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The Assessment of Medial Stability of the Elbow Using Sonography and Three Clinical Tests

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THE ASSESSMENT OF MEDIAL STABILITY OF THE ELBOW USING SONOGRAPHY AND THREE CLINICAL TESTS

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APPROVAL OF THESIS

We, the faculty supervising the work of Andrew M. DeMoss, affirm that the thesis, *The Assessment of Medial Stability of The Elbow Using Sonography and Three Clinical Tests* meets the high academic standards for original scholarship and creative work established by the Masters of Science in Athletic Training and the College of Health Professions. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

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ABSTRACT

Introduction: Injuries to the Ulnar Collateral Ligament of the elbow are a common occurrence in overhead throwing athletes. Clinical assessment of the medial elbow can be assisted using Sonography. Ultrasound imaging can be used to determine the width of the medial joint space. This study will determine whether altering the joint angle in the elbow during various clinical tests has an effect on the width of the medial joint space.

Methods: Ultrasound images of the non-dominant elbow were collected during three clinical tests of medial elbow stability; valgus stress test, weighted valgus test and the milking maneuver. The width of the medial joint space was measured on images collected in unstressed and stressed conditions.

Results: Research found a significant stress main effect (mean difference=0.7mm, p=<0.001) and a significant difference in medial joint space in the stressed condition (3.7±0.1mm) compared to the unstressed condition (2.9±0.1mm). Analysis revealed that the clinical tests main effect was significant ($F_{(58,2)}$=4.936, p=0.010). Valgus test means were unstressed (3.0±0.5 mm) and stressed (3.8±0.6mm), and the Milking Maneuver was unstressed (2.8±0.6 mm) and stressed (3.6±0.6mm).

Conclusions: The current study provides evidence that changes in the width of the medial elbow during clinical evaluation of the unimpaired elbow can be detected using sonography. By changing the flexion angle of the elbow, and the position of the forearm we saw a decrease in the width of the medial joint space.

CHAPTER 1

INTRODUCTION

Repeated overhead throwing activity has been associated with increased medial elbow instability (Bruce, Hess, Joyner, & Andrews, 2014; M. G. Ciccotti et al., 2014; Tsuyoshi Tajika et al., 2016). The earliest report on the stability of the medial elbow by Waris (Waris, 1946) investigated the medial elbow instability of javelin throwers. The stability of the dominant side elbow of javelin throwers was monitored over time, and athletes with increased elbow instability were found to have an increased risk of becoming unable to participate for durations ranging from a few weeks to a year (Waris, 1946). In 2016, Tajika et al (2016) reported decreased athletic performance, decreased elbow range of motion and greater elbow pain was associated with an increase in the width of the medial elbow joint space of high school baseball pitchers. Given the association between medial elbow instability and increased disability there is a need for increased understanding of the clinical assessment of stability of the medial elbow.

The Ulnar Collateral Ligament (UCL) provides up to 50% of the frontal plane stabilization of the elbow (Berry, 2013). Clinical evaluation of the elbow includes the assessment of medial elbow stability. During a clinical evaluation of the elbow, the patient is subjected to the application of a valgus stress. Preference of testing method will vary amongst clinicians, with the same valgus stress throughout all ways of testing. Sasaki et al. (Sasaki, Ogino, Kashiwa, Ishigaki, & Kanauchi, 2002) performed valgus stress tests in 90 degrees of elbow flexion and with a gravity force, with the patient lying supine off the edge of the table. The researcher chose to test in 90 degrees because previous studies have shown that the highest point of stress on the UCL is during the late cocking phase and early acceleration phase of the pitching sequence. The elbow in full extension has equal valgus stabilization from the ulnohumeral articulation, anterior joint capsule, and UCL. As the elbow moves into 90° of flexion, the UCL then becomes responsible for 55% of the valgus stabilization of the elbow (Kancherla, Caggiano, & Matullo, 2014). Recently clinicians have been using the "milking maneuver." This test mimics the motion of overhead throwing and is similar to the position described by Sasaki et al (2002). To date there has not been research on whether these clinical tests appropriately assess the width of the medial joint space.

The width of the medial elbow joint space during valgus stress can be an indicator of UCL laxity (Tajika et al., 2016). An excessive width of the medial joint space can also indicate a potential UCL injury. A recent study showed that comparing patients with partial and complete tears, the width of the medial joint space was greater than the control group with no tear. The group with complete tears also showed greater width of the medial joint space than that of the group with partial tears. Diagnostic Ultrasound has been shown to be just as effective as MRI in the diagnosis of UCL tears (Roedl et al., 2016). Diagnostic ultrasound can be used to monitor the anatomical changes that take place in the throwing athletes. Ultrasound offers a similar view as MRI, yet in a simple and more cost effective way. Diagnostic ultrasound allows the patient's elbow to be manipulated providing the clinician views of the medial elbow while in differing anatomic alignments (M. C. Ciccotti et al., 2014). Both ultrasound and radiography are capable of revealing joint space at the medial elbow; however, ultrasound allows for visualization of the integrity of the UCL, as well (Hackel & Tabacco, 2014).

Many studies have shown the effects of overhead throwing on the medial elbow. (Bruce et al., 2014; M. G. Ciccotti et al., 2014; Tajika et al., 2016). Repeated valgus stress over time causes the increase in medial joint laxity, and morphologic changes to the UCL (Tajika et al., 2016). Improved understanding of the clinical tests used to assess medial elbow stability will help the clinician spot subtle changes in the medial elbow stability, and could prevent the occurrence of a more significant injury.

Purpose

The purpose of this study was to evaluate the width of the medial joint space during clinical valgus stress tests including the standard clinical valgus stress test, “the milking maneuver” and the gravity stress test. Previous studies have researched the anatomical changes that occur over time, but only use one form of clinical evaluation. This study investigated the various medial elbow stability assessment techniques used by healthcare providers to assess the structural integrity of the UCL. This study evaluated the width of the medial elbow joint space of the non-dominant elbow in participants without history of participation in overhead throwing activities. Participants in this study were examined for the effect of changing elbow flexion angle during the valgus stress test and the milking maneuver on the width of the medial joint space.

Hypothesis

- The null hypothesis (H_o): no difference will be noted in the width of the medial joint space between the special tests. All tests will be measured both consistently and accurately.
- The alternative hypothesis (H_1): The width of the medial joint space will increase during both the valgus stress test and the milking maneuver. The greatest increase in the width of the medial elbow joint space will occur during the valgus stress tests. The weighted stress test will show the most consistent measure due to the force being applied in the same manner for each of the tests.

Limitations

The limitations and assumptions of this paper are as follows:

- The researchers did not use a device to control for the application of equal force across test conditions. The amount of valgus stress applied will differ amongst clinicians. We alternated between three positions throughout the testing process to ensure that these tests carry clinical value, as well as to use the same clinician for the application of each test.
- The investigation will measure medial elbow laxity in participants without elbow pain and the observed change might not represent a clinical meaningful difference. Participants with elbow pain might behave differently on these clinical evaluation techniques.
- Testing will not be performed on throwing athletes.

Assumptions

- All testing will be applied in a consistent manner amongst participants.
- When asked about history of elbow pain and injury the researchers assume participants will provide honest responses, regardless of elimination from study.

Operational Definitions

- Valgus stress- participant has their elbow flexed to 25 degrees, with the glenohumeral joint in neutral, the clinician to the lateral side of the joint being tested, a valgus force (from the lateral portion of the elbow) is applied by the clinician, while the opposite hand stabilizes the forearm (Starkey & Brown, 2015).
- "The milking maneuver" - With the participant's shoulder at 90 degrees abduction, and 90 degrees of elbow flexion, the examiner first grasps the thumb of the patient. By using his or her own elbow as a fulcrum, the examiner then applies a direct valgus force to the patient's elbow (Kancherla, Caggiano, & Matullo, 2014).

- Weighted Stress Test -Participant has their elbow flexed to 25 degrees, with the glenohumeral joint in neutral. The clinician will place a 5 pound ankle weight around the forearm of the participant. A valgus force is applied using the weight and the effects of gravity. The role of the clinician is to ensure that elbow flexion angle remains the same throughout the testing procedure.
- Medial Elbow- refers to the anatomical location of the elbow, and is an umbrella term for all musculoskeletal features of that area.
- UCL- an acronym for Ulnar Collateral Ligament, the primary static stabilizer of the medial elbow.
- Valgus Stress- a force that pushes the forearm and hand towards the lateral portion of the elbow.
- Laxity- when applying a stress, the clinician feels for an end feel, as well as joint-play. If one side appears to have more movement under the stress, this is referred to as laxity.
- End-feel- during the application of a valgus stress, the feeling of an abrupt stop indicates a firm end-feel, whereas a slow or resisted stop would be a soft end-feel, and the inability to feel an end point, is no end-feel.

CHAPTER 2

LITERATURE REVIEW

Background

Injuries to the Ulnar Collateral Ligament (UCL) have plagued overhead throwing athletes for many years. Waris first researched the effects of overhead throwing in javelin throwers in 1946. The physiological changes were monitored over time in the dominant elbow of these throwers. These injuries were chronic and developed over a period of time, and also caused these athletes to miss up to a year of competition time (Waris, 1946). In today's world of sports medicine, it is hard to hear the term "UCL" and not think of baseball. The surgical procedure to repair the UCL is named after former Los Angeles Dodgers pitcher Tommy John, who was the first to undergo surgical repair of the UCL (Jobe, Stark, & Lombardo, 1986). Early detection of physiological changes, and quick diagnosis of UCL injuries can be attributed to the utilization of stressed ultrasound (Roedl et al., 2016).

High School pitchers were recruited to take part in a study performed by Tajika et al.; 12 pitchers with previous injury or surgery were excluded. Ultrasound images were taken of the UCL in both an unstressed and stressed position. The participants also had their range of motion recorded for both elbow flexion and extension. Researchers found that the dominant side of all participants exhibited significantly less ROM with elbow flexion and extension when compared to the non-dominant side. The participant's dominant side also showed an increase in the width of the medial joint space, in both an unstressed (4.7 ± 1.0) and stressed (6.1 ± 1.3) position, as well as a noticeable increase in the width of the medial joint space in the dominant arm (1.4 ± 0.9) than in the non-dominant elbow (1.0 ± 0.7) (Tajika et al., 2016).

The elbow is a hinge joint; therefore the stress placed on the elbow during an overhead throwing motion is not a natural motion of the elbow. Through a comparison of dominant and non-dominant elbows of a pitcher, the differences are noted with the thickening of the UCL, as well as an increase in the width of the medial joint space on the dominant elbow (Tajika et al., 2016). Poor mechanics, a lack of flexibility, as well as poor overall physical condition are just a few of the behaviors that influence these injuries (Eygendaal, Heijboer, Obermann, & Rozing, 2000). A look at the anatomy, biomechanics, and different tools of diagnosis, especially the use of stressed ultrasound, will reveal the complex nature of the UCL.

Anatomy

The UCL can be divided into three bundles; the anterior, posterior, and transverse bundles. The anterior band of the anterior bundle does the majority of the stabilization along the medial portion of the elbow (Berry, 2013). The anterior bundle of the UCL provides the greatest amount of valgus restraint from 30°-120° of elbow flexion. The anterior band is the primary stabilizer at 30°, 60°, 90° and the co-primary at 120° of elbow flexion. The posterior band is the co-primary at 120° elbow flexion (Bruce et al., 2014). While the elbow is in full extension valgus stabilization is provided equally by the ulnohumeral articulation, anterior joint capsule, and UCL. As the elbow moves towards 90° of flexion, the UCL then becomes responsible for 55% of the valgus stabilization of the elbow (Kancherla et al., 2014). Primary stabilization being at its highest at 90° of elbow flexion leads us to believe a noticeable difference will be noted when we compare the test we use in this study.

Musculature of the medial elbow has been shown to have an effect on the stabilization of the medial elbow. Park and Ahmad found that the flexor pronator mass plays a crucial role in stabilization. By loading and unloading the muscles of the forearm, the researchers learned the flexor carpi ulnaris is the primary dynamic stabilizer and the flexor digitorum superficialis is a secondary stabilizer (Park & Ahmad, 2004). However, Udall et al. conducted similar research and found the flexor digitorum superficialis to be the primary stabilizer (Udall, Fitzpatrick, McGarry, Leba, & Lee, 2009). An estimated valgus force of 290 N is applied to the elbow during the pitching sequence. The pitching technique seen most frequently is that of 90° of shoulder flexion, and the elbow flexed to around 90° and is replicated through the milking maneuver test that is used for this study. The tensile failure load of the UCL is 261 N; therefore, even though it is unsure which muscle plays the greatest role in stabilization of the medial elbow, it is known that musculature does play a crucial role in dynamic stabilization of the elbow (Ben Kibler & Sciascia, 2004).

The anatomy of the elbow plays a crucial role to this study. During each individual special test the elbow will be placed in different positions, therefore changing the anatomical constraints to elbow valgus. The anterior bundle is primary resistance to valgus forces applied to the elbow at 30° to 90° of flexion and is the co-primary, along with the posterior bundle at 120° of flexion (Kancherla et al., 2014). As the flexion angle of the elbow changes, the ligamentous restraints do as well; this study will allow us to evaluate those changes.

Biomechanics

Differences in pitching biomechanics may result in the pathologic changes that have been identified to occur over time. Wilk et al. evaluated 296 professional pitchers over an eight-year period. Pitchers who had a ≥ 5° deficit in total shoulder rotation were at a 2.6 times greater risk for injury to the UCL. Pitchers with ≥5° deficit in shoulder flexion were at a 2.8 times greater risk for injury to the UCL (Wilk et al., 2014). These are not deficits that occur through different anatomical features of each person, but from years and years of pitching a certain way, which has a physiological side effect on pitchers. Similar studies have shown that various behaviors can play a role in increased valgus stress. Aguinaldo and Chambers found that during the pitching sequence, late trunk rotation, reduced shoulder external rotation, and increased elbow flexion play a critical role in the valgus force applied to the elbow during pitching (Aguinaldo & Chambers, 2009). Ellenbecker et al. saw a 4° deficiency in wrist extension and a 5° deficiency in elbow extension in professional pitchers when bilaterally comparing the dominant and non-dominant arm (Ellenbecker, Mattalino, Elam, & Caplinger, 1998). The lack of external rotation means the load being placed on the UCL is coming at an earlier time during the pitching sequence.

Werner et al. found that instability at the elbow could be linked to four parameters in 97% of reported cases. The first parameter looked at the angle of shoulder abduction at the point of contact with the stride foot. Throwers with more limited shoulder abduction were found to have less of a valgus stress during pitching. The next parameter considered peak shoulder horizontal adduction during angular velocity. Pitchers that demonstrated less degree of horizontal adduction during angular velocity were subjected to far less valgus stress. Another parameter examined was the elbow angle at the peak of valgus stress. Throwers with increased elbow flexion at the peak of valgus torque had less valgus stress place upon the medial elbow (Werner, Murray, Hawkins, & Gill, 2002). Aguinaldo and Chambers noted that pitchers with a side arm delivery displayed much higher valgus torque than those who were at the proper 90° of flexion (Aguinaldo & Chambers, 2009). The final parameter was peak shoulder external rotation torque. Those pitchers who exhibited greater magnitudes of peak external shoulder rotation torque experienced less of a valgus stress (Werner et al., 2002). As previously mentioned, in a study by

Wilk et al., pitchers who had ≥ 5° deficit in shoulder external rotation were at a 2.6 times greater risk to injuries of the UCL (Wilk et al., 2014).

The biomechanics of the human elbow play a large role in those athletes that have injuries to the UCL. In this proposed study each test will differ in degrees of flexion angle of the elbow, or supination of the forearm. Although we are testing a population with no history of elbow pain or injury, we should get an accurate depiction of how the various angles of the elbow effect the UCL and the width of the medial joint space.

Clinical Evaluation

UCL injuries can be classified as either acute or chronic. An acute injury occurs at one moment or in one play, whereas a chronic injury develops and worsens over time; both acute and chronic injury leads to elbow instability. A pitcher with an acute injury may hear a "pop" after throwing a pitch, and may complain of numbness and tingling down the arm as a result of disruption of the ulnar nerve (Kancherla et al., 2014). Lee, Rosas, and Craig (2010) found that 40% of patients with instability at the medial elbow with UCL injuries also develop ulnar nerve traction injuries as well. Chronic injuries may yield signs of loss in ball control and velocity, and an increase in fatigue. Players who fail to treat these early signs may complain of medial elbow pain, and increased pain in full elbow extension (Kancherla et al., 2014).

Diagnosis of a complete tear is noted in diagnostic imaging with a two millimeter medial opening when compared to the bilateral side (Hackel & Tabacco, 2014). Partial tears of the UCL are, for the most part, non-operative and normally see a return to play in three to six months following injury and therapeutic intervention. In the past, surgery of the UCL meant an unsure future in competitive sports, but today's technology has raised the rate of players who make a full return to over 92% following surgery (Kancherla et al., 2014).

Clinical examination can be performed with an array of special tests. Various researchers have looked at different methods to find the most effective way to elicit the maximal opening at the medial elbow. Valgus stress is congruent throughout all methods of testing; however, proper positioning of the arm and angles of flexion vary amongst studies. In order to perform a proper valgus stress test, flexion of the elbow should not be >120 or < 30, because interference from other structures may yield difficulties with diagnostic imaging. Field and Altchek found that testing the elbow in 60°-75° of flexion would elicit the best results (Field & Altchek, 1996). Flexion at less than 30° does not allow the olecranon to unlock from its fossa, which decreases some of the stabilization provided by the UCL (Nazarian, McShane, Ciccotti, O'Kane, & Harwood, 2003). Lee et al. tested participants in both full extension and in 30° of flexion, and found that, on average, the width of the medial joint space was 0.2 mm smaller in valgus testing in full extension (Lee, Rosas, & Craig, 2010).

Sasaki et al. performed valgus stress tests in 90 degrees of elbow flexion and with a gravity force, with the patient lying supine off the edge of the table. The author chose to test in 90 degrees because previous studies have shown that the highest point of stress on the UCL is during the late cocking phase and early acceleration phase of the pitching sequence. By testing with the forces of gravity, every test is done with equal forces applied. However, without the examiner in contact with the patient, it is hard to get a true feel for the laxity during a clinical examination (Sasaki et al., 2002). When comparing valgus stress applied by a clinician to gravity only, Lee et al. found a 0.3 mm increase in the width of the medial joint space when a valgus force was applied (Lee et al., 2010).

Safran et al. took 12 cadaveric models and tested the medial stability of the elbow. Valgus testing was performed in 30°, 50°, 70° of elbow flexion, as well as with the forearm in pronation, supination, and neutral. The authors found that valgus stress produced the greatest amount of medial joint space with the forearm in neutral, while the different degrees of elbow flexion produced similar findings (Safran, McGarry, Shin, Han, & Lee, 2005). A similar study was conducted by Seiber et al. (Seiber, Gupta, McGarry, Safran, & Lee, 2009) but had a similar finding, and only examined flexion angles up to 70°. Also both studies used cadavers instead of human participants, and focused on cutting various stabilizers of the elbow to test the application each muscle contributed to stability of the medial elbow. Both studies showed that the most valgus laxity occurs with the forearm in a neutral position which occurs during both of our valgus stress tests we utilize within this study (Safran et al., 2005; Seiber et al., 2009).

Alternative ways of testing the integrity of the UCL include the "milking maneuver" and the "abduction stress test." With the "milking maneuver," the examiner first grasps the thumb of the patient. By using his or her own elbow as a fulcrum, the examiner then applies a direct valgus force to the patient's elbow (Kancherla et al., 2014). With the "abduction stress test," the patient's elbow is flexed to 15-20° and forearm is pronated. The examiner holds one hand at the distal portion of forearm and the other hand at the distal portion of the humerus and applies a valgus force (Patel & Savoie, 2008).

In order to perform a valgus stress test, flexion of the elbow should not be >120 or < 30, because of interference from other structures. (Nazarian et al., 2003). Lee et al. tested participants in both full extension and in 30° of flexion, and found that, on average, the width of the medial joint space was 0.2 mm smaller in valgus testing in full extension (Lee et al., 2010). With research showing the window of valgus stress being between 30 and 120 degrees, all testing for this study will follow those guidelines.

Ultrasound Imaging

As clinicians our ability to utilize ultrasound as a diagnosis tool hinges on the accuracy compared to the golden standard of MRI. Kim et al. compared the accuracy in diagnosing UCL tears using stress ultrasound, as well as MRI. This study found that the utilization of stress ultrasound had similar specificity (86.9% vs. 78.3%), sensitivity (61.1% vs. 66.7%) and accuracy (75.6% vs. 73.2) when compared to MRI to diagnose UCL tears. Physicians could save time and money for the patient by ordering a Stress US for a diagnostic tool as opposed to a MRI. Using the width of the medial joint space can also be an effective way to assess for UCL tears (Kim, Moon, Park, Choi, & Oh, 2017). Roedl et al. was the first to research the width of the medial joint space and its adherent correlation to injuries to the UCL. A significant difference in the width of the medial joint space was found in those with no tear (1.5 mm), partial tears (3.1 mm) and complete tears (4.8 mm) (Roedl et al., 2016).

Functionality is key when it comes to diagnostic ultrasound and proper diagnosis of UCL injuries. The ultrasound allows the patient to be manipulated in different positions, while still giving the clinician the ability to view the UCL (M. C. Ciccotti et al., 2014). Although magnetic resonance imaging (MRI) is often considered the gold standard for diagnosing UCL tears, stress ultrasound is becoming more prevalent as a diagnostic tool. Ultrasound offers a similar view as MRI, yet in a simple and more cost effective way. Both ultrasound and radiography are capable of revealing joint space at the medial elbow; however, ultrasound allows for visualization of the integrity of the UCL as well (Hackel & Tabacco, 2014).

Ultrasound imaging is not your typical choice for diagnostic imaging of the elbow. It offers a less expensive approach to the evaluation of tendons, ligaments and nerves. The sonographer can manipulate the joint to allow for better imaging quality. Ultrasound use has gained more clinical significance over the years, due to the advantage it yields of being able to move the patient and the transducer in order to gain the best look at the structure being tested (Berry, 2013).

To view the UCL, the probe should be oriented along the long axis of the ligament, using the trochlea of the humerus and the sublime tubercle of the ulna as landmarks. These are the land marks used to measure the width of the medial joint space (M. C. Ciccotti et al., 2014). The examiner should have the cranial aspect of the transducer over the medial epicondyle, with the transducer aligned in the coronal plane along the UCL (Konin, Nazarian, & Walz, 2013). Characteristics of the medial epicondyle appear hyperechoic with posterior acoustic shadowing, which is typical of bone. Using the medial epicondyle as a landmark, the examiner should then move the probe distally over the proximal ulna. Once found, the ligament will appear hyperechoic and compact (Jacobson, Propeck, Jamadar, Jebson, & Hayes, 2003). A trick is to hook the 2^{nd}-4^{th} fingers of the clinician behind the medial epicondyle from an anterior approach. Let the probe slide anteriorly along the fingers for better guidance (De Maeseneer et al., 2015). Preferred frequency for the assessment of the elbow ranges from 5 MHz- 13 MHz. The higher frequency provides better image resolution, whereas a lower frequency has a further depth of penetration. Linear probes are best suited for evaluation of musculoskeletal tissues, because the longer probe offers a better overview of the tissue (Schmidt & Backhaus, 2008).

Researchers examined the medial elbows of 40 professional handball athletes by using ultrasound, MRI, and radiographs. Ultrasound was found to be the most effective way of looking at the UCL, as they were able to observe the structure, thickness, and integrity of the ligament, while also examining the thickness of the flexor-pronator mass (Popovic, Ferrara, Daenen, Georis, & Lemaire, 2001). More evidence of the value of ultrasound was seen in a case study of a 19 year old with medial elbow pain, and complaint of an audible “pop” during a bullpen session. Diagnostic imaging that consisted of radiographs and MRI presented negative results according to the team orthopedic doctor. Ultrasound with use of the “milking maneuver” revealed a positive tear of the UCL (Wood, Konin, & Nofsinger, 2010).

Besides the higher costs, another disadvantage of radiographic imaging is that soft tissue cannot be visualized. Radiographs only provide visualization of the landmarks for attachments of the UCL, and not the individual structure itself. A disadvantage of MRI is that it fails to provide a functional assessment of ligament laxity, because it does not allow movement during the imaging process (M. C. Ciccotti et al., 2014). Because partial tears of the UCL cause only a slight increase in the width of the medial joint space, MRIs and radiographs may be read as negative when a tear does exist (Eygendaal et al., 2000).

All testing methods have their place in the medical community; however, diagnostic ultrasound has shown a high rate of success and reliability when it comes to imaging the structures of the medial elbow. With the proposed study, our patient will be placed in a variety of positions; the ultrasound allows you to image the elbow with minimal interference in all testing positions.

Conclusion

Injuries to the UCL have plagued overhead throwing athletes for many years. Through the advancement of research and technology, we are learning new ways to evaluate the UCL. Studies have shown that the body of an overhead-throwing athlete undergoes morphological changes, in part because of the mechanism of throwing the ball, and the stress it puts on the elbow. As a medical community, we apply knowledge gained from literature and research to not only correctly diagnose injuries, but also to prevent future injuries from occurring.

Research from many authors has shown the bilateral comparison of dominant and non-dominant arms over time. With this study we look at the various evaluation techniques used to assess medial elbow instability

CHAPTER 3

METHODS

Participants

The study was conducted with 31 healthy participants (Table 1) (One excluded due to previous injury). Prior to any testing, all participants provided written informed consent. The Marshall University Internal Review Board approved this project. Once written informed consent was given, each subject was screened for inclusion /exclusion criteria. Participants were excluded if they had a history of upper extremity fractures, surgery or any known elbow pathology. Demographic information including height, weight, gender, current age, and arm dominance were also collected for each participant. Using the standard goniometer we measured shoulder flexion and abduction, elbow flexion and extension, forearm supination and pronation, and wrist flexion and extension. Using the digital inclinometer we measured shoulder internal and external rotation (see Appendix A for measurement procedures). All measurements were made on the subject's left and non-dominant

Demographic Data		
Outcome Measure	Mean ± SD	
Subjects	31	
Included	30	
Excluded	1	
Age (years)	21.5 ± 1.9	
Sex (M / F)	(12 / 18)	
Height (cm)	170.2 ± 10.1	
Weight (kg)	71.2 ± 15.6	
QDASH	0.8 ± 2.3	Normal ROM
Elbow Flexion	138.9 ± 4.9°	140°-150°
Elbow Extension	6.6 ± 4.5°	0°
Pronation	88.3 ± 4.6°	80°
Supination	89.8 ± 6.7°	80°
Wrist Flexion	69.6 ± 12.2°	60°
Wrist Extension	58.7 ± 10.0°	60°
External Rotation	100.0 ± 11.0°	90°
Internal Rotation	75.5 ± 11.6°	70°
Abduction	178.8 ± 2.9°	180°
Shoulder Flexion	178.2 ± 3.7°	180°
Valgus Positive Tests	0	
Valgus Negative Tests	30	
Valgus Firm End-feel	30	
Valgus Empty End-Feel	0	

Table 1: **Demographic Data:** shows all recorded demographic data for this study

elbow, thus eliminating all left handed people. Use of the non-dominant arm was to ensure that all participants had not undergone the anatomical changes that occur over time as a result of overhead throwing and valgus forces. The Quick Disability of the Arm Shoulder and Hand (QDASH) questionnaire was used to determine the level of upper extremity disability, satisfaction and pain in all participants. The QDASH is an 11 item questionnaire asking the subject to rate their ability to perform tasks of the upper extremity (Beaton, Wright, Katz, & Upper Extremity Collaborative, 2005). The QDASH is scored 0-100, with higher scores indicating higher disability of the upper extremity (Table 1). All participants underwent stability testing using the valgus stress test and milking maneuver; all participants had negative tests with "firm end-feel."

A pilot study was performed on seven participants in order to perform sample size calculations. The 95% confidence interval for the minimal detectable change for the width of the medial joint space based on the pilot test data was 0.36mm. The sample size calculations were performed using G*Power version 3.0.10 (University Kiel, Germany copyright 1992-2008). Statistical power was established at $1- \beta = 0.80$; statistical significance was set at $p < 0.05$. In order to detect difference of 0.36mm a sample size of 15 participants was required. Following the testing of 15 subjects, analysis revealed that more testing was needed.

Protocol

This investigation used a repeated measure design. Ultrasound images were collected while the participants were in each of the test conditions. Each of the three elbow stability tests (see Procedures) were imaged two times in both the stressed and unstressed condition of each test, with the mean of the two measurements being used for analysis. These stresses had potential to cause discomfort to the participants. Participants were asked to inform the researchers of any pain or discomfort at any point during the stress test procedures. If pain or discomfort occurred the testing position was modified. If the pain or discomfort continued the testing procedure was discontinued. All images were collected from the participant’s medial left elbow. The landmarks used to measure the width of the medial joint space were the trochlea of the humerus and ulnar coronoid process (M. G. Ciccotti et al., 2014).

A total of three researchers (Figure 1) were used for each of these tests to insure the highest quality image is taken; each duty of the researchers is as follows:

- Researcher 1 was in charge of recording the image from the ultrasound, and information of the motion tracking software during the application of each special test.
- Researcher 2 played the role of the clinician for each application of the three special tests.
- Researcher 3 played the role of the sonographer, while capturing images under each of the special tests.

Figure 1: **Research Set-Up**

Procedures

Special Tests

Each of the following special tests were applied to the participants:

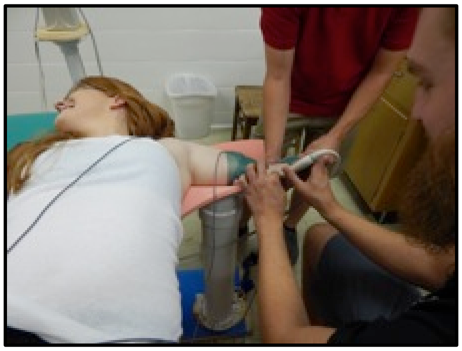

Figure 2: Valgus Stress Test

- Valgus stress test (Figure 2)- the participant’s elbow was flexed to 25 degrees, with the glenohumeral joint in a neutral position, the clinician is located to the lateral side of the joint being tested, a valgus force (from the lateral portion of the elbow) was applied, while the opposite hand stabilized the forearm (Starkey & Brown, 2015).

- "The milking maneuver" (Figure 3)- with the participant's arm at 90 degrees abduction, and 90 degrees of elbow flexion, the examiner grasps the participant's thumb (forearm supinated). Then using his or her own elbow as a fulcrum, the examiner applied valgus force to the participant's elbow (Kancherla et al., 2014).

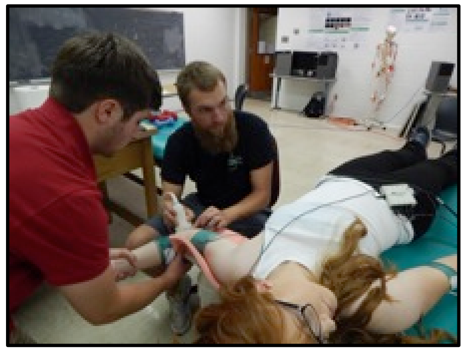

Figure 3: Milking Maneuver

- Weighted Stress Test (See Figure 4)- the participant's elbow was flexed to 25 degrees, with the glenohumeral joint in neutral, the clinician placed a 5 pound weight around the participant's distal forearm, applying valgus force along with gravity. The Clinician ensured that elbow flexion angle stayed at 25 degrees during the test.

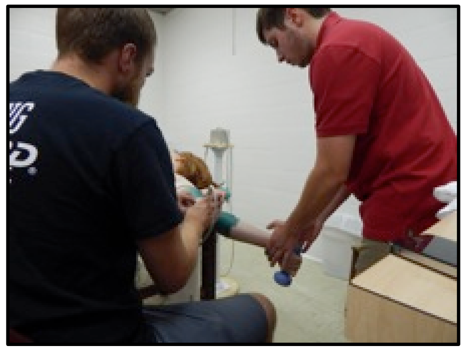

Figure 4: **Weighted Valgus Test**

Ultrasound Imaging

Ultrasound images of the participant's left elbow were collected using a Mindray m5, (Mindray Ltd. and National Ultrasound, Inc., Duluth, GA USA) ultrasound unit with an adjustable 8.0-12 MHz frequency linear array transducer. To view the UCL, the probe was oriented along the long axis of the UCL, using the trochlea of the humerus and the sublime tubercle of the ulna as landmarks. The technique to best view the UCL is done using a linear transducer placed in the coronal plane with the most medial aspect of the transducer head placed over the medial epicondyle (Konin et al., 2013). The ultrasound gain was set at 80 for all participants. The width of the medial joint space was defined as the distance between the trochlea of the humerus and the ulnar coronoid process of the ulna. These landmarks were identified by the hyperechoic edges that were present on ultrasound image of the medial elbow (Figure 5). All images were stored electronically within the ultrasound unit for future analysis, and all measurements were made using software housed within the ultrasound unit.

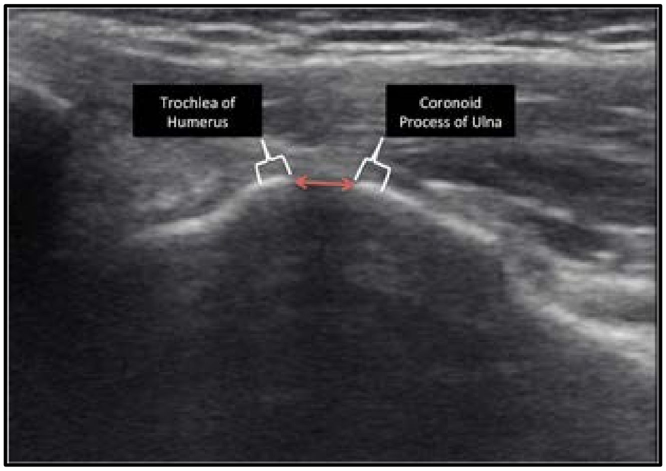

Figure 5: Width of the Medial Joint Space

The measurement error for the medial elbow width measures was determined prior to the investigation. Seven participants participated in a test re-test investigation in order to calculate the interclass correlation coefficient (ICC) and standard error of the measure (SEM). The ICC values for the unstressed position ranged from 0.864 - 0.983, and for the stressed condition ranged 0.939- 0.961. The average SEM was 0.1 mm for the unstressed position. The average

MDC for the unstressed position was 0.2 mm and for the stressed position 0.2 mm. The mean measurement of the width of the medial joint space was 2.6 mm in the unstressed position and 3.2 mm for the stressed position, leaving an average difference of 0.7 mm. ICC values were considered very good for values 0.81–1.00, good for 0.61–0.80, moderate for 0.41–0.60, fair for 0.21 – 0.40, and poor for values below 0.20. Measurement error was calculated with the standard error of measure SEM= standard deviation x [$\sqrt{(1–ICC)}$], which estimates the error about a single measure of a variable. The minimal detectable change (MDC) represents the error when a measure is taken twice (change over time), and was calculated by multiplying the SEM by the $\sqrt{2}$.

Statistical Analysis

Two-way analysis of variance (ANOVA) with repeated measures (stress x test) was used to determine differences in the width of the medial joint space amongst the test conditions. All statistical calculations were performed using SPSS 21 statistical software (SPSS Inc., Chicago, Ill), statistical significant difference was established at a $P<0.05$.

CHAPTER 4

RESULTS

Stress Main Effect

The width of the medial joint space increased with the applied stress (Figure 6). Analysis revealed significant stress main effect (mean difference=0.8 ± 0.04 mm, $F_{(29,1)}$=368.63, p=<0.001, β=1.00). The width of the medial joint space was greater in in the stressed condition (3.7 ± 0.1 mm) than in the unstressed condition (2.9 ± 0.09 mm) (Figure 6).

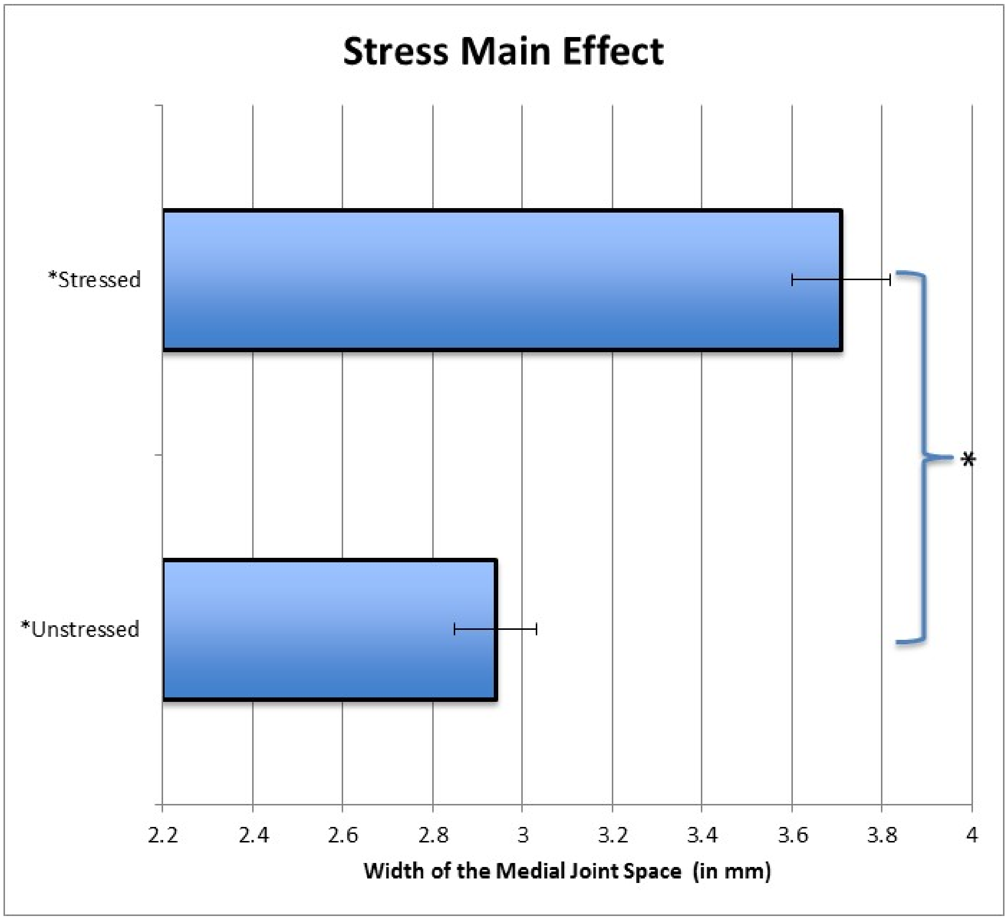

Figure 6: Graph (Stress Main Effect) - This graph represents the effect seen by applying stress during each of these clinical tests. The error bars represent the Standard Error. *Statistically significant main effect p ≤ 0.05.

Test Main Effect

The width of the medial joint space differed amongst the test condition (Figure 7) Analysis revealed that the clinical tests main effect was significant ($F_{(58,2)}$ =4.936, p=0.010, β=0.788). There was not significant difference (p= 1.00) in the mean measurement of the width of the medial joint space between the valgus stress test (3.4 ± 0.1mm) and the weighted valgus stress test (3.4 ± 0.1mm), while the width of the medial elbow joint space during the milking maneuver was narrower (3.2 ± 0.1mm, $p < 0.05$) (Figure 7).

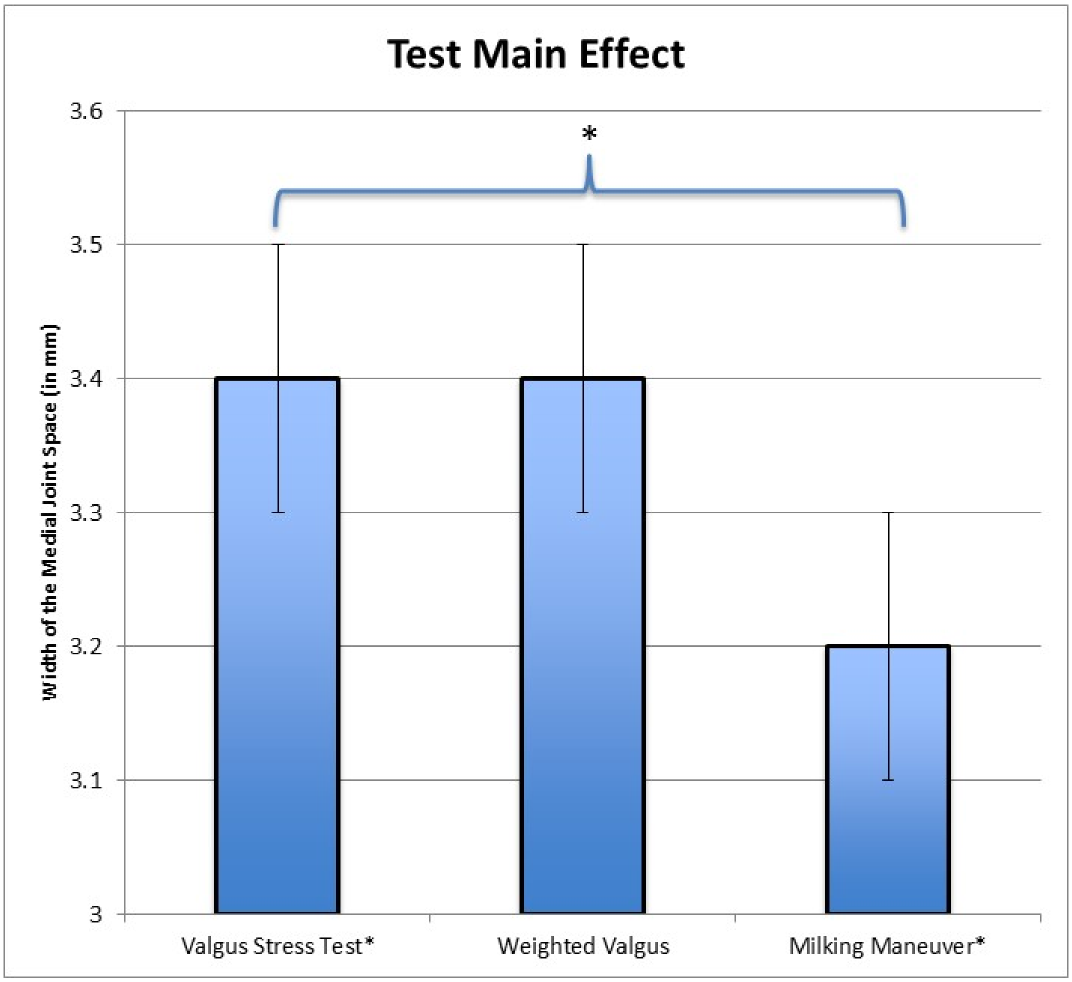

Figure 7: Graph (Test Main Effect) - This graph represents the effect of each individual test, calculated by taking the mean of all measurements for each test. The error bars represent the Standard Error. *Statistically significant main

Stress by Test Interaction

The increase in the width of the medial joint space with applied stress was consistent across the tests (Figure 8). Analysis revealed that the stress x test interaction was not significant (mean difference 0.8 ± 0.01mm, $F_{(58,2)}=1.205$, $p=0.307$, $\beta=0.253$). The increases in the width of the medial joint space due to the applied stress were consistent amongst the tests.

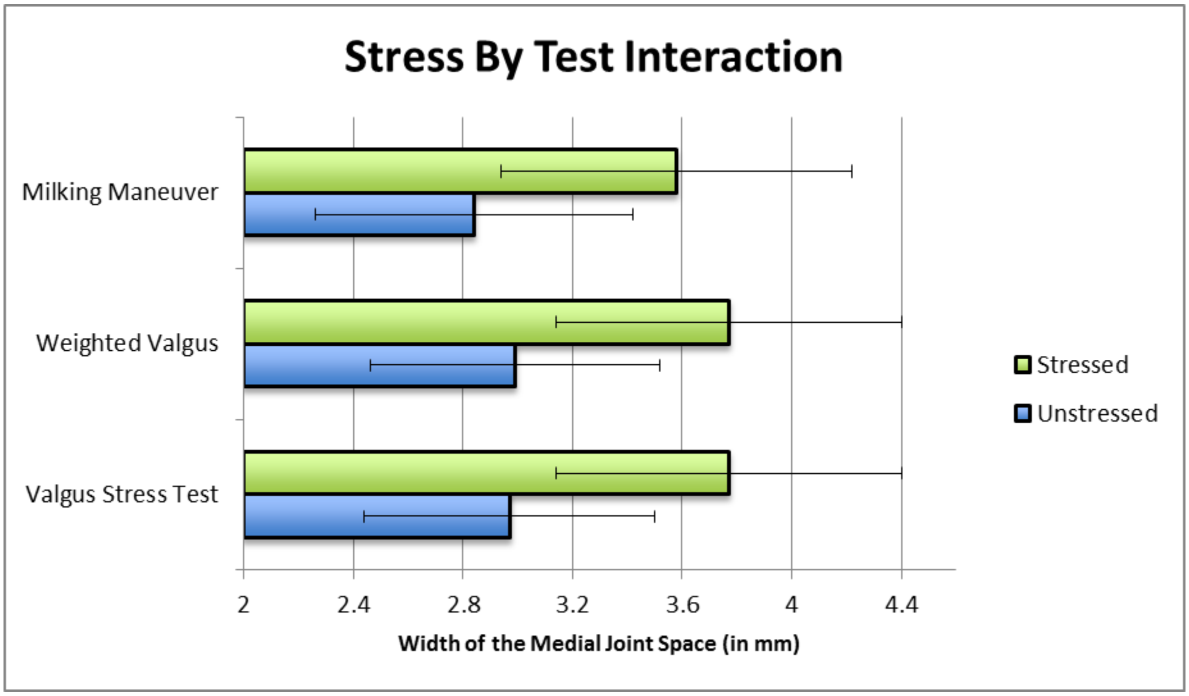

Figure 8: Graph (Stress by Test Interaction) - This graph represents the effect seen by applying stress during each of these clinical tests. The error bars represent the Standard Deviation.

CHAPTER 5
DISCUSSION

The width of the medial joint space increased (mean increase = 0.8mm) with an applied valgus stress. This finding supports the first part of the hypothesis that the width of the medial joint space would increase during each of the tests, which was shown by the results. The second portion of the hypothesis stated that the magnitude of the increase in the width of the medial elbow joint space would differ amongst the tests. We hypothesized that the width of the medial joint space would be greater during the valgus stress tests (Both clinician applied and weighted), when compared to the milking maneuver. The results of the current study do not fully support this hypothesis. A significant difference in the width of the medial joint space was found between the Valgus Stress Test and the Milking Maneuver, yet not between the Weighted Valgus test and milking maneuver. It was hypothesized that a greater increase would be seen during the valgus stress test. The change in the width of the medial joint space with applied valgus force was consistent amongst the tests. The clinical test used in this study showed that the effect of applying a valgus stress remains constant throughout the varying joint angles; however, the width of the medial joint space decreased when increasing the elbow flexion angle and supinating the forearm.

The design of this study was meant to initiate the discussion not only on how to evaluate medial elbow joint instability, but also the evaluation of overhead throwing athletes. As the elbow flexion angle increases, different parts of the UCL are placed under stress. Pitchers have an array of throwing styles that ask them to place their upper extremity in different ways, or change the joint angle of the elbow. Although this study was not completed on pitchers, we must assess elbows that have not been stressed. Past studies have shown that on cadavers an increase in laxity and the width of the medial joint space occurs in a neutral forearm position (Seiber et al., 2009). Other in vivo studies showed that in overhead throwing athletes have significant increases in the width of the medial joint space on the dominant arm (Bica, Armen, Kulas, Youngs, & Womack, 2015; M. G. Ciccotti et al., 2014; Tajika et al., 2016). Our study chose to use the non-dominant arms of those who were not overhead throwing athletes. Using these participants ensured that the differences we found within these tests were not due to physiological changes, but because of the anatomical changes that occur when we change the flexion angle and the forearm position.

Ciccotti et al. (M. G. Ciccotti et al., 2014) used dynamic US to evaluate the width of the medial joint space of 368 asymptomatic professional baseball pitchers prior to the season. They identified physiological changes of the elbows of baseball pitchers. Ciccotti el al reported the width of the medial joint space at rest was 3.32 ± 0.07 mm in the dominant elbow and 2.94 ± 0.12 mm in the non-dominant elbow. The differences in the width of the medial joint space was not statistically significant. Under stress, however, the width of the medial joint space in the dominant elbow was significantly greater than that of the non-dominant elbow, with values of 4.56 ± 1.1 mm in the dominant elbow and 3.72 ± 0.92 mm in the non-dominant elbow. Research has shown that these anatomical changes occur at an alarmingly early age, and not only in those with elongated careers. Tajika et al. (Tajika et al., 2016) evaluated high school pitchers both with and without symptoms of elbow pain or discomfort. Their findings were similar to that of Ciccoti et al. (M. G. Ciccotti et al., 2014) in that dominant side also exhibited significantly greater width of the medial joint space, with and without gravity valgus stress, and a greater difference between the width of the medial joint space. Both of these studies performed the test with the elbow flexed at 30°. Our testing showed that the change in joint positioning has an effect on the width of the medial joint space.

The magnitude of the increases in the width of the medial joint space exceeded the MDC (0.1-0.2 mm) calculated from pilot studies suggests that the observed increase was due to the experimental intervention rather than measurement error. The increase in flexion angle causes for different parts of the UCL to be labeled as the primary static stabilizer. As the joint is placed in 30° of flexion, the anterior band is the primary stabilizer. When that flexion angle increases the posterior band becomes the co-primary static stabilizer at the medial elbow (Bruce et al., 2014). With this change occurring as elbow flexion increases, the change in the width of the medial joint space may indicate that the milking maneuver tests both the anterior and posterior band of the UCL.

Lead Author	Unstressed	Stressed	N	Definition of "Medial Joint Space"
Bica et al.	4.3	4.9	36	Ulnohumeral joint gapping was measured from the trochlea of the humerus to the coronoid process of the ulna
Tajika et al.	4.4	5.4	122	defined the ulnohumeral joint space as the distance from the midportion of the trochlea of the humerus to the edge of the coronoid process of the ulna
Ciccotti et al.	2.9	3.7	736	from the trochlea of the humerus to the coronoid process of the ulna
Our Research	2.9	3.7	30	defined as the distance between the trochlea of the humerus and the ulnar coronoid process of the ulna

Table 2: Measurements of other studies- This table shows the mean findings of the similar studies that assessed the medial joint space; all figures are of non-dominant elbow (in mm).

The measurement with our study align and differ from other studies that assessed the width of the medial joint space, yet all studies use the same landmarks to measure from (Table 2). Although all four studies listed were measured using the same landmarks, error occurs when those landmarks are measured from different aspects (Figure 9). This error is what causes the differences from study to study, but our ICC numbers along with others demonstrate that the same observer can make these measurements at different times with minimal error. The change in the medial joint space ranged from 0.6-1.0 mm in the respective studies.

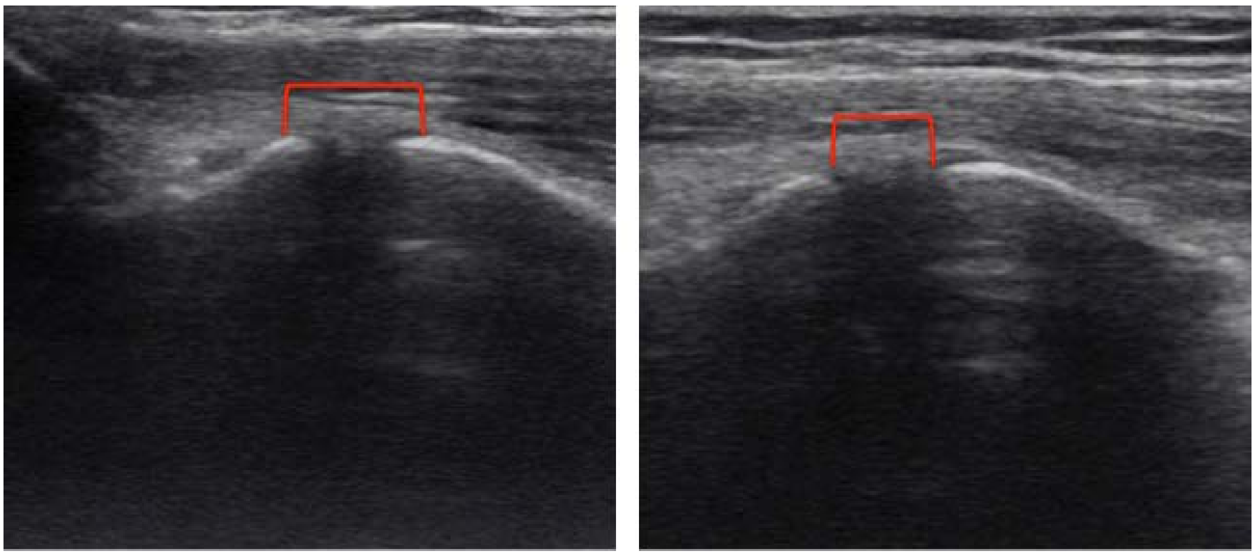

Figure 9: Measurement Error- Measurement of the width of the medial joint space, both show measurements of the distance between the trochlea of the humerus and the ulnar coronoid process of the ulna. Although both are measuring the same thing, the measurement can be far apart when you are measuring in mm.

Research investigating the width of the medial joint space, and the effect of forearm position and elbow flexion angle on the width of the medial joint space was completed on 14 cadaver models. Seiber et. al (Seiber et al., 2009) evaluated the role of elbow musculature, forearm rotation and elbow flexion angle and the effects on joint stabilization. This study found that there was no statistically significant relationship noted between the stability of the medial elbow and degree of elbow flexion used in testing in the range of elbow flexion angles tested. On the other hand, the greatest width of the medial joint space was seen when testing with the forearm in a neutral position. The two Valgus tests at 30° of flexion with the forearm in neutral showed a greater width of the medial joint space when compared to the milking maneuver in 90° of flexion, and the forearm supinated.

Our study examined live human elbows with no predisposition to anatomical or physiological changes, as opposed to other studies that utilized baseball players or cadavers. The changes that occur within the joint space during varying degrees of elbow flexion, and with the forearm in supination, show that this can be a potential cause and effect for injuries to the medial elbow. Changes in the joint positioning occurs multiple times throughout a single game with pitches varying from fast ball, to curve ball, to a slider or a cutter. As these pitches vary, this study shows that so does the width of the medial joint space.

Limitations

The results of the current study need to be considered with respect to the following limitations. The researchers do not use a device to control for the application of equal force across test conditions. As a result the amount of valgus stress applied would differ amongst clinicians. The clinician adjusted the application of force based on the size of test participants; however, the weight was constant throughout. Using the same weight for all participants may have caused for more variability in measuring the Weighted Valgus test in the stressed position. The interaction between the test and stress was not of statistical significance. We alternated the testing order in a predetermined random manner between three test conditions throughout the testing process to ensure that these tests carry clinical value. The same clinician was used for the application of each test performed.

The investigation measured the width of the medial elbow joint space in participants without elbow pain and the observed change might not represent a clinical meaningful difference. Participants with elbow pain might behave differently on these clinical evaluation techniques. We used a healthy subject pool that had no external interferences on the anatomy of the elbow. However, using subject who are uninjured makes it difficult to compare to a clinical application. Other studies have noted similar changes but by conducting this study on unaffected participants we grasp a better understanding and approach to our clinical evaluation.

Testing was not performed on throwing athletes. All previous in vivo studies have been completed on throwing athletes. However the effects of joint positioning on the width of the medial joint space have only been conducted on cadavers. We chose to use non-throwing athletes and non-dominant arms to avoid any outside interference.

Future Research

Our research along with others have shown that the width of the medial joint space changes when the elbow is flexed or the forearm is supinated. A foundation has been laid for future research to evaluate this same effect but in a clinical population or those with the presentation of medial elbow joint instability. This change is also seen in a variation of pitches, or in the technique used to throw a particular pitch. Future research should look into the number of pitches thrown a certain way or the pitcher's preferred pitch to see if a correlation exists between joint instability and the various tests used in this study. Another study that tracked these pitchers over an entire season would also be beneficial. Athletic trainers or other medical professionals could use the relatively easy practice of using diagnostic ultrasound as a tool to track these changes.

Conclusion

The current study provides evidence that changes in the width of the medial elbow during clinical evaluation of the unimpaired elbow can be detected using sonography. This study found that by increasing the joint angle of elbow flexion, and supinating the forearm, a significant change occurred in the width of the medial joint space. According to previous research this change occurs as result of an increased role of the posterior band of the UCL as the joint angle increases. It is also evident that in all clinical tests, an applied stress opens up the medial joint space. Using sonography, medical professionals can assess the stability of the medial elbow in three clinical tests utilized by clinicians.

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APPENDIX A: IRB APPROVAL

MARSHALL UNIVERSITY
w w w . m a r s h a l l . e d u

Office of Research Integrity
Institutional Review Board
One John Marshall Drive
Huntington, WV 25755

FWA 00002704

IRB1 #00002205
IRB2 #00003206

January 30, 2017

Mark Timmons, PhD
Marshall University, School of Kinesiology

RE: IRBNet ID# 868319-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title:	[868319-2] The Assessment of Medial Elbow Stability.	
Expiration Date:	February 11, 2018	
Site Location:	MU	
Submission Type:	Continuing Review/Progress Report	APPROVED
Review Type:	Expedited Review	

The above study was approved for an additional 12 months by the Marshall University Institutional Review Board #1 (Medical) Chair. The approval will expire February 11, 2018. Since this approval is within 30 days of the expiration date, the fixed anniversary date of 2/11 was maintained. Continuing review materials should be submitted no later than 30 days prior to the expiration date.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

APPENDIX B: CONSENT FORM

Informed Consent to Participate in a Research Study

Assessment of Medial Elbow Stability.

Mark K Timmons PhD ATC, Principal Investigator

Marshall University IRB

Approved on:	1-30-17
Expires on:	2-11-18
Study number:	868319

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. If there are any risks involved in this study then they will be described in this consent. Your participation is voluntary. Please take your time to make your decision, and ask your research doctor or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

The purpose of this study is to increase the understanding of 3 methods of measuring elbow stability and how fatigue of the forearm muscle effects elbow stability.

How Many People Will Take Part In The Study?

About 30 people will take part in this study. A total of 50 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During the study you will first fill out a questionnaire about your upper extremity, then the researcher will perform a brief examination of your arm. After the examination the researcher will use an ultrasound machine to make several images of the elbow and shoulder of the arm that you write with. During the ultrasound imaging you will need to wear a sleeveless or tank top shirt. During the ultrasound imaging you will be asked to lay down and your arm will be placed in several positions, while the researchers move your arm into several different positions. You will also be asked to perform several contractions of your arm muscles so that we can test your strength. After the ultrasound imaging is complete, the researcher will place several small sensors around your shoulders. These sensors will measure your motion and muscle activity. The research will then ask you to several wrist exercises while the motion of your shoulder and activity of your muscles are measured. You will hold a small weight in your hands while you do these exercises. The questionnaire, shoulder examination, motion testing and ultrasound imaging will take about 60 minutes to complete.

How Long Will You Be In The Study?

You will be in the study for one testing sessions that will take about 60 minutes to complete.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff to discuss what follow up care and testing could be most helpful for you.

Subject's Initials ________

The study principal investigator may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

Being in this study involves some risk to you. You should discuss the risk of being in this study with the study staff.

You should talk to your study doctor about any side effects that you have while taking part in the study.

Risks and side effects related to the testing session include: increased shoulder pain, muscle soreness, muscle fatigue and reduced forearm strength. These risks and side effects are temporary and are no greater than the risks associated with any physical exercise program. These side effects can be reduced by stretching exercises, and applying either moist heat or ice. **If you experience pain that you would describe as being more than 7 out of 10 you should stop the testing session contact your doctor.**

There may also be other side effects that we cannot predict. You should tell the research staff about all the medications, vitamins and supplements you take and any medical conditions you have. This may help avoid side effects, interactions and other risks. There are no funds available for compensation for any injury that occurs as a result of your participation in this study.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: You will gain information about the function of your shoulder.

What Other Choices Are There?

You do not have to be in this study.

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law states that we must keep your study records private. Nevertheless, certain people other than your researchers may also need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Those who may need to see your records are:

- Certain university and government people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. These include the Marshall University Institutional Review Board (IRB) and the Office of Research Integrity (ORI). Other individuals who may look at your records include: *the federal Office of Human Research Protection*, This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights

Subject's Initials ________

and your safety.

If we publish the information we learn from this study, you will not be identified by name or in any other way.

What Are The Costs Of Taking Part In This Study?

There are no costs to you for taking part in this study. All the study costs, including any study medications and procedures related directly to the study, will be paid for by the study. Costs for your regular medical care, which are not related to this study, will be your own responsibility.

Will You Be Paid For Participating?

You will not be paid if you decide to participate in this study.

Who Is Funding This Study?

This study is being sponsored by Marshall University School of Kinesiology

What Are Your Rights As A Research Study Participant?

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first to learn about any potential health or safety consequences.

Whom Do You Call If You Have Questions Or Problems?

For questions about the study or in the event of a research-related injury, contact the study investigator, Mark K Timmons ATC, PhD at (304)696-2925. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll or ORI at (304) 696-7320. You may also call this number if:

- You have concerns or complaints about the research.
- The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

Subject's Initials ________

SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you are entitled.

____
Subject Name (Printed)

____ ____________________
Subject Signature Date

____ ____________________
Person Obtaining Consent Date

____ ____________________
Principal Investigator Date

Subject's Initials ________

APPENDIX C: DATA COLLECTION FORM

Subject ID number: ______________________ **Date: ____/____/____**

Initial Data Collection Forms

Procedure Checklist

Assessment of Medial Elbow Stability

1. Inclusion & exclusion criteria
   a. Eligibility Screening exam
2. Subject Informed Consent
   a. Read, discuss, ask questions, sign
3. General Questions- Eligibility and Screening
   a. Intake information
   b. Patient reported outcomes (DASH)
   c. Height , Weight
4. Clinical Evaluation
5. Range of motion
   a. Flexion / extension
   b. Pronation / Supination
6. Strength Procedure
   a. Elbow flexion
   b. Elbow extension
   c. Grip strength
7. Ultrasound Imaging-
   a. Medial elbow rest
   b. Medial elbow stress 1
   c. Medial elbow stress 2
   d. Medial elbow stress 3
   e. Wrist flexor mass long
   f. Wrist extensor mass transverse
   g. GIRD
8. Wrist flexor fatigue protocol
   a. RPE
9. Strength Procedure, post exercise
   a. Elbow flexion
   b. Elbow extension
   c. Grip strength
10. Ultrasound Imaging
    a. Medial elbow rest
    b. Medial elbow stress 1

Inclusion criteria

At least 18 years old
Ability to sit still for up to 5 minutes

Exclusion criteria

History of shoulder, elbow or arm injury during the previous 2 years
History of fracture or surgery to the trunk or upper extremity
Upper extremity or throwing athletes
Systemic musculoskeletal disease
Elbow pain ≥2/10
Greater than 50% loss of shoulder or elbow range of motion

Subject meets inclusion/exclusion criteria (circle one):

1= Yes, continue **2= No**, stop

Page **1** of **7**

Subject ID number: ______________________ **Date:** ____/____/____

Research Study Questionnaire
Participant completes:

DOB (mm/dd/yy): ____/___/____

Age: _____ (years) **Sex:** 1 = Female 2 = Male

1. **Do you have any systemic musculoskeletal disease (like Rheumatoid Arthritis)?**
   (Circle One) 1 = Yes If yes, please list____________________________
   2 = No
2. **Do you currently have or have had elbow pain in the last 6 months?**
   (Circle One) 1 = Yes 2 = No

   If yes, how would you rate the pain?
   (0 = no pain at all, 10 = the worst imaginable pain) _____________
3. **Which shoulder is your dominant side?** Which hand do your write with or throw a ball with?
   1 = Right
   2 = Left
   3 = Ambidextrous
4. **How would you rate your elbow today (as "a percentage of normal")?**
   (0% - 100% with 100% being normal) = _______**%**
5. **Have you had elbow surgery?** 1 = Yes 2 = No
6. **Do you have a known elbow problem/ pathology?**
   1 = Yes 2 = No
   a. If yes, which elbow? 1 = Right 2 = Left 3= Both
   b. If yes, have you sought treatment for this problem
      1 = Yes 2 = No
   c. If yes, when did your elbow pain start?
      1 ____ Less than 6 weeks ago
      2 ____ 6-12 weeks ago
      3 ____ More than 12+ weeks ago
      4 ____ I do not have shoulder pain
   d. If yes, please describe: ____
      ____
      ____
      ____
      ____

Screening Exam

Subject ID number: ______________________ **Date:** ____/____/____

Research Team completes

Subject height: __________(cm) **Subject weight:**_______________(Kg)

Shoulder ROM:

Elbow Flexion ___________
Elbow Extension ___________
Pronation ___________
Supination ___________
Wrist Flexion ___________
Wrist Extension ___________

Shoulder ROM:

External Rotation ___________
Internal Rotation ___________
Abduction ___________
Flexion ___________

Special Tests:			**End Feel**
Elbow Valgus	+	-	___________________________
Milking Maneuver	+	-	___________________________

Subject ID number: ______________________ **Date:** ____/____/____

Participant's Physical Measures

Research Team completes

Pre Exercise

Force, and Pain

	Pre Fatigue		Post Fatigue					
Trial			1		2		3	
	Pain	Force	Pain	Force	Pain	Force	Pain	Force
Wrist flex 1								
Wrist flex 2								
Wrist flex 3								
Wrist ext 1								
Wrist ext 2								
Wrist ext 3								
Grip Strength position 2 1								
Grip Strength position 2 2								
Grip Strength position 2 3								
Grip Strength position 3 1								
Grip Strength position 3 2								
Grip Strength position 3 3								

Perceive Exertion

	Band Color	#reps	Exertion
Bout 1	________	______	____________
Bout 2	________	______	____________
Bout 3	________	______	____________
Bout 4	________	______	____________
Bout 5	________	______	____________

Subject ID number: ____________________ **Date:** ____/____/____

US Imaging of the Medial Elbow

File name (on US machine): ____________ Examiner Andrew DeMoss

Stress Test (UNSTRESSED):

Image 1 **Image 2**

Stress Test (STRESSED):

Image 1 **Image 2**

Stress Test (UNSTRESSED):

Image 1 **Image 2**

Stress Test (STRESSED):

Image 1 **Image 2**

Stress Test (UNSTRESSED):

Image 1 **Image 2**

Stress Test (STRESSED):

Image 1 **Image 2**

Post Exercise File name (on US machine): ____________

Stress Test (UNSTRESSED):

Image 1 **Image 2**

Stress Test (STRESSED):

Image 1 **Image 2**

Stress Test (UNSTRESSED):

Image 1 **Image 2**

Stress Test (STRESSED):

Image 1 **Image 2**

Subject ID number: ____________________ **Date: ____/____/____**

US Imaging of the Medial Elbow

File name (on US machine): ____________ Examiner Nathaniel Millard

Stress Test (UNSTRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Post Exercise File name (on US machine): ____________

Stress Test (UNSTRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED): ______________________

Image 1 **Image 2**

______ _____ ______ _____

APPENDIX D: QUICK DASH QUESTIONNAIRE

Subject Number
Date

Initial Visit

THE QuickDASH OUTCOME MEASURE

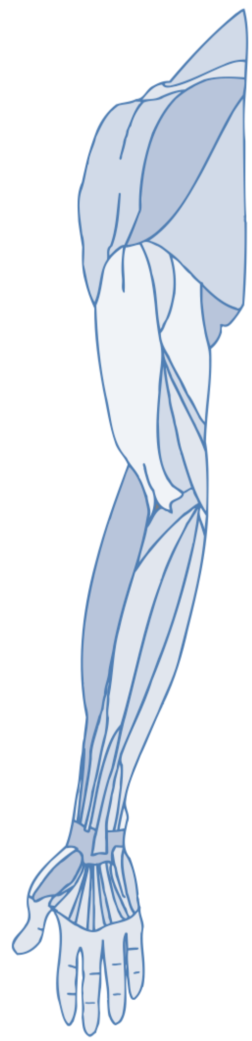
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* of which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.



*Quick*DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

***Quick*DASH DISABILITY/SYMPTOM SCORE** = $\left(\left[\frac{\text{sum of n responses}}{n}\right] - 1\right) \times 25$, where n is equal to the number of completed responses.

A *Quick*DASH score may not be calculated if there is greater than 1 missing item.

*Quick*DASH

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:____

❒ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	**NO DIFFICULTY**	**MILD DIFFICULTY**	**MODERATE DIFFICULTY**	**SEVERE DIFFICULTY**	**UNABLE**
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:_______________________________

❒ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	**NO DIFFICULTY**	**MILD DIFFICULTY**	**MODERATE DIFFICULTY**	**SEVERE DIFFICULTY**	**UNABLE**
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

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APPENDIX E: RANGE OF MOTION MEASUREMENTS

Range of Motion (ROM) using a Goniometer (Norkin & White, 2003)				
Motion	Fulcrum	Proximal Arm	Distal Arm	Normal ROM
Shoulder Complex Flexion	Over the lateral aspect of the greater tubercle	Parallel to the midaxillary line of the thorax	Lateral epicondyle of the humerus	180°
Shoulder Complex Abduction	Close to the anterior aspect of the acromial process	Align parallel with the midline of the anterior aspect of sternum	Anterior midline of the humerus	180°
Elbow Flexion	Over the lateral epicondyle of the humerus	Aligned with the midline of the humerus	Aligned with the lateral midline of the humerus	140°-150°
Elbow Extension	Over the lateral epicondyle of the humerus	Aligned with the midline of the humerus	Aligned with the lateral midline of the humerus	0°
Pronation	Laterally and proximally to the ulnar styloid process	Parallel to the anterior midline of the humerus	Dorsal aspect of the forearm, just proximal to the styloid processes of the radius and ulna	80°
Supination	Laterally and proximally to the ulnar styloid process	Parallel to the anterior midline of the humerus	Ventral aspect of the forearm, just proximal to the styloid processes of the radius and ulna	80°
Wrist Flexion	On the lateral aspect of the triquetrum	Lateral midline of the ulna	Lateral midline of the 5th metacarpal	60°
Wrist Extension	On the lateral aspect of the triquetrum	Lateral midline of the ulna	Lateral midline of the 5th metacarpal	60°

Range of Motion (ROM) using a Digital Inclinometer (Kolber & Hanney, 2012)			
Motion	Position of Subject	Inclinometer Placement	Normal ROM
Shoulder Internal Rotation	Subject's shoulder is in 90° of abduction and the elbow is flexed to 90°, while the wrist is in a neutral position.	Distal forearm, just proximal to the wrist	70°
Shoulder External Rotation	Subject's shoulder is in 90° of abduction and the elbow is flexed to 90°, while the wrist is in a neutral position.	Distal forearm, just proximal to the wrist	90°