fleisig et al., 1995; Werner et al., 1993; Werner et al., 2002). A maximum varus torque of 52 to 76 Nm is generated shortly before maximum external rotation to resist valgus torque at the elbow (Fleisig & Escamilla, 1996). According to Werner et al. (1993) the maximum compression force experienced on the lateral elbow was 780 N between the radius and humerus to produce the varus torque. A similar value was previously found by Feltner and Dapena in a 1989 study. Collectively,

these results indicate that the greatest likelihood for injury at the elbow will occur during the late-cocking to acceleration portion of the overhead throw, just as the shoulder makes maximum external rotation, the forces distracting or pulling the elbow joint apart are experienced. The structures in the elbow must be able to withstand these moments and forces with every repetition or failure of the tissue will result.

Preceding the acceleration phases of the throw, the elbow reaches 85° of flexion near the time of foot contact during the stride phase (Werner et al., 1993). After this point of flexion, the elbow rapidly extends at rates that have been observed as values as high as 3000°/s (Feltner & Depena, 1986; Fleisig et al., 1995; Wisleder et al., 1989) and a maximum extension torque of 40Nm (Werner et al., 1993). As ball release is approached, the magnitude of joint distraction forces at the shoulder and elbow rapidly increase to 1 to 1.5 times the body mass (Feltner & Depena, 1989; Fleisig et al., 1995; Fleisig et al., 1999). Following the release of the ball, Werner et al., found a maximum flexion torque of 55 Nm, which is also similar to the Feltner and Dapena study (1989) and a peak valgus torque of 40 Nm during this phase (1993).

As discussed, the valgus load on the elbow decreases during the acceleration phase of the throw. However, the rapid extension creates tension within the anterior oblique portion of the UCL (Callaway et al., 1997; Morrey & An, 1985). Werner et al. (1993) pointed out that the UCL may also contribute to the countering varus torque in the late cocking phase of the throw, however the ligament is not strong enough to withstand this torque by itself and must be assisted by the wrist flexor-pronator group. This can become an issue during an endurance event, such as pitching a 9-inning baseball game, where the muscle becomes fatigued and the ability to assist in the resistance of the valgus force declines. The

activity of the triceps and anconeus during this same phase also assists the UCL by adding stability and compression to the elbow joint. (Werner et al., 1993). These stressors on the small band of fibers of the UCL make it highly susceptible to microtrauma during the throwing motion and can eventually lead to complete rupture.

The high valgus loads seen just prior to maximal external rotation seem to be influenced by both the shoulder and the torso as forces transfer down the kinetic chain. Both Werner et al. (1993) and Sabick et al. (2004), found a link in the between external rotation of the shoulder and the moment at the elbow, indicating greater shoulder external rotation angle lead to greater elbow valgus moment. A link between elbow extension and the distraction force at both the elbow and shoulder joints have also been discussed. A more flexed elbow at the instant of peak valgus torque appeared to reduce the extent of elbow valgus stress (Werner et al., 2002), while having more extended elbow at specific time points have been linked to greater shoulder distraction force and greater elbow valgus moment, due to the extension of the elbow creating a longer lever since it would increase the distance between the forearm mass and the longitudinal axis of the upper torso, and thereby increase joint forces and moments associated with the motion (Aguinalda & Chambers, 2009; Oyama 2012; Werner et al., 2001). Werner et al (2002) also noted a relationship between shoulder abduction, horizontal or transverse adduction, and the moments recorded at the elbow. The researchers found that throwers with more limited ranges of shoulder abduction at the instant of stride foot contact and those with a reduced angular velocity in transverse adduction appeared to have less valgus stress at the elbow (Werner et al., 2002).

While Werner studied the role of the shoulder in joint kinematics, more recent studies have been studying the influence of the torso in the torque produced at the elbow. Aguinaldo, Buttermore and Chambers (2007) looked at the lateral trunk movement in relation to the elbow forces finding that a greater lateral trunk tilt at ball release lead to a greater peak elbow valgus moment. The connection between the trunk and elbow forces was further discussed in a study by Aguinaldo and Chambers (2009) demonstrated that pitchers had a greater elbow valgus moment when they started rotating their upper torso prior to stride foot making contact with the ground, compared to pitchers who rotated following the stride foot contact. The exact mechanism by which the trunk movement influences upper extremity joint loading is not well understood, and only the relationship has been noted as of yet, however, as will be discussed, inappropriate trunk movement is a risk factor for elbow injury as it disrupts the transfer of energy up the kinetic chain.

Understanding the kinetics and kinematics at the elbow provides guidelines for practitioners, athletes, and coaches to begin establishing methods to reduce valgus stress at the elbow joint. If the proper combination of forces can be determined, the reduction of throwing-related elbow injury could potentially be

2.3 Risk factors for injury

Angular velocity at the shoulder joint can exceed 7,000° per second and has been distinguished as the fastest human movement. (Wilk et al., 2000). As previously discussed, this angular velocity, along with the force generated about the shoulder, is transferred down the kinetic chain to the elbow. This significant force can be equal to 1-1.5 times the body mass of the thrower (Fleisig et al., 1995; Fleisig, et al., 1999). This high force and

velocity can lead to failure of the structures and significant injury due to the tensile stress on the medial elbow and compressive stress on the lateral. UCL ruptures, bony formation, and ulnar nerve damage are just a few of the significant injuries that occur at the elbow due to repetitive valgus stress of the throwing motion. Fleisig et al. (1995) discusses that there are at least 7 kinetic variables that have been associated with injury. During the arm-cocking phase, which ends at maximum shoulder external rotation, the throwing arm produces maximum anterior shoulder force, horizontal adduction torque, internal rotation torque, and elbow varus torque. During the arm acceleration phase, maximum elbow flexion torque is achieved and at deceleration, maximum proximal shoulder and elbow forces occur.

The high forces due to the overhead throw place significant stress on the medial elbow as it attempts to create varus torque to counter the high valgus stress. The primary structure tasked with stabilizing the elbow joint and overcoming high valgus stress is the anterior bundle of the UCL (Johnston et al., 1996; Werner et al., 1993), thus making the UCL most prone to injury. The greatest of these forces is generated during the late-cocking and acceleration phases of the throw (Johnston et al., 1996; Oyama, 2012; Seroyer et al., 2010). However, other studies have found that deceleration is also a high injury risk phase. (Oyama, 2012).

With the large moments developed about the elbow, a major risk factor for injury is the inability to create a varus torque to counter the high valgus force. This was supported by Fleisig et al. (1995), who looked at the elbow and shoulder kinetics for 26 healthy adult pitchers. They found two critical instances for injury: shortly before the arm reached maximum external rotation, when 67 N-m of shoulder internal rotation torque and 64 N-m

of elbow varus torque were generated, and shortly after ball release, when 1090 N of shoulder compressive force was produced. The elbow musculature must eccentrically contract to assist with shoulder internal rotation torque and elbow varus torque (Fleisig et al., 1996). These results were also reported by Fleisig et al. (1995) where 64 Nm of varus torque was developed about the medial elbow just before the shoulder reached maximal external rotation where the elbow was flexed to 95°. Not being able to develop sufficient elbow varus torque, often due to fatigue (Olsen et al., 2006), resulted in medial elbow tension and lateral compression.

In 2010, Anz et al. used 23 professional baseball pitchers to support the theory that higher levels of torque at the shoulder and elbow can result in increased risk of injury. They found a significant correlation of elbow injury with both higher elbow valgus torque and higher shoulder external rotation torque at the late cocking phase of the throw. Therefore, those with higher joint loads were more likely to get injured (Anz et al., 2010; Oyama, 2012).

Fleisig et al. (1995) made an interesting discovery by testing the varus torque about the elbow during acceleration. As prior-mentioned, they found 64 Nm of varus counter torque was developed throughout the throw. Morrey and An (1983) had previously found that the UCL contributes 54% of the varus torque, which means in the case of Fleisig et al. (1995) the UCL would contribute approximately 35Nm, which supports a previous study by Dillman et al., (1993) who found that the UCL could produce approximately 32 Nm of varus torque prior to the tissue failing. The anterior band of the UCL is the primary restraint at 30, 60 and 90° of elbow flexion. At 90°, which is the position of the elbow during the late cocking/acceleration phase, the UCL provides 55% of the resistance to

valgus stress (Langer et al., 2006). Thus, the acceleration phase puts the UCL at or near maximum ability to withstand torque every pitch. According to Werner et al. (1993), in cadaver studies, the ulnar collateral ligament fails under less stress than that which is thought to occur during pitching, indicating other structures, such as the wrist flexors, must provide some assistance.

Even while the maximal external rotation is seen as a risk factor for injury, not having enough shoulder movement is also an indicator for injury. Wilk et al. (2014) measured the range of motion of the throwing and non-throwing shoulders for both internal and external rotation in major and minor league pitchers. In 8 years they recorded 49 elbow injuries and 8 surgeries in 38 players, accounting for a total of 2551 days missed. Their results indicated pitchers with deficits of $>5°$ in total rotation in their throwing shoulders had a 2.6 times greater risk for injury and pitchers with deficit of $\geq 5°$ in flexion of the throwing shoulder had a 2.8 times greater risk for injury. Therefore, reduced mobility is possibly indicative of problems, as well as high mobility.

During arm acceleration the UCL is not the only elbow structure at risk for injury. The need to resist valgus stress at the elbow can result in a wedging of the olecranon against the medial aspect of the trochlear groove and the olecranon fossa. This impingement leads to osteophyte production at the posterior and posteromedial aspect of the olecranon tip and can cause chondromalacia and loose body formation. (Fleisig et al 1995; Fleisig & Escamilla, 1996; Wilson et al., 1983). Wilson et al. (1983) was one of the first groups to discuss this injury as “Valgus Extension Overload.” Wilson’s group found 5 high level pitchers who had pain between the acceleration phase and follow- through phase of the pitching motion, when the elbow should be rapidly extending. In each of the

pitchers, a significant osteophyte was discovered on the posteromedial aspect of the olecranon process causing impingement with the olecranon fossa leading to chondromalacia and pain. These loose bodies can also cause friction injury on the ulnar nerve leading to paresthesia or nerve pain (Johnston et al., 1996). The valgus stress also causes a compression force to the lateral side of the elbow, which can lead to loose body formation from radiocapitellar compression (Field & Altcheck, 1995; Johnston et al., 1996).

Although not discussed often, Fleisig et al., (1996) also found that the deceleration phase of the throw produced injury to the elbow, as the musculature surrounding the joint must be able to generate a large compressive force as the momentum of the arm is working to distract the joint as the velocity of the arm is rapidly decrease.

While the phases of the throw act as a risk factor to developing an elbow injury, there are other factors at play that can further reduce the ability of the medial elbow to withstand the high velocities of the overhead throw. Overuse and fatigue is a major risk factor leading to an elbow injury. In a group of 95 pitchers who had sustained an elbow injury, Olsen, et al., (2006) found that overuse and fatigue had the strongest associations with injury. In Olsen's study, pitchers who averaged more than 80 pitches per game were nearly 4 times more likely to require surgery. Pitching competitively for more than 8 months per year led to a fivefold increase in the need for surgery. However, the most compelling data from Olsen's study showed those who regularly pitched with a fatigued arm were 36 times more likely to have an injury that required surgery (Fortenbaugh et al., 2009; Olsen et al., 2006). Grantham et al., (2014) filmed 11 collegiate pitchers over 26 games and found alterations in mechanics in the entire kinetic chain throughout a game, and throughout a season. They found increased hip lean at hand separation, elbow height

at foot contact, and hip flexion and shoulder tilt at maximum external rotation were seen in innings lasting longer than 15 pitches. Maximum external rotation of the shoulder decreased over the course of a game. Hip lean at hand separation and elbow height at foot contact increased while elbow flexion decreased over the course of the season. Hip lean was previously shown to lead to greater valgus moments (Aguinaldo et al., 2007). These results indicate fatigue has a role in changing mechanics which impact how the elbow responds to the forces imposed upon it.

Gantham et al. (2014) supported previous studies finding improper mechanics leading to injury, by finding that premature upper torso rotation (prior to foot contact) leads to greater elbow valgus moments (Aguinaldo & Chambers, 2009). Distally, movements at the hip also have been shown to affect the injury rates of the elbow. Proper positioning of the leg contralateral to the throwing arm has been shown to be crucial for optimal rotation and force transfer up the kinetic chain (Dillman et al., 1993; Saito et al., 2014). Saito et al. (2014) examined the relationships between hip range of motion and elbow pain using 122 baseball players, 31 of which experienced elbow pain. After assessing goniometer measurements, they determined that both flexion and internal rotation in plant leg and trail leg were correlated with elbow pain, indicating a lack of mobility in the lower limbs is related to pain in the medial elbow. This kinetic chain connection is not a new theory. Saito et al. (2014) supports the idea of the "Anatomy Train" described by Myers in 1987. This theory is somewhat controversial, however, Myers uses Anatomy, or Fascial Trains, in describing how the meridians of the body are connected as a network, each affecting another, since all of the deep fascia of the body is connected and has a role in proprioception and motor coordination. As practitioners, the meridians can be used in

manual therapy and to relieve dysfunction (Myers, 1987). Saito et al. (2014) explained, "improper coordination of the kinetic chain from the lower extremity to the trunk results in an improper upper arm position and increased forces on the elbow." Saito et al. (2014) supported previous research by Ellenbecker et al. (2007) found no difference between limbs in terms of lower leg rotation but compared the motion of a baseball player to that of a tennis player finding that baseball players had significantly less motion all together. This study, though, was refuted by McCulloch et al., (2014) whose study found pitchers showed more internal rotation on their stance hip and more external rotation on their stride hip, including differences as large as 10° of external rotation. This is understandable due to the mechanics of throwing and the need to have external rotation of the stepping leg. The importance of hip motion was discussed in a previous study by Laudner, Moore, Sipes and Meister (2010), who compared professional pitchers to position players for differences in hip range of motion. Their research indicated that pitchers have significantly smaller hip internal rotation range of motion and abduction strength of the trail leg compared with position players. Meaning that position players have the ability to utilize the entire kinetic chain more efficiently, while pitchers must rely more on core and upper body strength, putting the upper extremity at higher risk of injury.

Johnston et al. (1996) reviewed how fatigue could impact the structures of the elbow in that repetitive throwing leading to fatigue decreases the ability for the musculature, primarily the flexor/pronator muscle group, to act as stabilizers. The high force against the muscle group creates microtears in the fibers that can lead to contractures, reducing range of motion. The flexor/pronator group can also cause friction upon its attachment site on the medial epicondyle, leading to inflammation known as

medial epicondylitis. This was supported by Tripp et al. (2007) who promoted fatigue by having 16 baseball players throw a ball every 20 seconds. The players rated their fatigue level after every 20 throws. They found that the athletes were fatigued after an average of 62 ± 28 throws. After fatigue was set in, the group saw errors in arm cock for scapulothoracic internal-external rotation, upward rotation, and posterior tilt; glenohumeral internal-external rotation and flexion-extension; elbow flexion-extension; and wrist ulnar-radial deviation and at ball release for scapulothoracic internal-external rotation and upward rotation, glenohumeral horizontal abduction-adduction, elbow pronation-supination, and wrist ulnar-radial deviation and flexion-extension, meaning the entire upper extremity was affected by fatigue. Fatigue can lead to compromised neuromuscular control, which facilitates injury to the structures (Tripp et al., 2007).

The lack of stability, whether from fatigue or structural failure can lead to ulnar nerve injury. The nerve can be stretched due to valgus instability or compressed due to hypertrophy of the flexor group. Ulnar nerve pain is also often related to injuries with more than 40% of patients experiencing ulnar neuropathy prior to UCL reconstruction (Conway et al., 1992; Erickson et al., 2016; Johnston et al., 1996). Conway et al. (1992) also had 15 out of 68 patients experience ulnar neuropathy following surgical intervention.

Other factors have been shown to be an injury risk, due to the increase of valgus stress on the medial elbow. High pitch velocity has often been linked to an increase in elbow injury due to a greater distraction force (Aguinaldo & Chambers, 2009; Olsen et al., 2006; Stodden et al., 2005). The greater pitching velocity puts older pitchers (college and professional) at a higher risk of injury due to the ability to pitch at a higher level (Fleisig et al., 1999). Olsen et al. (2006) showed that the pitchers who experienced an elbow injury

threw significantly more volume than the uninjured players including: more months per year, games per year, innings per game, pitches per game, pitches per year, and warm-up pitches before a game. Interestingly, those that were injured also used anti-inflammatory drugs and ice more frequently to prevent an injury.

3.0 IMAGING STUDIES OF ELBOW

The use of imaging in diagnostics and prevention of elbow injuries has drastically advanced in recent years. There are currently multiple methods for the assessment of injury, each with their own strengths and limitations, including magnetic resonance imaging (MRI), magnetic resonance arthography (MRA), ultrasound (US), radiograph (Xray), and computed tomography (CT). In 2008, Shahabpour et al. performed a meta-analysis examining the differences in many of the imaging techniques. Magnetic resonance was the best universal diagnostic tool. They found MRI or MRA was the best method for detecting bone injuries, biceps tear, bursitis, epicondylitis, nerve pathologies, and differentiating between complete and partial UCL tears. CT, though expensive, was found to excel at the assessment of the cartilage. US, which is more readily available and far more cost-effective than the other options, could detect epicondylitis, bursitis, and biceps tears. Fractures within the elbow complex are usually clearly visualized with Xray, but can be followed up with a CT scan (Wells & Ablove, 2008). With overlapping capabilities, the best course of action in imaging techniques has not been determined. As technology improves the ideal modality continuously fluctuates, making and understanding of each tool vital for a clinician.

3.1 Imaging Modalities

3.1.1 US

In recent years, the use of ultrasound (US), or sonography, in musculoskeletal conditions has increased as the tool has been recognized for its utility, cost-effectiveness, accessibility, safety, and ease of use (Figure 5). The US unit is also unique in its ability for dynamic, high-resolution assessment in real-time (Lee et al., 2010; Lento & Primack, 2008; Martinoli et al., 2001), while being convenient for practitioners due to the portability of an US unit (Lento & Primack, 2007). US is able to diagnose several pathologies affecting tendons, muscles, ligaments, nerve, bone, and bursae, along with joint effusion in the elbow complex (Lin et al., 2000; Martinoli et al., 2001), without the use of an injected contrast or ionizing radiation, unlike other modalities like the CT scan (Lento & Primack, 2007). When compared to the MRI, the US has an advantage for any patients who experience claustrophobia, as well as a more patient-guided examination where the practitioner can interact with the patient to find the correct location of a significant pathology (Lento & Primack, 2008). Multiple studies have examined the reliability of using the musculosketeletal ultrasound for detecting ligamentous injury to the medial elbow and found it to be an effective diagnostic tool.

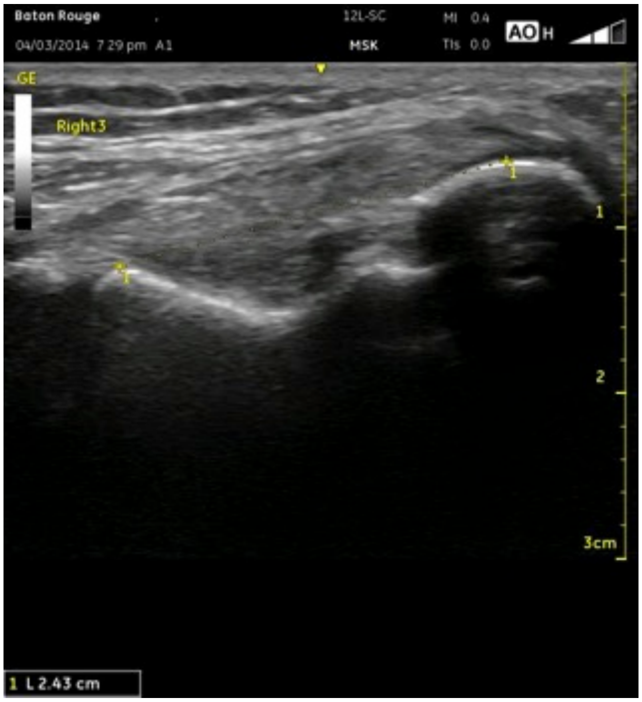

Figure 5 LSU Javelin thrower with Hx of UCL reconstruction. Reid (2015). unpub

3.1.2 Stress Sonography

One advantage of musculoskeletal US as a diagnostic tool is the ability to perform dynamic assessment. This allows the practitioner to apply a stress to the elbow complex to simulate the forces of an actual throw. The Sasaki et al. (2002) paper was an early study using stress sonography, or applying a gravity stress to the medial elbow joint at 90°. They measured bilateral joint spaces of 30 collegiate baseball players finding that the medial joint space was significantly wider on the throwing side than it was on the contralateral side, which was associated with medial elbow pain. They also found an angulation of the UCL indicating that the ligament has to stretch over the edge of the trochlea (Sasaki et al., 2002). Nazarian et al. investigated the reliability and feasibility of the dynamic US. The goal was to determine if US could both rapidly and accurately assess the UCL of a pitcher. They examined 26 professional pitchers and measured the thickness of the anterior band of the

UCL and the joint space bilaterally with and without a valgus stress. With a valgus stress applied, both the UCL thickness and the joint space were significantly larger in the dominant arm of the thrower and calcifications were seen on the dominant arm only. An interesting point to note, is the bilateral examination took an average time of 10.4 minutes, which is a markedly less amount of time when compared to other diagnostic modalities (2003). Ciccotti and colleagues (2014) later tested the reliability of the stress ultrasound using 12 cadaveric elbows. This group was able to measure the mean differences in the ulnohumeral joint gap when releasing different bands of the UCL. As was expected, the release of the anterior band resulted in the greatest increase in joint gap with a 3.4mm increase in the joint space (Ciccotti, Hammoud, Dodson, Cohen, Nazarian, Ciccotti, 2014). This study was important in demonstrating the capability of US to be a precise and reliable diagnostic tool.

Recently, the stress US has been used to identify risk factors for future medial elbow injury by assessing anatomical changes in the ligament. In 2014, Ciccotti et al. published a 10-year cross-sectional study measuring the UCL thickness and ulnohumeral joint space at rest and with a 150N force applied of 368 professional baseball pitchers. 131 players had more than one stress test, which showed an increase in joint space with each subsequent examination. Bilaterally, the UCL was significantly thicker on the dominant arm, along with a presence of hypoechoic calcifications in the dominant arm. The stress US also showed increased laxity with a valgus stress over time. This is supported by Atanda et al. (2015) who used 127 professional pitchers to measure the medial elbow both at rest and with 150N of force. They found a positive relationship between the number of years pitched professionally and mean UCL thickness, suggesting that an increase in UCL thickness is one

of the early changes developed in a player's pitching career (Atanda et al., 2015). While this study didn't find differences in joint space among the groups, it supported the use of ultrasound as a valid imaging tool.

One group, DeSmet et al. (2002) compared the use of the dynamic US and the gold standard, MRI, in a case study of two baseball pitchers. This study was the first published usage of a valgus force during an US examination. The MRI was able to show the expected UCL tear, however severity could not be detected. When applying a valgus force and performing an US assessment, the severity was able to be assessed due to the magnitude joint space opening. While this was only a case study, it illustrated the potential reliability of the US as a diagnostic modality.

3.1.3 MRI

The MRI (Figure 6) has been shown to be a useful tool for evaluation of the anterior bundle of the UCL. A torn UCL appears to have abnormal signal intensity, irregularity, or poor definition of the ligament (Kijowksi et al., 2005). While the MRI can visualize an irregular UCL, the modalities is much more useful at diagnosing full-thickness tears compared to partial. Timmerman, Schwartz, and Andrews found that MRI had both sensitivity and specificity of 100% in surgically confirmed full-thickness UCL ruptures. The sensitivity decreased to 57% with a partial-thickness tear (1994). However, MRA, which uses an intra-articular injection of diluted gadolinium (contrast) or saline solution, has been shown to have the greatest ability to visualize the full-thickness tear (Carrino et al., 2001; Nakanishi et al., 1996). MRA is helpful in delineating the articular structures, separating adjacent anatomic structures, and filling potential spaces that originate in the

joint. When additional information about the integrity of the structures, particularly, cartilage and ligaments, MRA is often the optimal choice (Cerezal et al., 2006). However, most studies completed to date focus on the shoulder and the use of MRA in diagnosing a torn glenohumeral labrum.

One important study demonstrated the value of the MRI in predicting rehabilitation outcomes in UCL injury. Kim et al. (2011) found, using the MRI of 39 baseball players prior to surgery or rehabilitation. By using MRI results only, physicians were able to predict whether the individual would go under reconstructive surgery or be able to use non-surgical techniques for rehabilitation. This is an important study to illustrate the need for early imaging studies to assist in making the often-difficult decision of the course of treatment. Making an early decision can save the athlete time in rehabilitation and away from the mound.

The MRI has been compared to plain dynamic radiographs. Eygendaal et al. (2000), found the dynamic radiograph to be more accurate at showing dynamic instability. The researchers took an x-ray image with out resistance and then applied 15N of force to the lateral humerus simulating a valgus force of an overhead throw. The same patients were also given an MRI or MRA to compare. In 13 of the 16 subjects, the joint space opened significantly and was clearly visualized. In 4 of those subjects with instability, MRI images were normal, meaning the MRI has low sensitivity. While this is an important finding, it is also imperative to note that it may not be in the best interest of a patient with an acute rupture to perform a dynamic radiograph where 15N of valgus force is required (Eygendaal, Heijboer, Obermann & Rozing, 2000).

The CT scan and MRI are often used interchangeably. However, each technique has advantages and disadvantages. Timmerman et al. (1994) compared the reliability of the two scans on 25 baseball players with medial elbow pain. The results showed that the CT scan was 86% sensitive and 91% specificity; whereas the MRI was 57% sensitive and 100% specificity. This indicates that by utilizing the MRI, there is very little risk in a false positive, meaning all the no one without a UCL tear will be identified as having a tear. However, with 57% sensitivity, this implies that roughly half of the individuals with a tear will be missed. Miller et al. (2002) had similar findings for specificity with the MRI for medial epicondylitis, when comparing MRI with US. In 11 patients examined with both MRI and US modalities, sensitivity ranged from 64% to 82% for US and from 90% to 100% for MRI. Specificity ranged from 67% to 100% for US and from 83% to 100% for MRI. This indicates the US, with high specificity, is a good first option due to cost and time effectiveness and MRI is best suited as a follow up tool (Miller et al., 2002).

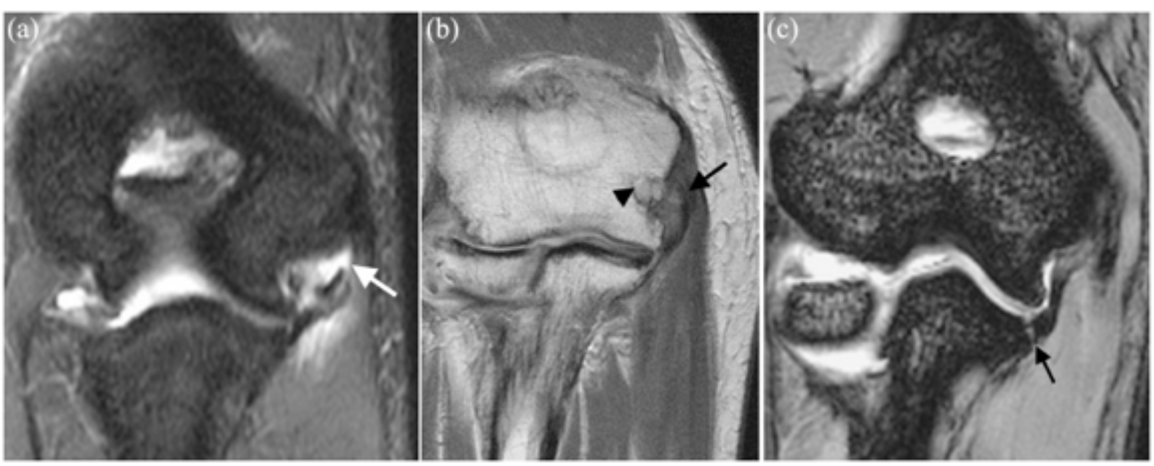

Figure 6 MRI with varying contrasts Sampath et al. (2014).

3.1.4 CT Scan

The CT scan is most suited defining for bony landmarks when compared to the previous options (Wells & Ablove, 2008). While the UCL is soft-tissue, the considerable load placed on the elbow joint can lead to a stress reaction within the bone. This can be seen on the CT scan and could be used as an early detection method for high stress on the elbow joint. Funakoshi and his colleagues used CT technology to test the bone density of 24 pitchers, 12 with UCL pathology and 12 who are asymptomatic. They found in the symptomatic group, the percentages of high-density areas in the anterolateral part of the humerus and the anterolateral part of the ulna were significantly greater than those in the asymptomatic group, indicating areas of high stress due to UCL insufficiency (Funakoshi et al., 2016). The CT scan, due to its ability to visualize osseous trauma, is recommended as an additional imaging technique with x-ray, especially when positive fracture signs are exhibited with a negative x-ray image (Acar et al., 2016), however CT may not be the preeminent imagine option regarding UCL injury, when a simultaneous bone injury is not suspected.

3.1.5 Xray

Radiography (X-Ray) is still the most efficient method for effectively visualizing damage to the bone. For detecting fractures, dislocations, joint effusion/hemarthrosis and soft tissue swelling, x-rays are cost and time effective. X-rays are a part of the initial examination and diagnostics in an injury; however, additional imaging may often be necessary to further determine the full extent of injury (O'Dell, Urena, Dursevich, Sanchez, LiMarzi, Bancroft, 2015).

Stress radiographs have been used as a diagnostic modality in a similar fashion to that of the stress US and can show an expanding ulnohumeral joint (O'Dell et al., 2015). Bruce et al. (2014) used stress radiographs to detect the valgus instability in 273 professional baseball players with previous UCL injuries, used the stress radiograph. By applying a valgus stress of 15daN, the group found the dominant extremity to have .4mm of joint opening greater than the contralateral limb. However, the more substantial result was that those players who experienced a full thickness tear had an opening of .6mm compared to a partial thickness tear opening only.1mm. This indicates the stress radiograph is beneficial for diagnosing the severity of the tear, but may not be the best tool for preventing future UCL injury (2014). Ellenbecker et al. (1998) had previously performed a similar study utilizing the stress radiography with 40 professional baseball pictures and had comparable results with significant differences between the medial joint space opening of the dominant and nondominant elbows with no stress applied and a significantly greater difference in medial joint space opening between the stressed and unstressed elbows was measured in the dominant extremity.

3.1 Limitations

One major limitation for many of the studies mentioned is the small sample sizes available. Individuals with significant medial elbow injuries must be located, and then expensive imaging studies must be performed. This often keeps the sample size of an imaging study relatively small.

The efficacy of each diagnostic modality has been scrutinized, as each has limitations. Without visual confirmation through an operative procedure, the true efficacy

of each tool cannot be fully determined. However, as previously shown, none of the diagnostic modalities discussed have 100% sensitivity or specificity (Timmerman, Schwartz, and Andrews, 1994; Miller, Shapiro, Schultz, Kalish, 2002).

The musculoskeletal ultrasound system, while convenient and cost-effective, does have limitations. According to Lento and Primack (2007), one limitation to the ultrasound is the penetrance of the US waves. For example, superficial structures can be seen using a 12 MHz linear array transducer, however, visualizing a deep structure, such as the rotator cuff, in a large patient, as many professional athletes are considered, is significantly limited. As depth is increased with lower MHz transducers, clarity and resolution is sacrificed. Lento and Primack (2007) also discussed how MRI is the customary imaging modality, and while US is continuously becoming more popular, many physicians are inexperienced in analyzing an US image.

While the MRI is often considered the "imaging modality of choice for evaluation" (O'Dell et al., 2015), there are significant disadvantages to choosing this tool in research and diagnostics. Ciccotti et al. (2014) discusses many of the limitations of the MRI including expense, time, static positioning, and invasiveness. As discussed, US and X-ray both have the dynamic capability. This allows for more the replication of forces experienced by the elbow during motion, while the MRI cannot provide the dynamic real time, observing for pathologic movement (Lento & Primack, 2007). While an US scan takes only minutes, the time for MRI is significantly longer, increasing claustrophobic reactions and more movement during the procedure, leading to inaccurate measures (Lento & Primack, 2007). The MRI is not as cost-effective when compared to other imaging techniques, which can make follow-up imaging a pecuniary issue (O'Dell et al., 2015). Part of the expense is the

lack of convenience. Unlike the US, the MRI is not portable and requires scheduling, travel, and oftentimes, additional personnel for a single image (Lento & Primack, 2007). Due to the size and the complexity of the elbow joint, MRI imaging can be difficult (Carrino et al., 1998). As an alternative to MRI, the MRA is extremely accurate, however invasive and requires the use of contrast which involves direct or indirect injection (Carrino et al., 1998; Kim et al., 2011).

As previously mentioned, X-rays are an excellent tool for ruling in or out fracture or dislocation, but it is best used as a primary tool and additional imaging modalities are often necessary (Grayson, 2005; O'Dell et al., 2015). Stress radiographs can be an effective method of measuring joint space changes, however, as indicated by Ellenbecker et al. (1998), even uninjured pitchers experienced an adaptation of an increased medial elbow laxity, which has prevented the establishment of standard normal values, thus it is difficult to set medial laxity as risk factor for UCL injury.

Each imaging modality has advantages and disadvantages, however each has its specialty. X-ray is often is best choice for the first image to rule out significant bone damage. US, MRI, and CT can be ordered as follow-up imaging to determine the extent of tissue damage based on x-ray results. While MRI is often seen as a top choice, there are relatively few studies to support this idea and as US technology advances, the use of US imaging in medial elbow injuries will continue to progress.

4.0 CLINICAL CONSIDERATIONS

It is imperative for an accurate diagnosis and treatment plan that the clinician be able to fully perform a physical examination. The components of the physical examination include: A thorough history, observation of the condition of the body, palpation, and special tests. Once an accurate diagnosis is achieved, a treatment plan may be developed. Rehabilitation and prevention programs require the clinician to comprehend the biomechanical and physiological needs of the movements.

4.1 Evaluation and diagnosis

As previously established, the role of the Ulnar Collateral ligament is to provide support to the medial elbow and resist high valgus forces in overhead movements. A thorough evaluation is critical in making an appropriate clinical decision for diagnosis and treatment. Getting a clear diagnosis of the injury sustained in the medial elbow is vital in developing appropriate treatment parameters. A proper evaluation must be completed in order to develop the treatment plan. Physical examination should include a detailed history, inspection, palpation, and motion of both upper extremities; a thorough neurovascular examination, and assessment of integrity of the UCL.

Often with orthopedic injury, the history gives a good indication of the underlying issue, or is a helpful guide for the clinician to the next evaluative steps. A thorough history includes factors such as age, how often the athlete is throwing, types of pitches thrown, as well as when the player began to throw those pitches, and all previous injuries to the elbow and treatments used (Azar et al., 2000; Freehill & Safran, 2011). The timing of pain during the throwing motion also indicates the type of injury, as a UCL injury customarily causes

discomfort during the late cocking and early acceleration phases (Conway et al., 1992). Acute injuries to the UCL are associated usually with one pitch where a ''pop'' occurs, followed by sudden pain and an inability to throw. Chronic injuries are seen more often with overuse, longer standing, and often-recurrent inner elbow symptoms. The most common complaint in a chronic elbow injury is decreased velocity and a lack of command, or accuracy with the throw (Freehill & Safran, 2011). However, it is also important to note that pain over the UCL can signal weakness and has 81% sensitivity, but only 22% specificity for UCL tears (Timmerman et al., 1994).

One observation that indicates a potential anatomical adaptation from the repetitive stress of throwing is the carrying angle, which is termed "cubitus valgus" (Andrews et. Al, 1993) (Figure 7). The carrying angle is the angle between a line drawn along the axis of the humerus and a line drawn along the axis of the forearm in the frontal plane (Cain et al., 2003). This can be measured non-invasively with a standard goniometer or plain radiographs (Zampagni et al, 2008). The carrying angle in the general population is 11° to 13°, however, pitchers have been shown to have a carrying angle of 15° or greater in the throwing arm (Andrews et al., 1993; Cain et al., 2003; King, 1969). According to King (1969) a medial stress, such as throwing, while having cubitus valgus, impinges the olecranon process on the medial wall of the olecranon fossa, which will lead to pain especially in the acceleration phase of the throw. However, Eygendaal (2004) indicated that chronic valgus instability leads to cubitus valgus, and not the other way around. Meaning if this adaptation has already occurred, the joint was previously experiencing instability. While cubitus valgus this is an adaptation that occurs due to a repetitive

throwing motion, there is no clear indication how carrying angle affects the risk of injury to the UCL.

Figure 7 Cubitus valgus
Kim et al. (2005).

Examining for soft tissue pathology requires palpation of the major structures of elbow complex. The UCL is difficult to palpate directly (Andrews et al., 1993) however, can be followed along its course from distal and slightly posterior to the medial epicondyle. UCL injury characteristically presents with point tenderness about 2 cm distal to the medial epicondyle, however, tenderness over the UCL has an 81% to 94% sensitivity but only a 22% specificity for UCL tears (Freehill & Safran, 2011). Assessment of the ulnar nerve should also be included to evaluate for neurological issues. Andrews et al. (1993) discussed how it is possible for the ulnar nerve to be dislocated from the groove between the medical epicondyle and the olecranon process, which can leave the nerve exposed and lead to permanent damage. In a study by Azar et al. (2000) out of 91 examined, 40 patients (44%) had a positive Tinel's sign, or distally radiating numbness and tingling (Ciccotti et al., 2004) at the ulnar nerve indicating potential damage or compression to the ulnar nerve in the cubital tunnel, therefore, this is an imperative portion of the evaluation to rule out neurological involvement.

4.1.2 Special Tests

In order to evaluate the integrity of the UCL, laxity and tenderness can be tested using three special tests: abduction (valgus) stress test, the moving valgus stress test, and the milking maneuver (Andrews et al., 1993; Freehill & Safran, 2011; O'Driscoll, 2004). The UCL stability can be tested with the elbow flexed to 25-30° and the forearm pronated (Cain & Dugas, 2004). A valgus stress can be applied on the flexed elbow joint to assess the integrity of the UCL Excessive gaping compared to the contralateral elbow along with pain with the valgus stress indicates UCL instability (Andrews et al., 1993 Freehill & Safran, 2011). However, excessive gaping is considered 1mm to 2mm, a relatively small value, which as a result, the results are often misinterpreted (Cain & Dugas, 2004; Freehill & Safran, 2011).

The moving valgus stress test, described by O'Driscoll et al. (2004) (Figure 8A), places the patient's shoulder in 90° of abduction and external rotation. A constant moderate valgus torque is applied to the fully flexed elbow and then the elbow is extended while maintaining the valgus elbow rotation force. A positive test is concluded when the patient complains of maximal medial elbow pain between 120° and 70° of elbow flexion (Freehill & Safran, 2011; O'Driscoll, 2004). O'Driscoll (2004) found that the moving valgus stress test was highly sensitive (100%) and specific (75%), indicating that this is an accurate physical examination technique and can be used to correctly identify UCL attenuation in the elbow.

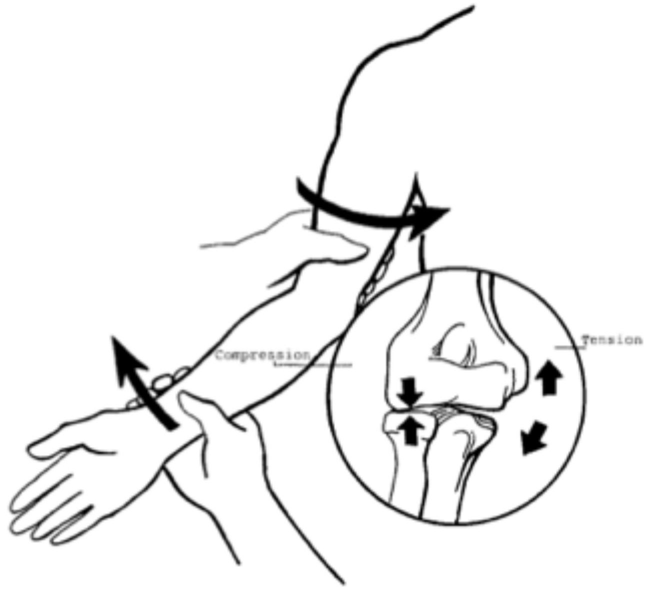

Figure 8 Special tests for the elbow Valgus test Azar et al. (2000)

The "milking maneuver" has been described as a valid method for evaluating valgus stability of the elbow. The patient's is positioned with 90° shoulder abduction and 90° elbow flexion while the examiner grasps the thrower's thumb applies valgus stress by pulling down on the thumb. A variation of this test is performed with the examiner beginning in the position of the milking maneuver and slowly extending the elbow from 90° flexion to 20° flexion while applying valgus stress (Cain & Dugas, 2004; Freehill & Safran, 2011). Laxity and pain are indicative of a positive test.

Again, it is important to note that with each of these special tests, a positive test is indicated by an increase in laxity of >1mm, therefore must be compared bilaterally. The success of the test is largely based on the experience of the practitioner, consequently, the reliability of the above special tests is relatively low. An incorrect diagnosis can lead to additional concerns such as an increase in strength deficits, uncontrolled pain, and further

playing time lost. Therefore, with a history of symptoms consistent with UCL injury, often supplemental diagnostic tools such as US and MRI must be used.

Once a thorough history is obtained, a physical examination can be completed to determine the extent of the medial elbow injury. The clinician is able to apply a valgus stress to the elbow; however, the laxity in an injured UCL is minimal, therefore, a positive test should be referred for radiographic imaging to complete a diagnosis and development of a proper treatment plan.

4.2 Treatment protocols

Currently, little published literature exists comparing nonsurgical and surgical intervention of UCL injury. However, the general perception of conservative, nonsurgical treatment is that the probability of returning to sports at the same level is low; therefore, caution must be used when using this management choice with athletes participating in competitive throwing. Conservative intervention can be appropriate and likely successful in a non-thrower, however the probable higher risk of failure without surgical management makes surgery the more common option in the competitive thrower.

4.2.1 Surgical Intervention

Dr. Frank Jobe performed the first Ulnar Collateral reconstruction on professional baseball player, Tommy John, in 1974. The technique was first reported on by Dr. Jobe in 1986, where he presented the results of 16 autograft reconstructions. Using the Jobe, figure of eight weave with a tendonous autograft, 10 of the 16 patients, or 63%, were able to return to pre-injury level of throwing. However, 31% had significant ulnar nerve damage due to transposition of the ulnar nerve (Jobe et al., 1986). Since the publication of this

landmark study, other surgical methods have been developed to increase return to play rates and reduce complications.

Indications for surgery include an acute, complete tear of the anterior bundle of the ulnar collateral ligament as documented by positive findings on the history, physical examination, and imaging studies in an athlete who anticipated return to sport at a high level. An athlete with chronic UCL injury where 3 months of conservative treatment has not relieved symptoms is also an indication for surgical intervention (Azar, 2000; Freehill & Safran, 2011). Surgery is considered for throwers with partial-thickness tears as shown by diagnostic imaging, and generally necessary for those with complete tears. Since complete tears are less likely to be rehabilitated successfully, early consideration for surgical intervention is preferential (Azar, 2000; Freehill & Safran, 2011).

Surgical intervention has been shown to be an effective treatment with return-to-play rates of up to 95% following the treatment (Ford et al., 2016). Erickson et al. (2016). supported those findings when they found that in 187 patients who underwent surgical intervention, 94.1% of patients were able to return to sport. Erickson et al. (2014)had previously assessed the outcome of 179 Major League pitchers and found that with UCL reconstruction, 83% were able to return to major league pitching, and 97% were able to remain in professional baseball. Values of this magnitude often push competitive athletes to an early surgical mediation instead of conservative therapy. Interestingly, Erickson et al. (2014) also discussed the improvement of pitching performance following the UCL surgery, including improved accuracy and decreased ERA. These improvements have prompted athletes to seek a pre-emptive UCL reconstruction. However, as discussed previously, one of the main symptoms reported is a decrease in accuracy and velocity, therefore, the

athletes were already declined, making any improvements relative to their decrease in performance due to elbow instability. Meaning, they are returning to baseline following reconstruction, rather than improvements from their previous peak. Revision surgery, or secondary surgery, is rarely required, however, the return to pitching rates for professional players is markedly decreased with 78% returning to play at the professional level within two seasons and only 35% of starters returning to their prior workload (Jones et al., 2013).

Currently, there are many surgical options for the repair and reconstruction of the ulnar collateral ligament that have evolved over the last 40 years. While repair may be possible, autograft is generally recommended (Azar, 2001). UCL reconstruction uses a free tendon graft, tensioning it between the medial humeral epicondyle and the tubercle of the ulna (Freehill & Safran, 2011), however the techniques of attachment during the reconstruction vary. The current techniques most commonly utilized by surgeons in reconstructing the UCL are: Jobe, ASMI modified Jobe, docking, and interference screw. Most modern fixation methodologies are apparently biomechanically and clinically equivalent with viable graft choices used for reconstruction coming from the ipsilateral palmaris longus tendon autograft, gracilis, tibialis anterior, or semitendinosus allograft (Erickson, Harris et al., 2015; Freehill & Safran, 2011; Paletta & Wright, 2006) and depends mostly on surgeon's expertise and preference (Hibberd, 2015). However, the palmaris longis, if available, has been shown to have a high failure load of 357 N compared to the UCL at 260N (Regan et al., 1991) and removal does not affect the biomechanics of the pitching motion (Azar et al., 2000). Little information available compares graft types.

The original Jobe technique (Figure 9) included detaching the flexor-pronator mass and transpositioning the ulnar nerve from the cubital tunnel posterior to the medial

epicondyle. Then bone tunnels must be drilled, with 3 in the humerus and 2 place in the ulna. The tendon graft is fed through each tunnel and sutured to itself (Jobe et al., 1986; Langer, et al., 2006). Following Jobe's landmark article, Conway et al. (1992) also compared the Jobe technique to repair of the UCL in 71 patients. Of 14 patients who had a ligament repair, only 7 returned to preinjury level, whereas 68% of those with Jobe' reconstruction were able to return.

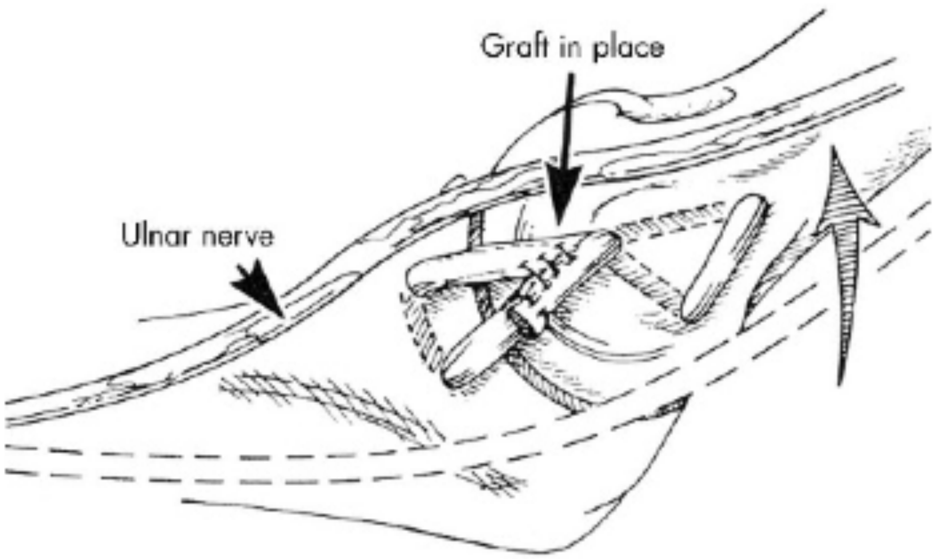

Figure 9 Jobe Figure 8 technique. Langer et al. (2006).

However, 21% of all of the patients had recurring ulnar nerve dysfunction (Conway et al., 1992). While studies support the use of reconstruction, rerupture can occur. Interestingly, in a retrospective surgery of 15 elite pitchers who underwent revision surgery for a UCL rerupture, 11 had previously had the Jobe technique performed. In this particular review, only 33% returned to their previous level of play (Dines et al., 2008). Modifications to the original Jobe technique were developed to reduce the interference with the ulnar nerve and the detachment of the flexor-pronator mass. This included the American Sports Medicine

Institute (ASMI) technique by Dr. James Andrews. This technique uses a posterior approach between the two heads of the flexor carpi ulnaris with the ulnar nerve transposition occurring subcutaneously (Jones et al., 2012; Langer et al., 2006). Azar et al. found that in 91 professional baseball players either receiving the ASMI reconstruction, or a repair, 79% with the reconstruction returned to same level of play, whereas 63% returned with the repair. However, the most common complaint was still ulnar nerve pain (Azar et al., 2000; Jones et al., 2012; Langer et al., 2006).

Altcheck introduced the docking technique in 1996 which uses muscle splitting (Figure 10), instead of muscle reflection, which involves the muscle being split through the posterior third of the common flexor bundle (Langer et al., 2006).

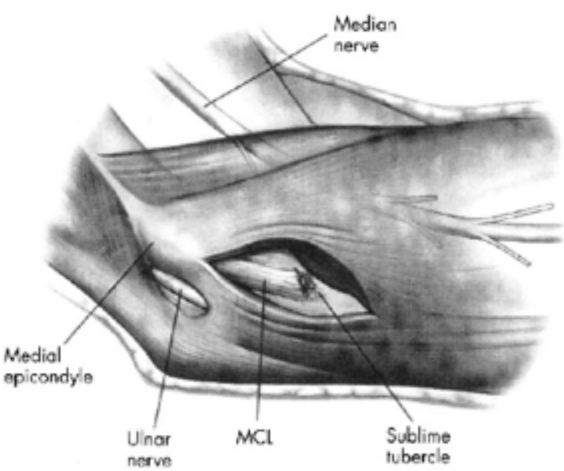

Figure 10. Muscle Splitting
Langer et al. (2006)

Instead of the Jobe figure-eight, the docking technique uses a triangular pattern with one tunnel in the humerus and two in the ulna (Langer et al., 2006; Rohrbough et al., 2002). With this technique, Rohrbough et al. (2002) in a retrospective study, found 33 of the 36 elite players returned to or exceeded their previous competition level, a 92% success rate, including all 22 collegiate players returning to competitive play. The docking technique (Figure 11) continued to be highly effective, as Paletta and Wright (2006) found the

modified docking technique, using 4-strand palmaris longus graft yields highly successful return to pre-injury level of competition rates as high as 92% in elite baseball players (2006). Watson et al. (2014) also supported the modified docking technique finding that in 1368 patients, the technique resulted in a significantly higher rate of return to play and a lower complication rate when compared with the Jobe and modified Jobe methods. The docking technique is quickly becoming the most prevalent choice among surgeons for reconstruction. Erickson et al. (2016) found in 187 patients, the docking technique and a palmaris longus graft to be the most prevalent choices in operative methodology. The study by Erickson et al. (2016) also had the return to play rate at 97% using the docking method. While this technique was developed relatively recently compared to the Jobe technique, data supports the use of the docking technique with high success rates of returning to competitive activity.

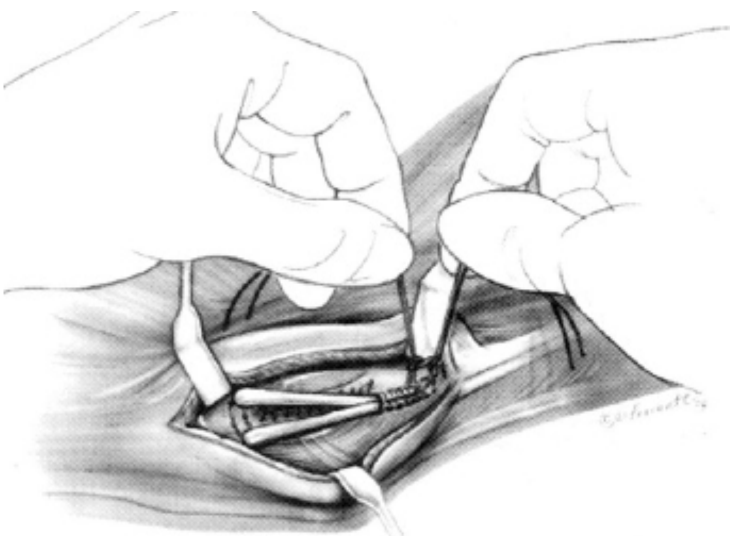

Figure 11 Docking Technique Langer et al. (2006)

Other technique alterations that have been developed include the direction of drilling the tunnels, tying the sutures over a humeral bone bridge, fixing the tendon graft into two blind tunnels with interference screws, and different graft configurations

(Erickson et al., 2015; Freehill & Safran, 2011). The screw fixation method (Figure 12) uses an interference screw placed in a single tunnel in the humerus and ulnar to hold tendon grafts in place (Ahmad et al., 2003; Langer et al., 2006). With the screw fixation method, failure strength was comparable with that of the innate ligament and physiologic elbow kinematics was returned to near normal (Ahmad et al., 2003).

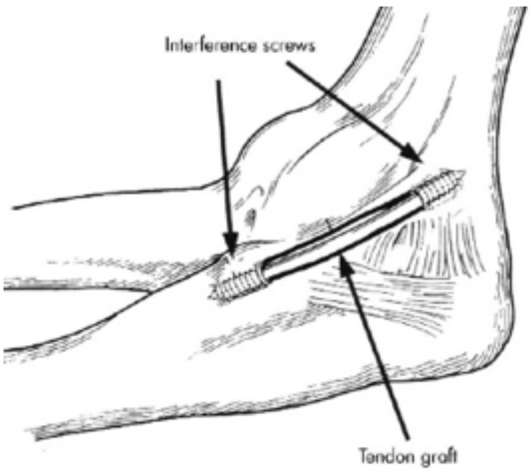

Figure 12 Interference Screws
Langer et al. (2006).

However, little research to date compares the interference screw to the additional techniques, making it difficult to accurately assess the validity of the surgical method. Surprisingly, few clinical investigations have been done in recent years comparing each method, though it appears the docking technique is becoming the optimal choice for surgical intervention.

One of the most commonly reported complications with surgical intervention is ulnar neuropathy, due to the ulnar nerve transposition still being performed in a majority of procedures (Erickson et al., 2015; Vitale & Ahmad, 2008). Vitale and Ahmad (2008), in a review of literature, found the use of a muscle-splitting approach to the flexor-pronator mass, decreased handling of the ulnar nerve, and use of the docking technique, have resulted in improved outcomes of 95% and reduced complications of ulnar neuropathy to

3%. This indicates an ulnar nerve transposition should only be used if symptoms specify ulnar nerve involvement. With the reputation of the docking technique, which does not require ulnar nerve transposition, the overall number of ulnar nerve injury with surgical may decrease in the future, as full recovery rates continue to improve.

Following surgical intervention, the elbow is immobilized at 70 to 90° of elbow flexion for approximately 10 days (Freehill & Safran, 2011; Jobe et al., 1986). This allows for incision healing and time for the allograft to get established. Once the splint is removed, range of motion exercises of the wrist, elbow, and shoulder are begun. Freehill and Safran (2011) recommend mobilizing between 30 and 100° of elbow flexion. However, some studies indicate that immediately following surgical intervention, full extension is safe, and recommended, due to an increase in the risk of contractures with immobilization (Bernas et al., 2009; Wilk et al., 2012) and places less than 3% of strain on the new ligament, while flexion beyond 50 degrees may place detrimental strain on the reconstruction. Also, isometric flexion and extension exercises do not increase ligament strain; however, 90 degrees of flexion should be avoided with no valgus stress (Bernas et al., 2009; Wilk et al., 2012). After a period of 6 weeks, full, pre-operative range of motion should be returned (Freehill & Safran, 2011; Jobe et al., 1986). It is important to note the extension capabilities of the thrower prior to surgical intervention. According to Wright et al. (2006) in 33 professional baseball players, the average loss of elbow extension was 7°, and the average loss of flexion was 5.5° compared to the opposite elbow joint, indicating that full range of motion may be less than the general population normative values.

Following achievement of full range of motion, strengthening exercises at both the shoulder and the elbow are initiated, however, a valgus stress should be avoided for four

months postoperatively (Freehill & Safran, 2011; Jobe et al., 1986). At 14 to 16 weeks, a throwing program can be introduced, beginning with distances of 30 to 40 feet on flat ground and progressing to long toss of 120 to 180 feet (Jobe et al., 1986; Freehill & Safran, 2011; Wilk et al., 2012). The long toss is controversial for pitchers, as Fleisig et al. (2012) found that as intensity and distance increase, the stresses increase on the medial elbow and anterior shoulder joint. The longer distances significantly increased these forces, however, this may help exacerbate any deficiencies allowing for additional intervention prior to return-to-play (Fleisig et al., 2011; Wilk et al., 2012). The rehabilitation will continue to progress to throwing off of a mound to increase stress on both the elbow and the shoulder. According to Wilk et al. (2012), the pitcher begins at 50% intensity and gradually progresses to 75%, 90%, and 100% over 4 to 6 weeks. Breaking balls are initiated once the pitcher can throw 40 to 50 pitches at a minimum of 80% intensity without symptoms. The average pitcher is able to return to full activity in 10 to 12 months (Freehill & Safran, 2011; Jobe et al., 1986) barring any additional complication

4.2.2 Non-surgical intervention

When possible, UCL injury is treated conservatively with non-operative intervention. Recent evidence suggests that if the UCL is in continuity or demonstrates a low-grade partial tear on the MRI, patients were more likely to respond to rehabilitation (Freehill & Safran, 2011).

Incomplete UCL injuries in professional baseball players can be successfully treated non-operatively in the majority of cases. Ford et al. (2016) found that in a study of 43 professional baseball players that 28 players were able to undergo a non-operative

treatment and had return-to-play rates of 93%. However, each of these subjects had an incomplete rupture. Those subjects involved in the study with a grade III tear, were treated surgically, and 7 subjects required surgery after attempting rehabilitation (Ford et al., 2016). This creates disagreement among clinicians due to the time lost attempting conservative treatment, in addition to those that were treated surgically had a 100% return-to-play rate (Ford et al., 2016). Previously, Kim et al. (2011) discussed the treatment of 39 baseball players with 12 successfully treated non-surgically, a 67% success rate, however, only 8 were able to return to the same level of participation, a 33% success rate. While less invasive, for those athletes wanting to return to pre-injury competition status, non-surgical treatment is relatively unsuccessful.

Non-surgical or conservative treatment can be broken into two phases: resolution of symptoms and strengthening. The goal of the first phase is to manage pain while restoring any range of motion deficits. Initially, range of motion should be limited to 10 to 100° of elbow flexion and gradually increased by 5° to 10° per week over 3–4 weeks (Hibberd et al., 2015; Wilk et al., 2012).

Following return of full range of motion, a progressive strengthening program should commence. Isometric exercise can be performed for the shoulder, elbow, and wrist to prevent muscular atrophy during the range of motion phase (Wilk et al., 2012); but should be progressed to isotonic strengthening during the second phase. The muscle groups supporting the elbow complex should be emphasized to provide dynamic stability from valgus stress, specifically the flexor-pronator group (Hibberd et al., 2015) due to the varus moment provided by the group to resist the valgus stress at the elbow, particularly the flexor digitorum superficialis (Udall et al., 2009).

The advanced strengthening phase is usually initiated at 6 to 7 weeks postinjury. During this phase, the athlete is progressed to the Thrower's Ten isotonic strengthening program, plyometric exercises, core stabilization, and open and closed kinetic chain exercises are slowly initiated (Wilk et al., 2012; Hibberd et al., 2015). A gradual return to throwing is initiated once the athlete regains full motion, adequate shoulder and elbow strength, and dynamic stability of the elbow (Wilk et al., 2012). This is vital to the healing process to allow the elbow complex to be properly stressed to achieve appropriate adaptations for return-to-play (Hibberd et al., 2015). The athlete is allowed to return to competition following the asymptomatic completion of the interval sport program, however, strengthening, stretching, and adequate recovery time must be enforced (Hibberd et al., 2015; Wilk et al., 2012). If symptoms reoccur during the interval-throwing program, it is usually at longer distances, at greater intensities, or with off-the-mound throwing, much like that of the surgical intervention. However, if symptoms persist, the non-operative option may be considered a failure and surgical intervention will take place.

4.3 Prevention protocols

While understanding the proper evaluation, diagnosis, and rehabilitation techniques is essential in providing appropriate medical care, preventing the injury for occurring, when possible, is even more vital. Not all injuries can be prevented, however, decreasing the associated risk factors can limit the extent of the injury. One major risk factor that is often focused on is the pitch count, or the volume of throws made. Even with proper mechanics, sheer volume of throw put an athlete at a higher risk of injury. Each level of baseball has implemented guidelines for volume, however, the most stringent of guidelines

are for little league baseball, with no true regulation on upper level athletes (Lyman et al., 2001; McNeil, 2006; Olsen et al., 2006, USA Baseball, 2006; Hibbard et al., 2015). Using current research and clinical experience, The USA Baseball Medical and Safety Advisory board developed participation recommendations for youth and high school baseball players limiting outing, weekly, season, and year pitching limits (USA Baseball, 2006; Hibbard et al., 2015). Potentially reducing the risk of negative anatomical adaptations in youth and high school may reduce the risk of those athletes being injured later in their career, however, there are no specific guidelines for collegiate or Major League Baseball. Although no current guidelines exist, Olsen et al. (2006) did correlate a higher number of warm-up pitches, more innings pitched per game, more pitches thrown per game, and pitching eight or more months out of the year with a higher risk of elbow injuries. Recently, Major League baseball has had a trend toward lower pitch counts and five-man pitching rotations to limit volume. Often, a starting pitcher is limited to approximately 100 pitches per outing and a starting rotation every five or six days (McNeil, 2006). However, this is only a trend, and not a practiced regulation.

Maintaining shoulder range of motion, specifically, internal rotation may be the essential component to reducing medial elbow injury. Internal rotation at the shoulder has been shown to form the "physiologic counter to the valgus torque" generated during the late cocking phase of throwing (Dines, Frank et al., 2008; Hibberd et al., 2015). Dines et al. (2008) tested this theory by matching 29 baseball players with elbow injury with asymptomatic 29 players and measuring glenohumeral internal and external rotation, elbow flexion and extension, and forearm pronation and supination. They found the injured players had significantly less arm internal rotation, as well as decreased total range of

motion in the injured group. This indicates that elbow instability may be associated with glenohumeral internal rotation deficit (Dines et al., 2008). Wilk et al., supported this finding in 2014 with professional baseball players, however, they found a ≥5° in flexion of the throwing shoulder had a 2.8 times greater risk for injury in addition to rotation deficit (Wilk et al. 2014). In throwers, a loss of internal rotation is often due to posterior shoulder tightness and lack of stabilizing strength (Hibbard et al., 2015). Interestingly, ipsilateral shoulder external rotation is not affected when the UCL is intact, and the external rotation seems even greater when the UCL has been injured (Mihata et al., 2008).

Many stretching and strengthening programs exist that focus on the shoulder. The structures of the posterior shoulder can be stretched through using techniques such as the "sleeper stretch." McClure et al. (2007) tested the efficacy of the sleeper stretch, comparing the technique to the "cross-body stretch," or supine horizontal adduction. With a 54-subject sample size, they found significant positive results with the cross-body compared to the sleeper following a 4-week intervention. However, both saw long-term improvements with performing the stretch daily for 5 repetitions for 30 seconds, indicating there are chronic adaptations with a long-term stretching program. Laudner et al. (2008) also tested the efficacy of using the sleeper stretches for decreasing posterior tightness. The group held the passive sleeper stretch for 30 seconds, 3 times with range of motion testing before and after the intervention. Significant differences in ROM were seen following the passive stretching, however, no follow up was taken, therefore, the results were acute only, but indicates that improvements can be made with passive stretching.

A regular stretching program can increase the lack of mobility, but a regular strengthening program can improve the stability of the shoulder girdle. The strengthening

program most commonly used is the Thrower's Ten (Wilk et al., 2012; Wilk et al., 2009). This progressive strengthening program includes external and internal rotation with exercise tubing at 0° of abduction and active ROM exercises against gravity. These exercises initially include standing scaption in external rotation, standing abduction, side-lying external rotation, and prone rowing. The program can continuously advance as the athlete improves in strength, emphasizing the posterior rotator cuff muscles and scapular strengthening (Wilk et al., 2012). Establishing a range of motion and strength maintenance program may decrease the stress on the medial elbow and potentially decrease the risk of UCL tear.

Stretching and strengthening of the upper body is essential in returning to full function, however, as previously discussed, Saito et al. (2014), established the link between lower limb and upper limb mobility, therefore the entire kinetic chain needs to be addressed for full recovery and to reduce the risk of re-injury to the UCL of the elbow.

SUMMARY

Overhead athletes, most commonly pitchers, due to repetitive motion, are likely to experience an upper extremity injury. The biomechanical nature of the movement places a large valgus force on the medial elbow, which requires the structures to withstand the force, while developing a sizable counter-torque; specifically the small ulnar collateral ligament undergoes this stress. While improper mechanics can lead to injury, even "proper" mechanics can cause the tissue of the ligament to breakdown and rupture over time. Currently, no specific guidelines exist for optimal recovery between bouts of throwing activity in the elite overhead athlete to avoid the overuse or chronic injury. Most imaging

modalities are used once injury has occurred, however few articles have examined changes to the ligament throughout the course of a game or season prior to injury. Most prevention programs for overhead athletes are based on the shoulder, therefore there is a general need for a protocol for tracking changes to the physiological structure of the elbow complex and examining variables that may be effected by these anatomical changes.

RESEARCH QUESTIONS

Based on the literature reviewed in this paper, the following research questions are proposed:

1. Would the use of Musculoskeletal US for tracking the opening of the medial elbow opening space reduce the risk of UCL rupture?
    a. How long, if at all, is required for the joint space to return to baseline following a throwing bout.
2. How is the medial joint space opening correlated with kinematic changes in the throw including ball velocity and accuracy?
3. How is the medial joint space opening correlated with kinetic changes in the throw including torque and linear force at the elbow?
4. How do therapeutic exercises focusing on the muscles crossing the elbow complex affect performance and injury risk in a positive way in a patient population?
5. What therapeutic exercises of the trunk and lower body affect the forces developed at the elbow?
6. How does increasing shoulder internal rotation affect the medial joint space of the elbow during an overhead throw?

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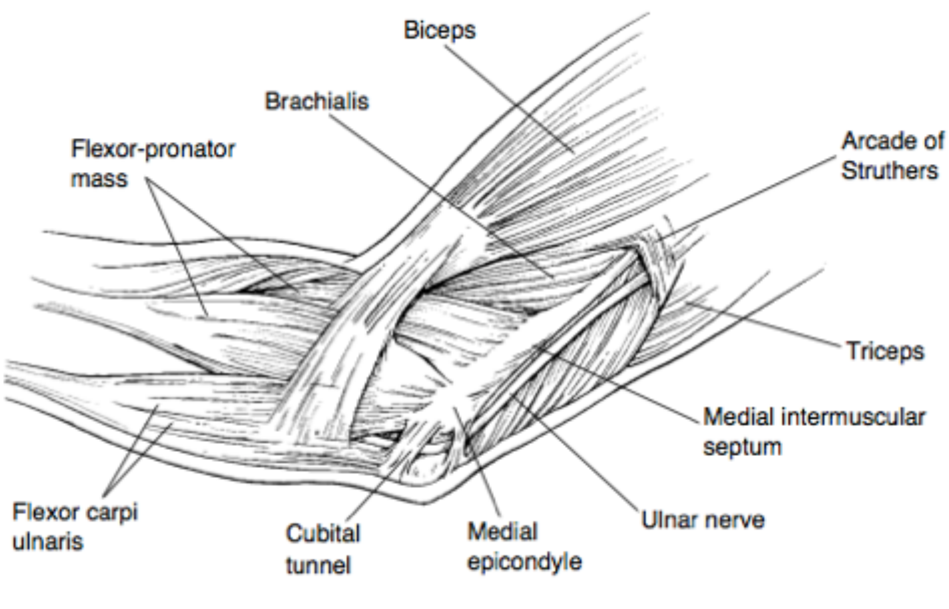
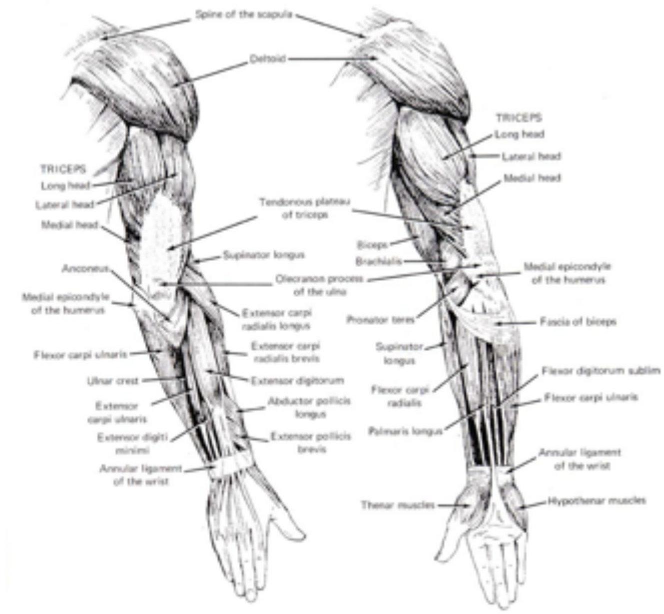
Appendix





Appendix 1 Muscular Anatomy of the medial elbow Stroyan and Wilk (1993)

APPENDIX C: IRB AP PROVAL AND CONSENT FORMS

ACTION ON PROTOCOL CONTINUATION REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Meghan Reid
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: July 9, 2014

RE: **IRB#** 3407

TITLE: Using Musculoskeletal Ultrasound in Determining Ulnar Collateral Ligament Length Changes

New Protocol/Modification/Continuation: Continuation

Review type: Full ___ Expedited _X_ **Review date:** 7/8/2014

Risk Factor: Minimal __X__ Uncertain ______ Greater Than Minimal_______

Approved____X____ **Disapproved**__________

Approval Date: 7/8/2014 **Approval Expiration Date:** 7/7/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 60

LSU Proposal Number (if applicable)**:** __________

Protocol Matches Scope of Work in Grant proposal: (if applicable) ___

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

ACTION ON PROTOCOL CONTINUATION REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Meghan Reid
Kinesiology

FROM: Alex Cohen
Associate Chair, Institutional Review Board

DATE: December 8, 2016

RE: **IRB#** 3459

TITLE: Using Musculoskeletal Ultrasound in Determining Ulnar Collateral Ligament Length Changes in Overhead Athletes

New Protocol/Modification/Continuation: Continuation

Review type: Full ___ Expedited X **Review date:** 12/8/2016

Risk Factor: Minimal X Uncertain ________ Greater Than Minimal_______

Approved X **Disapproved**__________

Approval Date: 12/8/2016 **Approval Expiration Date:** 12/7/2017

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 100

LSU Proposal Number (if applicable)**:**

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Alex Cohen, Associate Chairman ____________________

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: Make sure to use bcc when emailing more than one recipient.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

Informed Consent

1. Study Title: Using Musculoskeletal Ultrasound in Determining Ulnar Collateral Ligament Length Changes in Overhead Athletes

2. Performance Sites: Baton Rouge General Family Health Center
3800 Florida Boulevard, Baton Rouge, LA 70806

Martin J. Broussard Center for Athletic Training
Louisiana State University
Baton Rouge, LA 70803

3. Investigators: The investigator listed below is available to answer questions about the research, M-F, 8:00 a.m. - 4:00 p.m.
Meghan Reid, MS, ATC, CSCS mreid6@lsu.edu 225-578-2491

4. Purpose of the Study: The purpose of this research project is to investigate, utilizing a musculoskeletal ultrasound, the difference in ulnar collateral length in dominant and non-dominant arms in overhead athletes

5. Subject Inclusion: College aged, Overhead Athletes.

6. Number of Subjects: 100

7. Study Procedures: 6 total images will be taken on each subject. 3 images on both dominant and non-dominant arms at 90°.

8. Benefits: There are no direct benefits to the subjects. However, information gained from the study may provide an indication for risk of elbow injury.

9. Risks/Discomforts: There are minimal risks of injury in this project.
No compensation is available in case of study-related illness or injury.

10. Injury/Illness: In the unlikely event of injury or medical illness, you will be referred for treatment, but the expense of medical treatment will be your responsibility. No compensation is available in case of study-related illness or injury.

11. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time with no jeopardy to their treatment by their respective doctors or other penalty at the present time or in the future.

12. Privacy: The LSU Institutional Review Board (which oversees university research with human subjects) may inspect and/or copy the study records.

Results of the study may be published, but no names or identifying information will be included in the publication.

13. Financial Information: There is no cost to the subjects, nor is there any compensation for participating in the study.

14. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Dennis Landin, Chairman, LSU Institutional Review Board, (225)578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

Subject Signature:________________________________ Date:____________________

The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.
Signature of Reader: ________________________________ Date:____________________

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Meghan Jackson
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: October 7, 2016

RE: **IRB#** 3761

TITLE: Kinetic and Kinematic Variables related to Medial Elbow Joint Space in Collegiate Baseball Pitchers

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Bilaterally test grip strength.

Review type: Full ____ Expedited __X___ **Review date:** 10/3/2016

Risk Factor: Minimal ____X_____ Uncertain __________ Greater Than Minimal_______

Approved___X____ **Disapproved** ___________

Approval Date: 10/7/2016 **Approval Expiration Date:** 9/15/2017

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 25

LSU Proposal Number (if applicable)**:**

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: Make sure you use bcc when emailing more than one recipient.**
   **All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

1. Study Title: Kinetic and Kinematic Variables related to Medial Elbow Joint Space in Collegiate Baseball Pitchers

2. Performance Sites: Alex Box Baseball Stadium
Louisiana State University
Baton Rouge, LA 70803

Martin J. Broussard Center for Athletic Training
Louisiana State University
Baton Rouge, LA 70803

3. Investigators: The investigator listed below is available to answer questions about the research, M-F, 8:00 a.m. - 4:00 p.m.
Meghan Reid Jackson, MS, ATC, CSCS
mreid6@lsu.edu 225-578-9232

4. Purpose of the Study: The purpose of this research project is to investigate medial elbow joint space in collegiate baseball pitchers and to discover any correlation between joint forces and ball kinematics and joint space.

5. Subject Inclusion: Louisiana State University Division I Collegiate baseball players

6. Number of Subjects: 25

7. Study Procedures: LSU Varsity Baseball Pitcher's medial elbow space will be measured prior to throwing a simulated (practice) game using MSK US. Baseline maximal forearm strength using a dynamometer will be taken with 2 trials on each arm. Pitchers will wear a neoprene force sleeve while throwing during practice. Throwers medial elbow joint space with the MSK US and forearm strength with the hand dynamometer, will then be reassessed following the outing and 48-72 hours following the outing.

8. Benefits: Adding to the knowledge of potential factors for medial elbow injury. Subjects will receive no direct benefits.

9. Risks/Discomforts: The risks of using MSK US is exceptionally small, but a very small risk of injury cannot be 100% ruled out, none has ever been reported, no adverse side effects has ever been reported. No compensation is available in case of study-related illness or injury. No adverse side-effects have been reported from the use of the hand dynamometer.

Loss of Confidentiality
Participating in research studies that collect personal data may result in a breach of confidentiality of personal data. All attempts will be made to keep your personal data confidential. Participants will be assigned unique ID number and information that could identify a participant will not appear in publications. Additional information regarding how your confidentiality will be kept private can be found below in section 12.

Unknown risks
In addition to the risk listed above, you may experience a previously unknown risk or side effect.

10. Injury/Illness: In the unlikely event of injury or medical illness, you will be referred for treatment, but the expense of medical treatment will be your responsibility. No compensation is available in case of study-related illness or injury. If you have any questions about your rights as a research volunteer, you should call Dennis Landin, Ph.D., Institutional Review Board Office at 225-578-8692.

If you have any questions about the research study or think you have a research-related injury or medical illness, contact Meghan Jackson 225 578-2491 during regular working hours.

11. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time with no jeopardy to their treatment by their respective doctors or other penalty at the present time or in the future. All subjects will be aware they are receiving the treatment

12. Privacy:
Every effort will be made to maintain the confidentiality of your study records. However, someone from Louisiana State University may inspect and/or copy the medical records related to the study. Results of the study may be published; however, we will keep your name and other identifying information private. The data collected by this study may be shared with other biomedical researchers who are doing their own research studies, but your identifying information will not be shared with these researchers. Other than as set forth above, your identity will remain confidential unless disclosure is required by law. In addition, because you are being recruited from a select group of individuals, LSU Athletes, the dates of your sport participation and data collection will not be presented publically or published.

13. Financial Information: There is no cost to the subjects, nor is there any compensation for participating in the study.

14. Alternatives: Alternative therapies do exist, however, the subject is experiencing no improvement with current treatment options.

15. Unforeseeable Risks: The assessment has the potential for unforeseeable risks, however no adverse effects have been reported.

16. New Findings: Significant new findings developed from the study data or independent sources during the course of the research which may relate to the subjects' willingness to continue participation (e.g., adverse response to the treatment) will be explained to the subjects.

17. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Dennis Landin, Chairman, LSU Institutional Review Board, (225)578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

____
Printed Name of Volunteer

________________________________ Date ____________
Signature of Volunteer

Date of Birth of Volunteer

VITA

Meghan Jackson serves as an Instructor in the School of Kinesiology at Louisiana State University. She supervises and advises students in the Human Movement Concentration within the School of Kinesiology. She has taught courses in the Bachelor of Science in Athletic Training as well as Biomechanics and Human Anatomy and assisting in the human cadaver anatomy course. Jackson serves as a faculty advisor for the Kinesiology Club. She is a Certified Athletic Trainer and a Certified Strength and Conditioning Coach who has practiced in a variety of settings. She has worked as an Athletic Trainer for several high school, and community outreach programs, and in DI athletics. She has also served as a Strength Coach for Lindenwood University in St. Charles, Missouri, as well as a coach for the Disabled Athlete Sports Association in St. Louis, Missouri.

Jackson, a St. Louis native, worked as a Graduate Assistant Athletic Trainer at Southern Illinois University in Carbondale, Illinois, where she earned a Masters Degree in Kinesiology. She also served as an athletic training intern for the Gateway Grizzlies Minor League Baseball team. Jackson earned her Bachelors Degree from Truman State University in Kirksville, Missouri in Exercise Science where she was an Athletic Training Student for four years. She is married to Daniel Jackson since 2016.