2021

Side-to-differences of medial elbow anatomy adaptations in youth throwing athletes

Rudolph Matthew Morrow

SIDE-TO-DIFFERENCES OF MEDIAL ELBOW ANATOMY ADAPTATIONS IN YOUTH THROWING ATHLETES

A thesis submitted to
the Graduate College of
Marshall University
In partial fulfillment of
the requirements for the degree of
Master of Science
In
Exercise Science
With a Concentration in Athletic Training
by
Rudolph Matthew Morrow
Approved by
Dr. Mark Timmons, Committee Chairperson
Dr. Gary McIlvain
Ms. Jennifer Johnson

Marshall University
May 2021

APPROVAL OF THESIS

We, the faculty supervising the work of Rudolph Matthew Morrow affirm that the thesis, *Side-to-side Differences of Medial Elbow Anatomy Adaptations in Youth Throwing Athletes*, meets the high academic standards for original scholarship and creative work established by the Master of Science in Exercise Science 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.

4/22/2021

Dr. Mark Timmons, School of Kinesiology — Committee Chairperson — Date

4/22/21

Dr. Gary McIlvain, School of Kinesiology — Committee Member — Date

4/22/21

Ms. Jennifer Johnson, School of Kinesiology — Committee Member — Date

ACKNOWLEDGMENTS

I would like to express gratitude to the committee members for their help and support. Thank you to the Huntington Little League for allowing us to use their athletes as subjects for this study. Thank you to my best friend Colin, who has been an anchor throughout this experience. Lastly, I would like to express my utmost thanks to my parents for their unwavering support. None of this would have been possible without you. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Background: Injuries to the medial elbow are common in overhead sports, with the most common occurring at the medial/ulnar collateral ligament (UCL). Injury to the UCL is associated with elbow joint laxity which tends to develop over time in athletes who place their elbows under chronic valgus forces like those present during throwing.[27, 37] This instability is well documented in professional, collegiate, and high school athletes.

Purpose: The purpose of this study was to investigate the medial elbow joint width and common flexor tendon thickness in the arms of youth baseball players. The hypotheses were (1) the medial elbow joint space would be greater on the dominant arm compared to the non-dominant arm in a resting position, (2) the medial elbow joint space would be greater on the dominant arm compared to the non-dominant arm in the stressed position; and (3) the common flexor tendon would have a greater thickness on the dominant arm compared to the non-dominant arm.

Methods: Six participants were included in this investigation.. The width of the medial elbow was measured on ultrasound images of the medial elbow and common flexor tendon. The medial elbow joint space was measured at rest and with an applied valgus stress.

Results: There was no significant difference in medial elbow joint space width between the dominant and non-dominant sides at rest or with an applied valgus stress. There was no significant difference in common flexor tendon thickness at the elbow between the dominant and non-dominant sides within subjects. The mean medial elbow joint space width at rest was 3.39mm ± 0.96mm on the dominant side and 3.47mm ± 0.87mm on the non-dominant side. When a valgus stress was applied, the dominant side mean increased to 3.92mm ± 1.02mm and

the non-dominant side increased to 4.04mm ± 1.04mm. The mean flexor tendon thickness was 3.8mm ± 0.54 on the dominant side and 3.92mm ± 0.59mm on the non-dominant side.

Conclusion and Practical Significance: No side-to-side difference in medial elbow joint space width or flexor tendon thickness was observed in youth baseball/softball athletes. These findings are expected in youth throwers due to their relative inexperience with overhead throwing and lack of accumulated stress on the medial elbow. Maintaining the stability of the elbow as youth throwing athletes age is a vital step in preventing costly injury later in their careers.

CHAPTER 1

INTRODUCTION

Injuries to the medial elbow are common in overhead sports.[1, 10, 27] Injury to the ulnar collateral ligament (UCL) appears almost specifically in overhead throwing athletes, but is also seen in wrestlers, tennis players, javelin throwers, and football players.[27] Conte et al. reported that an estimated 18% of relief pitchers in professional baseball have a history of UCL reconstruction.[9] A study conducted by the NCAA found that over the course of 5 academic years (2009-2010 to 2013-2014), 1936 UCL injuries occurred in collegiate baseball with 55% of injuries resulting in lost playing time—15% were season ending.[10] It is reported that up to 74% of youth baseball players ages 8-18 report participating in their sport with some level of arm pain.[29] The same study reported 23% of youth baseball players have a history of arm injury consistent with overuse.[29] Pytiak et al. studied the elbow of the throwing arms in Little League players (average age 11.5 years old) before and after a season of play to identify risk factors for pain.[40] However, no studies comparing bilateral elbow anatomy in youth throwing athletes could be found.

The majority of documented injuries to the UCL are believed to be a result of repetitive microtrauma over time.[37] Elbow stability is sustained by ligamentous staticstabilization along with muscular dynamic stabilization.[36] Damage to the stabilizing structures—especially the UCL—can cause instability, or an increase in the medial joint space.[27, 37] Fatigue of the dynamic stabilizers such as the wrist flexor muscle group can also decrease overall stability and allow increase of the medial joint space.[31, 36] The repetitive stress of throwing begins to fatigue the flexor muscles and stretch the UCL, allowing for greater opening of the medial elbow during valgus torque.[37] Nazarian et al.[33] reported a greater widening of the medial elbow joint space while placed under a valgus stress on the throwing arm compared to the non-throwing arm of healthy professional baseball pitchers. Glousman et al.[16] reported that pitchers with UCL injuries demonstrated decreased wrist flexor activity. Millard et al.[31] demonstrated that fatigue of the wrist flexors may lead to an increase in medial elbow joint space. These differences have been found in professional and collegiate baseball players, though studies focused on youth athletes have not been reported.[9, 10, 13, 33, 42] The prevalence of UCL injury is higher in professional baseball players than seen in collegiate baseball players.[9, 10] This is thought to be related to the overall amount of time an individual has been involved in the sport. As a player ages and plays longer, the injury becomes more likely due to the total amount of stress placed on the UCL over time. Because these adaptations are thought to develop over time, we may be able to intervene with preventative measures if we can identify when the changes in anatomy begin to occur. However, this author was not able to find any studies examining the side-to-side differences in medial elbow joint space or flexor tendon thickness in youth throwing athletes.

Diagnostic ultrasound imaging (US) is a cost-effective tool that can be used clinically to visualize musculoskeletal anatomy.[48] It can also be used to monitor anatomical changes such as an increase in medial elbow joint space. DeMoss et al.[11] demonstrated the ability of US to detect differences in medial elbow joint space from unstressed to stressed positions.

Research looking into chronic effects of throwing has been conducted. Keller et al. measured UCL thickness in high school pitchers before and after a competitive season and reported a significant increase in thickness of the structure after a season of play.[19] Millard et al. reported the acute effects of fatigue on wrist flexor muscles and its contribution to elbow instability.[31] Hattori et al. reported the acute effects of throwing on elbow stability in high school baseball players.[17] However, research examining the dominant to non-dominant side differences of the UCL and common flexor tendon in youth throwing athletes has not greatly been reported.

The purpose of this study was to answer the question: can we detect differences in the width of the medial elbow joint space and the thickness of the flexor tendon between dominant and non-dominant arms in youth throwing athletes?

Hypotheses

H_0: There would be no difference in the width of the medial joint space or common flexor tendon thickness between dominant and non-dominant arms in youth baseball players.

H_A:

1) The medial elbow joint space would be greater on the dominant arm compared to the non-dominant arm in a resting position.

2) The medial elbow joint space would be greater on the dominant arm compared to the non-dominant arm in the stressed position.

3) The common flexor tendon would have a greater thickness on the dominant arm compared to the non-dominant arm.

CHAPTER 2

LITERATURE REVIEW

Introduction

Elbow injury prevalence in sports is overall a rare occurrence, with the majority of injuries being damage to the ulnar collateral ligament (UCL). Ulnar collateral ligament injury is almost exclusively present in overhead sports such as baseball, tennis, javelin, and football with the highest prevalence in baseball—specifically pitchers.[27] In a report of the 2002-2003 MLB season, it was documented that 75 of 700 pitchers who appeared in game had a history of UCL reconstructions.[27] A sharp increase of UCL reconstruction instances has been seen across all ages from 1995-2000 versus 2000-2004: 2 times more in professional athletes, 4 times more in collegiate athletes, and 6 times as many in high school athletes.[27] A possible explanation for the increase of cases can be the institution of year-round training implemented at a younger age. The lack of rest associated with this can hinder the body's ability to properly recover from acute damage occurring during bouts of throwing, specifically at the medial elbow.

The purpose of this study was to examine the difference between medial elbow joint space width and common flexor tendon thickness between the dominant (throwing) and non-dominant arms of youth baseball players. We hypothesized that the medial elbow joint space on the dominant arm would be wider compared to the non-dominant arm with and without valgus stress, and that the dominant side common flexor tendon would show increased thickness compared to the non-dominant side.

This review examined the current literature and describes the elbow anatomy and kinematics, effects of structural instability on function, the effects of exercise on musculature and ligaments, the elbow's role in throwing mechanics, and the forces placed on different structures during the throwing motion.

Anatomy Review of Shoulder and Elbow

The elbow consists of the articulation between the ulna and the humerus. It is responsible for controlling the length of the upper limb and positioning the hand in space. The elbow articulation allows two main motions: flexion and extension.[18] The joint provides approximately 140° of range of motion (0° terminal extension, 140° terminal flexion) in an uninjured person.[18] The soft tissue stabilizers of the elbow include the medial and lateral collateral ligament bundles that provide static stabilization and the surrounding musculature of the upper arm and forearm that provide dynamic stabilization. The medial collateral ligament complex consists of three portions—anterior bundle, posterior bundle, and transverse ligament.[8, 18, 24] The anterior and posterior bundles originate on the inferior aspect of the medial epicondyle of the humerus and span across the joint to the anterior and posterior aspects of the ulna, respectively.[18] It has also been shown that the posterior bundle of the UCL plays a minor role in stability during a valgus load in the elbow.[43] The anterior bundle (referred to as the ulnar collateral ligament or UCL) is further broken down into two bands—the anterior band, which is tight during extension, and the posterior band, which is tight during flexion.[8] The UCL provides support for the elbow, limiting lateral motion caused by valgus forces on the lower arm.[18, 24] The UCL is the primary stabilizer of the elbow during valgus stress, especially during overhead throwing, and is the most commonly injured structure in the upper extremity in throwing athletes.[48]

The dynamic stabilizing musculature of the elbow provide joint stability by compressing the joint space, increasing total articulation area and therefore enhancing stability.[8, 18] The dynamic stabilizers of the elbow include any musculature that cross the joint. They consists of the biceps, brachialis, brachioradialis, triceps, lateral wrist extensors, and medial wrist flexors.[27] The main dynamic stabilizers that resist valgus forces are the flexor carpi ulnaris, flexor carpi radialis, flexor digitorum superficialis, and pronator teres (medial flexors).[8, 18, 36] The main stabilizers that resist varus forces are the extensor carpi ulnaris, extensor digitorum communis, extensor carpi radialis brevis, and extensor carpi radialis longus (lateral extensors).[18] The tension in these flexor and extensor groups is what acts to compress the joint space, resisting medial/lateral motion as well as increasing the bony articulation. A cadaver study by Park et al.[36] tested each medial wrist flexor's influence on valgus angle at the elbow at flexion angles between 30° and 90°. It was observed that the largest correction in valgus angle occurred when both the flexor carpi ulnaris and flexor digitorum superficialis were contracted together.[36] In isolation, the flexor carpi ulnaris was observed to produce the greatest valgus correction angle, followed by isolated flexor digitorum superficialis contraction.[36] Unrecognized injury or uncontrolled fatigue to these dynamic stabilizers can lead to excess laxity and increased forces placed on the static structures of the medial elbow.[8, 36]

The elbow joint is responsible for controlling the length of the upper limb and positioning the hand in space. To maintain proper function and disperse forces placed upon it, it relies on the static and dynamic stabilizers—mainly the UCL and the medial wrist flexors. Any unrecognized injury or trauma to these stabilizers may result in excess laxity of the elbow joint and increased stress on the supporting structures.

Instability Effect on Function

Overhead athletes are at a higher risk for medial elbow instability.[24] Overhead throwing motions such as throwing a baseball, football, or swinging a tennis racket, puts stress on the UCL, specifically the anterior bundle of the UCL.[18, 24] Repeated microtrauma or acute trauma can lead to partially torn or sprained UCL fibers which can result in medial elbow instability.[18, 24] Without proper diagnosis and treatment, this instability places an increased load on the already damaged tissues, increasing the risk of total failure of the UCL.[24, 27]

Stability at the glenohumeral (GH) joint is required to maintain proper arm and shoulder range of motion.[47] When the stability of the GH joint is compromised, the body cannot properly distribute forces placed upon it. The presence of GH instability and/or medial elbow instability can be detrimental to athletic performance as well as be debilitating to normal acts of daily living (ADL).[26] Athletes with instability often do not directly feel unstable; GH and/or elbow instability may present as pain, decreased accuracy, decreased power, and/or decreased velocity when throwing.[24] Continued activity without proper treatment of the pathology can lead to more serious injuries such as full ruptures of the UCL or rotator cuff tears, requiring more invasive treatments.[8, 18, 24, 36]

Previous injury—properly treated or unrecognized—can also result in underlying instability. Anz et al.[4] reported that athletes with pre-existing/treated elbow or shoulder injuries demonstrated higher peak elbow valgus torque (91.6 Nm) compared to healthy athletes (74.7 Nm) while pitching at maximal effort.

Stability in the elbow and shoulder is vital for proper movement, especially during overhead activities. Repetitive overhead motions like throwing can lead to accumulative microtrauma that compromises joint stability. Previous injury, whether treated or unrecognized, may lead to instability which has been associated with decreased performance and joint failure.

Effects of Acute Exercise on Musculature

Proper shoulder function requires scapular and GH stabilizers working together.[3] Joint stabilization and muscular strength and activation is vital for proper function and preventing shoulder and elbow injuries.[3, 30] While proper strength is important, muscular endurance plays a major role in maintaining shoulder stability.

It is well documented that, as the rotator cuff muscles begin to fatigue, the body begins to compensate. In a non-fatigued shoulder, the rotator cuff acts to increase the subacromial space by pulling the humerus inferiorly.[28, 32] However, as the muscles begin to fatigue, they become less effective. It has been reported that the two main consequences to shoulder fatigue during repetitive overhead motion are (i) superior translation of the humerus, and (ii) changes in scapular kinematics to make up for decreased rotator cuff motion.[32] These changes can lead to a tired pitcher altering his mechanics, such as their throwing arm angle, which can increase the load placed on the structures of the elbow. Aguinaldo et al.[2] reported that when a pitcher throws from a side-arm delivery, valgus torque on the medial elbow increased (66 ± 24 Nm) compared to traditional/overhead delivery (46 ± 29 Nm). This increased stress may predispose an athlete to injury. Similar results can be seen at the elbow with the medial flexor group and lateral extensor group during repeated use. It was reported that after a repetitive push/pull activity, activation in the extensor/flexor groups at the elbow began to decrease, and compensation via increase in motion in the shoulder, trunk, and wrist was recorded.[28] Tajika et al.[45] reported a positive significant association between flexor carpi ulnaris strength on subjects' throwing arms and their perceived pitching performance, suggesting the flexor carpi ulnaris strength plays an important role in pitching. If this muscle fatigues and begins to function sub-optimally, a pitcher's performance may begin to decline.

Muscle endurance is a vital factor in overall function. When muscles begin to fatigue, the body tends to find ways to compensate in order to complete the task at hand. While this may be good for our survival, it can have negative effects on the structures involved and sports performance overall.

Effects of Exercise on Ligament Stability

Joint stability or laxity is maintained primarily via the ligamentous structures surrounding the joint.[18, 27, 34] Excess joint laxity can increase the risk of traumatic injury.[34] The degree of joint laxity has also been associated with physical function—with excess laxity or stiffness associated with decreased function.[34] Traumatic injury is not required for joint laxity to be present.

It has been documented by Keller R. that over the course of a baseball season, UCL thickness in pitchers tends to increase in response to the repetitive loads placed upon it.[19] Medial elbow joint laxity was also reported in this study, confirming that repeated loads over time increase laxity, placing individuals at further risk of traumatic injury and possibly decreasing physical function as stated above.[19]

Increased joint laxity as a result of UCL adaptations is well documented in professional, collegiate and even high school baseball players.[9, 10, 19]

Force During Throwing

Overhead motions across sports generally consist of similar mechanics. The mechanics of throwing are split into six phases: windup, stride (early cocking), late cocking, acceleration, deceleration, and follow through.[6, 19, 39] During these motions, tremendous forces can be placed on the shoulder and elbow. For our purposes, we will focus on the cocking and acceleration stages because this is where the most stress is placed on the elbow.

<u>Early Cocking</u>

During this phase, the pitcher removes the ball from the glove and abducts the arm to shoulder height. The elbow is flexed to 80-100°.[6]

Late Cocking

The pitcher makes contact with the mound with his stride leg and the shoulder reaches maximum external rotation.[6] This phase is where the most stress is placed on the medial elbow. Between the late cocking and early acceleration phases of throwing, valgus forces upwards of 120 N are placed on the UCL at the elbow.[19, 39]

Acceleration

The pitcher shifts from external rotation to internal rotation, generating energy and transferring it to the ball when it is released. The explosive shift from maximum external rotation to internal rotation occurs at over 9000°/second.[6] This incomprehensible movement places the UCL under tremendous stress (between 60-120 N).[6, 19, 39] Even if only for a fraction of a second, due to the nature of pitching, these small bursts of stress can take a toll on the UCL.

Rarely is UCL trauma in sports thought to be acute in nature; it has been reported that the overwhelming majority of cases occur as overuse phenomena.[19] Because of the repetitive nature of overhead sports, the constant application of these valgus forces on the tissues of the body often leads to microtrauma (instability) or acute trauma as a result of poorly managed microtrauma.[19, 24, 39]

During the phases of throwing, the upper extremity goes through a great range of motion in a fraction of a second. The nature of that quick movement places repeated heavy loads upwards of 120 N on supporting structures such as the UCL.[19] Due to the repetitive nature of most overhead sports, these small bursts of stress can add up over time leading to an eventual total failure of the structure if left untreated.

Conclusion

Elbow and shoulder injuries can be debilitating when it comes to sport activity and acts of daily living. In overhead sports, elbow pathologies can be detrimental to performance.[24] A major cause of elbow pain in sports is damage to the primary valgus stabilizer, the UCL.[18, 27] The musculature of the elbow act as dynamic stabilizers to reduce the stress placed on the UCL and compress the joint to maximize articulation.[18, 27] As these muscles fatigue, the body compensates for the decreased stability by changing its kinematics. This change increases pressure and stress on other supporting structures in the body.[28] Repetitive valgus stress during the late cocking/early acceleration phase of throwing which places extensive valgus forces on the elbow, is the main mechanism responsible for laxity or rupture that upwards of 50% of professional pitchers experience at some magnitude at some point in their career.[19, 39] Instability at the elbow commonly presents as pain, decreased accuracy, decreased velocity, or decreased power.[24]

The long-term effects of acute bouts of throwing are well documented in the literature,[19] as is acute adaptations of other ligaments in the body to exercise.[34] However, these adaptations have not been identified or studied in the youth population. The purpose of this study is to determine if these adaptations to chronic valgus stress from repetitive throwing are present in the medial elbow in youth throwing athletes.

CHAPTER 3

METHODS

Introduction

Elbow injures are common in overhead sports and can be detrimental to performance. The ulnar collateral ligament (UCL) is one of the most commonly injured structures in throwing athletes because of the tremendous stress placed on it during the early acceleration phase of throwing.[10, 19, 39, 44] This study is a comparative study to determine if there is a difference in medial elbow joint space widths between dominant and non-dominant arms of youth baseball players. We hypothesize that the medial elbow joint space width of the dominant arms will be wider compared to the non-dominant arms.

Participants

Power analysis conducted from pilot data revealed a sample size of 25 participants would be adequate to detect a mean difference in bilateral differences in the width of the medial elbow joint space of 0.2mm and standard deviation of 0.34mm, setting $\alpha = 0.95$, $1\text{-}\beta = 0.80$. Sample size calculations were determined using G*Power 3.13 software (copyright 1992-2010 University of Kiel) based on the minimal detectable change (MDC = 0.16mm) and standard error of measure (SEM = 0.2mm). These values were determined from pilot testing performed for the current investigation. However, 14 subjects were recruited for this study. Demographic data for the subjects can be found in Table 1.

Inclusion Criteria

Participants in this study were: (1) active in organized youth baseball or softball; (2) under the age of 18 years old; and (3) able to sit still for up to five minutes.

Exclusion Criteria

Participants were excluded from this study if they: (1) were greater than 17 years of age; (2) had shoulder or elbow pain ≥ 7/10; (3) had a history of shoulder or elbow surgery; (4) had a history of arm, rib, or shoulder fracture within the past year; or, (5) had greater than 50% loss of shoulder or elbow range of motion.

	Age (years)	**Weight (kg)**	**Height (cm)**	**Participation (years)**
Mean ± SD	10.5 ± 3.15	48.77 ± 18.83	149.17 ± 20.43	5.17 ± 3.31

Table 1: Sample Demographics

Demographic data for the sample included age, weight, height, wrist circumference, and how long the subjects have participated in organized youth baseball/softball.

IRB Approval

This study was approved (IRBNET # 1566840-1) by the Marshall University Institutional Review Board (IRB). (See Appendix A). All participants provided written informed assent and parental consent was obtained prior to participation (See Appendix B, C). Each child's parent was in attendence and witnessed all testing procedures.

Materials

Ultrasound imaging was used to measure the medial joint space. The imaging method has been previously described by Konin, et al.[23] The images were taken using a Mindray m5 US unit (Mindray Ltd and National Ultrasound, Inc, Duluth, GA) with an adjustable 8.0-12.0 MHz frequency transducer. Measurements of force were made using a handheld dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT). Grip strength was assessed using a Jamar Hand Dynamometer (Lafayette Instruments, Lafayette, IN, USA).

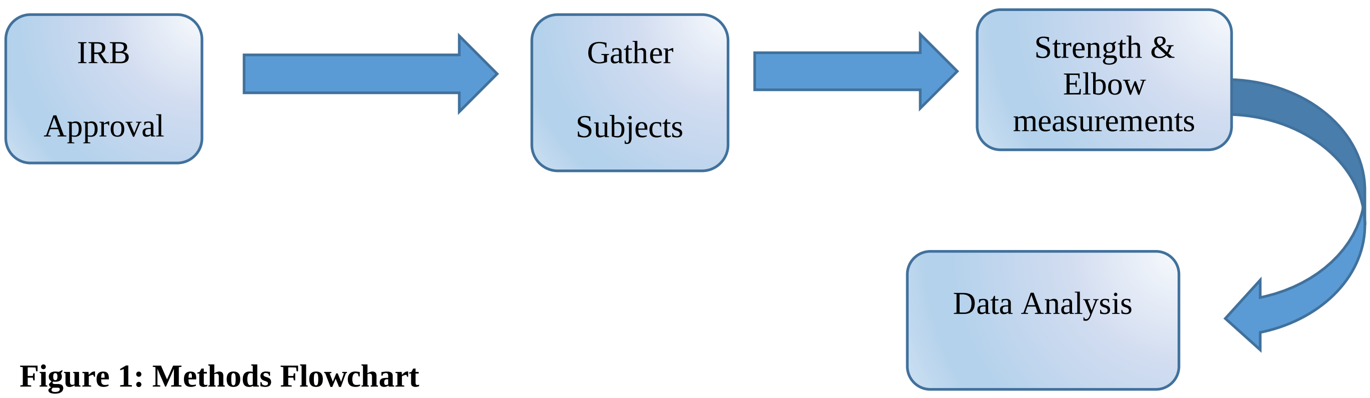

Figure 1: Methods Flowchart

A flowchart describing the methods used in this experiment.

Protocol

The participant's maximal voluntary isometric (MVIC) strength was measured for shoulder internal rotation, shoulder external rotation, wrist extension, and grip strength using a handheld dynamometer. All measurements were collected by the same certified athletic trainer. The participants then had ultrasound images of the medial elbow joint space taken as previously described by Ciccoti, et al.[7] and DeMoss, et al.[11] The subject was placed in the supine position with their shoulder abducted to 90° and the elbow flexed to 30°. The researchers collected measurements of the medial elbow joint space in the unstressed position and again with the valgus stress test applied. Then, measurements of the common flexor tendon thickness were collected. Each measurement was collected twice. This procedure was then repeated on the contralateral side.

Procedures

Self-Reported Outcome Measures

Information regarding the self-reported outcomes measure in patients with elbow pain and dysfunction is limited. The level of function was measured at the time of the elbow testing. Self-reported elbow pain and disability was determined by Pediatric / Adolescent Shoulder Score (PASS). The reliability and validity, as well the minimal detectable change and minimal clinically important change (MCIC) of the PASS[5, 25, 35] questionnaires have been reported in the literature. Self-reported outcome measures can be used to determine the level of shoulder and elbow dysfunction and to monitor change in function of the shoulder over a period.

Manual Muscle Strength

Assessment of shoulder girdle muscle strength was performed using techniques described by Kendell.[20] Muscle strength was measured using hand held dynamometry. Force was recorded to the nearest tenth of a pound. Each measurement was made twice with a minimum 60 second rest given between each measurement. The mean of the two measures was used for analysis. Mean strength measures are presented in Tables 2 and 3.

Shoulder External Rotation

External rotation strength was assessed by having the subject stand upright with their arm hanging in a relaxed slightly abducted position with the elbow flexed to 90°. The examiner was positioned to the side of the subject with one hand stabilizing the subject’s elbow. The examiner grasped the subject’s wrist with their other hand. The subject was instructed to externally rotate their shoulder as the examiner resisted their motion.

Shoulder Internal Rotation

External rotation strength was assessed by having the subject stand upright with their arm hanging in a relaxed slightly abducted position at with the elbow flexed to 90°. The examiner stood to the side of the subject with one hand stabilizing the subject's elbow, the examiner grasped the subject's wrist with their other hand. The subject was instructed to internally rotate their shoulder as the examiner resisted their motion.

Grip Strength

The participant's grip strength was determined for both arms. Grip strength was assessed using a Jamar Hand Dynamometer (Lafayette Instruments, Lafayette, IN, USA). Participants were in a seated position with their shoulder against their side, their elbow flexed to 90°, and the forearm in a neutral position. The handle position was set at positions two and three. The participant was told to perform two repetitions at each handle position, and a minimum 60 second rest was given between the maximal contractions. The participants performed several (three to five) submaximal contractions in order to familiarize them with the procedure. Subjects were then instructed to grip the handle as hard as they could for five seconds.[14, 22]

	Shoulder IR	**Shoulder ER**	**Grip strength**
Mean ± SD (lbs)	47.83 ± 10.67	98.0 ± 13.5	23.17 ± 8.35

Table 2: Dominant Arm Strength Measures

Mean maximal voluntary isometric contraction strength (pounds ± standard deviation) measures for the dominant arm.

	Shoulder IR	Shoulder ER	Grip strength
Mean ± SD (lbs)	37.83 ± 13.44	89.83 ± 15.21	26.0 ± 6.32

Table 3: Non-Dominant Arm Strength Measures

Maximal voluntary isometric contraction strength (pounds ± standard deviation) measures for the non-dominant arm.

Elbow Joint Laxity Tests

Valgus stress is stress applied to the lateral aspect of the elbow, while also applying stress to the medial aspect of the forearm. This stress will be applied with the participant in approximately 30° of elbow flexion.

Ultrasound Imaging

Ultrasound (US) images of both of the participants' elbows were collected in stressed and unstressed positions. Images of the common flexor tendon were also collected. To view the medial elbow joint space, the probe was oriented along the long axis of the ulnar collateral ligament, using the trochlea of the humerus and the sublime tubercle of the ulna as landmarks.[7] The medial elbow joint space width is defined as the distance between the trochlea of the humerus and the coronoid process of the ulna.[7] These measurements were collected following the tests and then compared between dominant and non-dominant sides. A total of two researchers were used for each of these tests to ensure the highest quality image is taken. The first researcher operated the transducer in line with the anatomical landmarks mentioned previously. The second researcher applied the valgus stress, as they would do during a clinical evaluation of a patient with suspected medial elbow instability.

Pilot testing prior to this investigation revealed moderate to excellent reliability for measuring the medial elbow joint space as well as flexor tendon thickness. For the unstressed measurement, the ICC was 0.972 and 0.82 for the dominant and non-dominant side, respectively. The ICC for the stressed measurement was 0.742 and 0.71 for the dominant and non-dominant side, respectively. For the tendon thickness, the ICC was 0.673 and 0.90 for the dominant and non-dominant side, respectively. The minimal detectable change for the unstressed elbow, stressed elbow, and tendon thickness was determined to be 0.08mm, 0.26mm, and 0.37mm, respectively. The standard error was determined to be 0.06mm, 0.18mm, and 0.26mm, respectively.

Figure 2: Ultrasound Testing Position and Ultrasound Image of the Medial Elbow.
Test subject positioning during measurements (Left) and an ultrasound image of the medial elbow joint with labels signifying the trochlea and the coronoid process (Right).

Data Analysis

All calculations will be completed using SPSS version 21 statistical software (IBM Corporation, Armon, NY). A 2-way analysis of variance with repeated measures will be used to determine the differences in width of the joint space. Using paired t-tests, we will determine the differences among the tests using a statistically significance value of $P<0.05$.

CHAPTER 4

RESULTS

This study included a convenience sample of 14 subjects (13 male, 1 female). Demographic data for the subjects can be found in Table 1. Twelve of the subjects were ages 10-13 while the remaining two were ages 6-7 (one each). All of the subjects were right hand-dominant.

The results for medial elbow joint distance for all subjects can be seen in Table 4. Overall, the mean medial joint distance of the dominant side was 3.39mm ± 0.96mm (mean ± SD) in the unstressed position and 3.92mm ± 1.02mm with the applied valgus stress. The non-dominant side mean joint widths were 3.47mm ± 0.87mm in the unstressed position and 4.04mm ± 1.04mm with the applied valgus stress. The mean flexor tendon thickness was 3.80mm ± 0.54mm on the dominant side and 3.93mm ± 0.59mm on the non-dominant side (Table 7).

The results for medial elbow joint distance for the older subjects can be seen in Table 5. In the older subjects, the mean medial elbow joint space distance on the dominant side was 3.45mm ± 0.93mm, 3.96mm ± 0.98mm (unstressed, valgus-stressed). The mean joint distance on the non-dominant side was 3.48mm ± 0.79mm, 4.08mm ± 1.06mm, demonstrating no significant difference in joint space width between dominant and non-dominant sides with valgus stress ($t=-1.764$, $P=0.11$). There was a significant increase in joint space (mean difference, 0.50 ± 0.30mm, $t=-5.967$, $P<0.001$) with the applied valgus stress on the dominant side. There was a similar increase (0.56mm $\pm$ 0.75mm, $t=-2.60$ $P=0.025$) seen on the non-dominant side. The mean flexor tendon difference between dominant and non-dominant sides was not significant (-0.15mm ± 0.25mm, $t=-2.098$, $P=0.06$)

The results for medial elbow joint distance for the younger subjects can be seen in Table 6. In the younger subjects, the mean medial elbow joint space distance on the dominant side was 2.4mm ± 0.64mm, 2.95mm ± 0.71mm (unstressed, valgus-stressed). The mean joint distance on the non-dominant side was 2.34mm ± 0.32mm, 3.1mm ± 0.28mm, demonstrating no significant difference in joint space width between dominant and non-dominant sides with valgus stress (t=0.42, P=0.67). There was a significant increase in joint space (mean difference, 0.65mm $\pm$ $0.21\text{mm}, t{=}2.201, P{=}0.028$) with the applied valgus stress on the dominant side. There was a similar increase (0.73mm $\pm$ $0.04\text{mm}, \text{t} = 2.201, \text{P} = 0.028$) seen on the non-dominant side. The mean flexor tendon difference between dominant and non-dominant sides was -0.35mm ± 0.49mm

	Unstressed	**Valgus-Stress**
Dominant	3.39mm ± 0.96mm	3.92mm ± 1.02mm
Non-Dominant	3.47mm ± 0.87mm	4.04mm ± 1.04mm

Table 4: Medial Elbow Measures for All Subjects

The average (± standard deviation) medial elbow joint space width of the dominant and non-dominant sides with and without valgus stress in all subjects.

	Unstressed	**Valgus-Stress**
Dominant	3.45mm ± 0.93mm	3.96mm ± 0.98mm
Non-Dominant	3.48mm ± 0.79mm	4.08mm ± 1.06mm

Table 5: Medial Elbow Measures for Older Subjects

The average (± standard deviation) medial elbow joint space width of the dominant and non-dominant sides with and without valgus stress in the older subjects (10-13 y/o).

	Unstressed	Valgus-Stress
Dominant	2.40mm ± 0.66mm	2.95mm ± 0.71mm
Non-Dominant	2.38mm + 0.39mm	3.10mm ± 0.28mm

Table 6: Medial Elbow Measures for Younger Subjects

The average (± standard deviation) medial elbow joint space width of the dominant and non-dominant sides with and without valgus stress in the younger subjects (6-7 y/o).

	Dominant	Non-Dominant
Tendon Thickness	3.90mm ± 0.39mm	4.05mm ± 0.43mm

Table 7: Common Flexor Tendon Thickness

The mean (± standard deviation) thickness of the common flexor tendon at the elbow of all subjects.

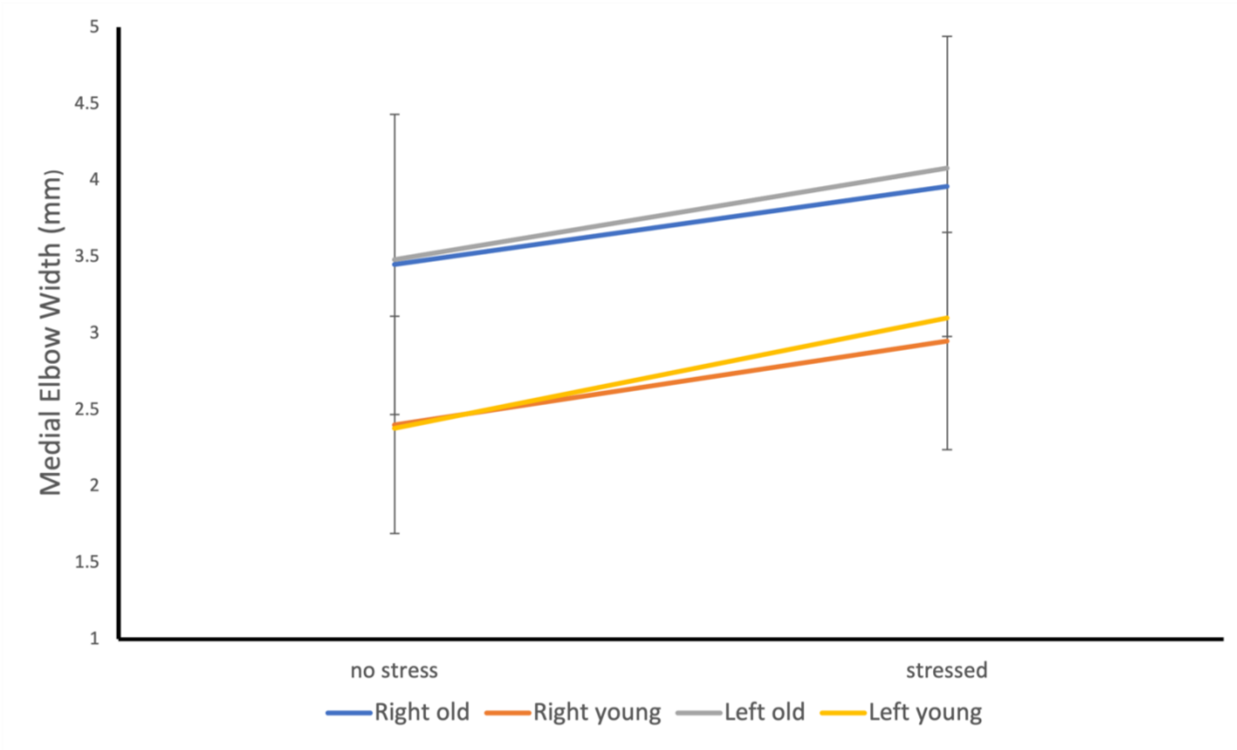

Figure 3: Medial Elbow Joint Width With and Without Valgus Stress

Width of the medial elbow joint space (in mm) from unstressed to stressed positions in the younger (6-7y/o) subjects and older (10-13y/o) subjects (error bars represent standard deviation).

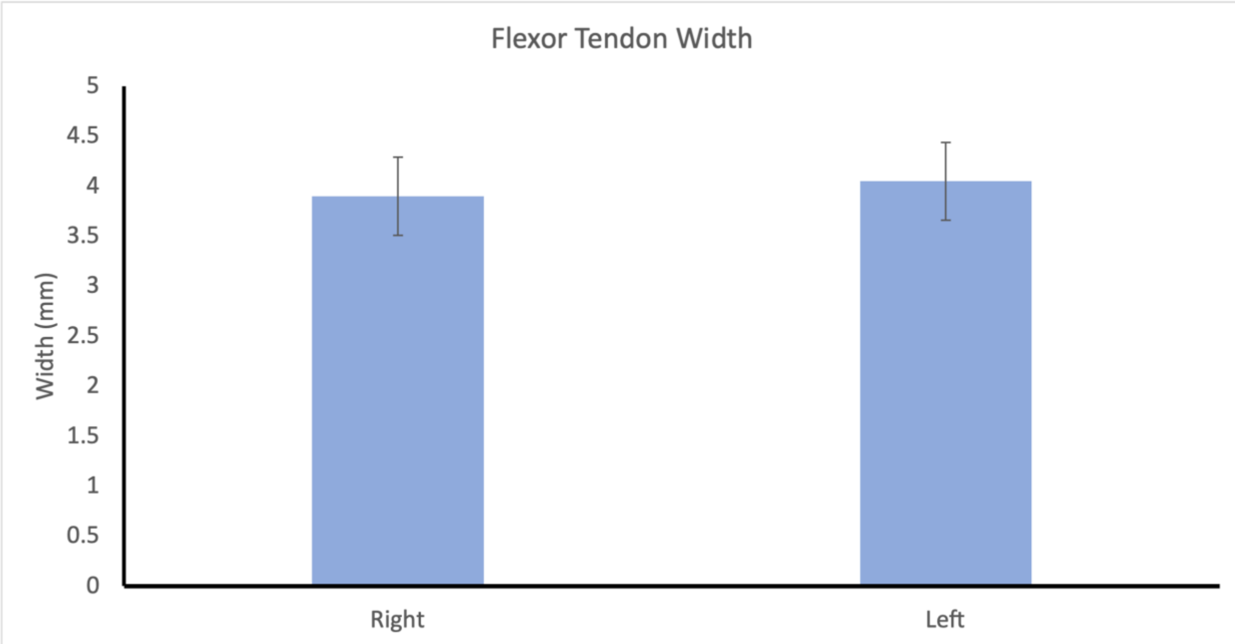

Figure 4: Common Flexor Tendon Thickness

Average thickness of the flexor tendon of the dominant and non-dominant arms (error bars represent standard deviation).

CHAPTER 5

DISCUSSION

The purpose of this study was to determine if we could detect differences in the medial elbow joint space width between the dominant and non-dominant arms and the common flexor tendon thickness in youth baseball/softball players. We measured an increase in the medial elbow joint space width with applied valgus stress. However, there was no significant difference between dominant and non-dominant arms. Our results did not support our alternate hypotheses. We observed no difference in the medial elbow joint space width in the resting position between dominant and non-dominant arms.

The absence of side-to-side difference can be attributed to the subjects' relative lack of exposure to medial elbow stress. The specific adaptations in question are thought to be as a result of accumulated stress over long periods of time.[37] These subjects are relatively new to the sport (mean participation, ± standard deviation; 5.17 ± 3.31 years) and overhead throwing in general. An increased medial elbow joint width has been documented in professional baseball,[7, 33] collegiate,[10] and even high school level athletes,[17, 45, 46] showing that the longer these athletes have been participating in the sport (higher playing age), the greater the magnitude the joint space has shown to increase. Our findings showing no increase of joint space width on the dominant side fit this theory as our subjects were relatively new to throwing sports. Tajika[46] and Sakata[41] examined physical factors of youth athlete's elbow via ultrasonography and reported abnormalities such as instances of osteochondritis dissecans and fragmentation of the epicondylar apophysis (little leaguer's elbow). However, they did not report changes in medial elbow joint space. The absence of difference between elbow joint spaces could be attributed to the subjects' overall inexperience with throwing sports, so it would be expected that their medial elbow has not developed these adaptations.

In the literature, instances of little leaguer's elbow and osteochondritis dissecans are common in youth throwing athletes—much more than medial elbow instability.[41, 46] The prevalence of these abnormalities could result from the forces generated during the throwing motion distributed to anatomical structures other than the UCL in the young elbow, such as immature epiphysial plates, resulting in the literature's abnormalities.

Hattori et al.[17] measured medial elbow joint space width of the dominant arm in high school baseball players. The same method of imaging the medial elbow joint was used in the present study. Their results showed that with the applied valgus stress on the medial elbow, the average width measurement was 5.6mm ± 0.9mm—compared to our measurements of 3.92mm ± 1.02mm.[17] The increased gapping that was measured by Hattori could be due to the average age of their participants being 16.6 years old with an average of 8.8 years of baseball experience. Our participants were much younger with significantly less baseball experience. A greater medial elbow joint space width is expected as players mature and grow as they age. The increased gapping in Hattori's sample may also result from greater amounts of accumulated stress due to greater playing experience than our sample.

Keller et al.[19] conducted a similar study where they used ultrasound imaging to measure medial elbow joint space width and UCL thickness of high school pitchers before and after a season of competition. During the pre-season measurements, the average joint gapping was 3.13mm ± 0.70mm in the unloaded position and 3.87mm ± 1.03mm with the applied valgus load.[19] The given results show slightly smaller medial elbow gapping than our sample's data which is unexpected as the sample in the study done by Keller had an average age of 16.9

compared to the average age being 10.5 in the present study. This difference may be attributed to the measurement protocol used in their study. They measured the subjects while positioned sitting upright in a chair with their shoulder in maximum external rotation and elbow flexed to 30°. The measurements in our study were taken with the subjects lying supine with their elbow flexed to 30°. Subjects in the supine position may be able to relax more than subjects in a seated position, allowing for greater valgus movement in the medial elbow with added stress.

Tajika et al.[45] conducted a similar study examining 132 high school baseball pitchers (age 15-17) using ultrasound imaging and measured medial elbow joint space width at rest and with valgus stress on dominant and non-dominant arms. The authors found a significant increase in joint space width similar to the present study after applying valgus stress on both the dominant and non-dominant arms.[45] Like the present study, the side-side difference between the dominant and non-dominant sides was not significant for the relaxed or valgus-stressed positions.[45] The results found in the current study support the results of Tajika's study.

Sasaki et al.[42] used ultrasound to examine elbow laxity in 30 collegiate baseball players (average age 21.7 years). Using ultrasound to view the medial elbow under gravity-valgus stress, they observed a significant increase in joint space width on the dominant side (2.7mm ±1.4mm) compared to the contralateral side (1.6mm ± 1.4mm).[42] These results show that an increase in medial elbow joint space can be observed in collegiate baseball players, most likely due to the greater time spent participating in the sport than youth players. Their results, however, were smaller in magnitude compared to the results of our study—meaning the joint space width they observed in their collegiate-aged sample was smaller than the width observed in our youth sample. This could be due to the method in which Sasaki gathered their measurements; in their study, they used ultrasound imaging with the subject in a supine position with their elbow at 90°

of flexion. The authors made this decision as they said it more accurately emulated the positioning of the elbow during the throwing motion.[42] However, this examination position is not commonly used among researchers, and may affect the results of their measurements. As the elbow flexes, the ulna's sublime tubercle comes closer to the humerus's trochlea, resulting in a shorter distance between the landmarks. Positioning the elbow in 90° of flexion results in the medial joint space appearing smaller than when measured with the elbow at 30° of flexion like in the present study.

A study examining medial elbow joint space width in professional pitchers using stress radiography was conducted by Ellenbecker et al.[12]They reported a statistically significant increase of 0.32mm on the dominant side compared to the the non-dominant side with valgus stress applied.[12] While statistically significant, this minor increase would be unidentifiable using manual orthopedic laxity tests. These results oppose other authors who examined elbow joint space width of professional baseball players, such as Nazarian et al., who observed increased laxity on pitchers' dominant arms.[33] The use of stress radiography compared to dynamic ultrasound to measure medial elbow joint space could be the source of the discrepancies in the results. Typically, a 0.5mm difference seen using stress radiography is used to differentiate between injured and uninjured conditions regarding medial elbow laxity.[12] This study reported an average increase of 0.34mm in medial joint space gapping, which, considering the sample population was uninjured athletes, falls within and supports the use of the 0.5mm designation for injured patient populations.[12]

As previously mentioned, Nazarian et al.[33] conducted a study in which they used dynamic ultrasound to measure the medial elbow joint space in professional baseball pitchers. The authors reported a non-significant difference in medial elbow joint space between sides at rest, with

2.8mm in the dominant arm and 2.5mm in the non-dominant arm.[33] However, with a valgus stress, the dominant side measurements increased to 4.2mm and 3.0mm in the non-dominant side. Both dominant and non-dominant sides saw an increase in joint gapping with the application of valgus stress. However, the 1.4mm increase on the dominant side compared to the 0.5mm increase on the non-dominant side exhibits a significant increase in the medial elbow laxity of the throwing arm compared to the non-throwing arm of professional pitchers.[33] The authors also measured the thickness of the anterior band of the UCL. They reported an average thickness of 6.3mm in the throwing side and 5.3mm on the non-throwing side, exhibiting the adaptations that develop in response to repetitive chronic stress, which is expected in a sample of professional pitchers.[33]

There was no difference in thickness of the flexor tendon between dominant and non-dominant arms in the current study. According to a study by Pexa et al,[38] the wrist flexor muscles play a role in maintaining elbow stability when a valgus force is applied to the medial elbow. The contraction of these muscles creates a varus moment, decreasing the width of the medial joint space. This serves as a stabilizing force to counteract the immense valgus force applied during the throwing motion's acceleration phase. It would be expected in an experienced baseball pitcher to see an increase in the thickness of the flexor tendon as an adaptation to repetitive loads, however our results do not support such findings. This may be credited to the inexperience of our sample population. Our subjects have not participated in throwing sports for enough time to accumulate that repetitive load. Therefore they do not exhibit these adaptations.

This study supports the theory that increased laxity of the dominant elbow in throwing athletes is directly correlated with the amount of time an individual has spent participating in throwing sports. Tajika et al.[46] identified multiple risk factors for elbow pain in youth throwers, including age >11 years and height > 150cm (~5ft). Sakata et al.[41] also identified increased age as a risk factor for developing elbow pain and the position one plays—pitchers have a higher risk for elbow pain than non-pitchers. Pytiak et al.[40] documented that youth athletes who participate in year-round baseball also have a higher risk of developing medial elbow abnormalities such as little leaguer's elbow. These risk factors support the theory that repetitive stress applied to the UCL and the medial elbow result in adaptations to these structures that predispose athletes to injury later in their career.

The current study demonstrated no difference in medial elbow joint space width between dominant and non-dominant arms in youth baseball/softball players. We observed an increase in joint space on both sides under the applied valgus stress, however there was no difference between sides. According to our data, the adaptations to throwing under focus during this study were not present in our sample of youth throwing athletes; however, these adaptations have been well documented in professional, collegiate, and even high school level throwing athletes. We know these changes are not present in youth throwers, so when do they develop? Another question of interest is how does a bout of throwing acutely affect medial elbow stability?

In the study conducted by Hattori et al., medial joint space width was measured in high school-aged pitchers during and after a pitching protocol of 100 pitches. The authors reported an increase in joint space width as more pitches were thrown: 6.0mm after 20 pitches, 6.2mm after 40, 6.4mm after 60, 6.7mm after 80, and 7.0 after 100.[17] These results exhibit the effect that fatigue and acute stress have on the stability of the medial elbow. It is important to consider how long these acute changes take to resolve. Khalil et al.[21] measured elbow joint space in the throwing arms of 11 collegiate pitchers after a season of play and then again before the upcoming season. They found that both UCL thickness and medial elbow joint space were significantly increased after a season of play compared to pre-season baselines.[21] However, after the off-season rest period, both measures returned to the pre-season baseline.[21] Further, Millard et al.[31] found that when the wrist flexor muscles were fatigued, the medial elbow exhibited increased laxity during a valgus stress test. Combining the results of these studies with the knowledge that increased elbow laxity increases the risk of an acute elbow injury, we can support the implementation of injury prevention strategies in youth baseball/softball, such as pitching limits.

According to Fleisig[15] and Sakata[41] the number one risk factor for elbow injury in youth baseball players is the number of throws they conduct per day. The previously mentioned studies by Hattori, Millard, and Khalil support this.[17, 21, 31] Considering our results show that increased elbow laxity is not present in youth throwers, these injury prevention strategies must be monitored and enforced by leagues, coaches, and parents to ensure the risk of elbow injury is minimized in the youth throwing athlete.

There were several limitations to this study. First, our convenience sample of 14 youth throwers puts a strain on applying our results. Our pilot data gathered previously determined that with 25 subjects, our measures' reliability would be moderate and have a standard error of 0.2mm and a minimal detectable change of 0.16mm. With only having 14 subjects to measure, it is expected that those values are higher. It is also more difficult to apply our findings to the general population of youth throwing athletes. Secondly, our sample population was relatively heterogeneous in that they had different levels of experience in throwing sports, a wide age range, and a wide range of height/weight. These disparities further complicate the applicability of our results to youth populations as a whole.

CONCLUSION

Following a bilateral comparison of the medial elbow joint space width and flexor tendon thickness in youth throwing athletes, no significant difference was observed between the dominant and non-dominant arms with and without applied valgus stress. Also, no difference in the thickness of the flexor tendon was observed. It is expected that there would be no difference as youth throwing athletes have relatively little long-term experience with overhead throwing. Considering our results show increased elbow laxity is not present in the dominant arm of youth throwing athletes, it is vital that injury prevention measures such as pitch counts are strictly monitered by leagues, coaches, and parents to minimize the risk of medial elbow injuries. Further research that includes more subjects is needed in order to apply results to general youth throwing athlete populations. Following up with these athletes on a yearly basis may provide a more precise timeline for when the adaptations to throwing begin to develop on the life cycle of throwing athletes.

REFERENCES

1. Agresta CE, Krieg K, Freehill MT. Risk Factors for Baseball-Related Arm Injuries: A Systematic Review. *Orthop J Sports Med.* 2019;7(2):2325967119825557.

2. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med.* 2009;37(10):2043-2048.

3. Andrade MS, de Carvalho Koffes F, Benedito-Silva AA, da Silva AC, de Lira CA. Effect of fatigue caused by a simulated handball game on ball throwing velocity, shoulder muscle strength and balance ratio: a prospective study. *BMC Sports Sci Med Rehabil.* 2016;8:13.

4. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med.* 2010;38(7):1368-1374.

5. Beaton DE, Wright JG, Katz JN, Upper Extremity Collaborative G. Development of the QuickDASH: comparison of three item-reduction approaches. *J Bone Joint Surg Am.* 2005;87(5):1038-1046.

6. Calabrese GJ. Pitching mechanics, revisited. *Int J Sports Phys Ther.* 2013;8(5):652-660.

7. Ciccotti MG, Atanda A, Jr., Nazarian LN, Dodson CC, Holmes L, Cohen SB. Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study. *Am J Sports Med.* 2014;42(3):544-551.

8. Cinque ME, Schickendantz M, Frangiamore S. Review of Anatomy of the Medial Ulnar Collateral Ligament Complex of the Elbow. *Curr Rev Musculoskelet Med.* 2020;13(1):96-102.

9. Conte SA, Fleisig GS, Dines JS, et al. Prevalence of Ulnar Collateral Ligament Surgery in Professional Baseball Players. *Am J Sports Med.* 2015;43(7):1764-1769.

10. DeFroda SF, Goodman AD, Gil JA, Owens BD. Epidemiology of Elbow Ulnar Collateral Ligament Injuries Among Baseball Players: National Collegiate Athletic Association Injury Surveillance Program, 2009-2010 Through 2013-2014. *Am J Sports Med.* 2018;46(9):2142-2147.

11. DeMoss A, Millard N, McIlvain G, Beckett JA, Jasko JJ, Timmons MK. Ultrasound-Assisted Assessment of Medial Elbow Stability. *J Ultrasound Med.* 2018;37(12):2769-2775.

12. Ellenbecker TS, Mattalino AJ, Elam EA, Caplinger RA. Medial elbow joint laxity in professional baseball pitchers. A bilateral comparison using stress radiography. *Am J Sports Med.* 1998;26(3):420-424.

13. Erb J, Sherman H, Williard S, Bui J, Kachingwe A. Ultrasound study of elbow ulnar collateral ligament changes in collegiate baseball players: A pilot study. *J Bodyw Mov Ther.* 2017;21(2):259-266.

14. Fess E. Grip Strength. In: Therapists ASoH, ed. *Clinical Assessment Recommendations*. Chicago, IL: American Society of Hand Therapists; 1992:41-45.

15. Fleisig GS, Weber A, Hassell N, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Curr Sports Med Rep.* 2009;8(5):250-254.

16. Glousman RE, Barron J, Jobe FW, Perry J, Pink M. An electromyographic analysis of the elbow in normal and injured pitchers with medial collateral ligament insufficiency. *Am J Sports Med.* 1992;20(3):311-317.

17. Hattori H, Akasaka K, Otsudo T, Hall T, Amemiya K, Mori Y. The effect of repetitive baseball pitching on medial elbow joint space gapping associated with 2 elbow valgus stressors in high school baseball players. *J Shoulder Elbow Surg.* 2018;27(4):592-598.

18. Karbach LE, Elfar J. Elbow Instability: Anatomy, Biomechanics, Diagnostic Maneuvers, and Testing. *J Hand Surg Am.* 2017;42(2):118-126.

19. Keller RA, Marshall NE, Bey MJ, et al. Pre- and Postseason Dynamic Ultrasound Evaluation of the Pitching Elbow. *Arthroscopy.* 2015;31(9):1708-1715.

20. Kendall F, McCreary EK, Provance PG. *Muscles testing and function*. Baltimore, MD: Williams and Wilkins; 1993.

21. Khalil LS, Okoroha KR, Jildeh TR, et al. Do anatomic changes found in the throwing arm after a season of pitching resolve with off-season rest? A dynamic ultrasound study. *JSES Open Access.* 2019;3(4):338-343.

22. Kim JK, Park MG, Shin SJ. What is the minimum clinically important difference in grip strength? *Clin Orthop Relat Res.* 2014;472(8):2536-2541.

23. Konin GP, Nazarian LN, Walz DM. US of the elbow: indications, technique, normal anatomy, and pathologic conditions. *Radiographics.* 2013;33(4):E125-147.

24. Labott JR, Aibinder WR, Dines JS, Camp CL. Understanding the medial ulnar collateral ligament of the elbow: Review of native ligament anatomy and function. *World J Orthop.* 2018;9(6):78-84.

25. London DA, Stepan JG, Boyer MI, Calfee RP. Performance characteristics of the verbal QuickDASH. *J Hand Surg Am.* 2014;39(1):100-107.

26. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* 2009;39(2):90-104.

27. Lynch JR, Waitayawinyu T, Hanel DP, Trumble TE. Medial collateral ligament injury in the overhand-throwing athlete. *J Hand Surg Am.* 2008;33(3):430-437.

28. McDonald AC, Mulla DM, Keir PJ. Muscular and kinematic adaptations to fatiguing repetitive upper extremity work. *Appl Ergon.* 2019;75:250-256.

29. Melugin HP, Leafblad ND, Camp CL, Conte S. Injury Prevention in Baseball: from Youth to the Pros. *Curr Rev Musculoskelet Med.* 2018;11(1):26-34.

30. Mendez-Rebolledo G, Gatica-Rojas V, Guzman-Munoz E, Martinez-Valdes E, Guzman-Venegas R, Berral de la Rosa FJ. Influence of fatigue and velocity on the latency and recruitment order of scapular muscles. *Phys Ther Sport.* 2018;32:80-86.

31. Millard N, DeMoss A, McIlvain G, Beckett JA, Jasko JJ, Timmons MK. Wrist Flexion Exercise Increases the Width of the Medial Elbow Joint Space During a Valgus Stress Test. *J Ultrasound Med.* 2019;38(4):959-966.

32. Mulla DM, McDonald AC, Keir PJ. Upper body kinematic and muscular variability in response to targeted rotator cuff fatigue. *Hum Mov Sci.* 2018;59:121-133.

33. Nazarian LN, McShane JM, Ciccotti MG, O'Kane PL, Harwood MI. Dynamic US of the anterior band of the ulnar collateral ligament of the elbow in asymptomatic major league baseball pitchers. *Radiology.* 2003;227(1):149-154.

34. Nicholettos A, Barcellona MG, Morrissey MC. The immediate effects of open kinetic chain knee extensor exercise at different loads on knee anterior laxity in the uninjured. *Knee.* 2013;20(6):500-504.

35. Ochi K, Iwamoto T, Saito A, et al. Construct validity, reliability, response rate, and association with disease activity of the quick disabilities of the arm, shoulder and hand questionnaire in the assessment of rheumatoid arthritis. *Mod Rheumatol.* 2014:1-5.

36. Park MC, Ahmad CS. Dynamic contributions of the flexor-pronator mass to elbow valgus stability. *J Bone Joint Surg Am.* 2004;86(10):2268-2274.

37. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am J Sports Med.* 2004;32(5):1158-1164.

38. Pexa BS, Ryan ED, Myers JB. Medial Elbow Joint Space Increases With Valgus Stress and Decreases When Cued to Perform A Maximal Grip Contraction. *Am J Sports Med.* 2018;46(5):1114-1119.

39. Post EG, Laudner KG, McLoda TA, Wong R, Meister K. Correlation of Shoulder and Elbow Kinetics With Ball Velocity in Collegiate Baseball Pitchers. *J Athl Train.* 2015;50(6):629-633.

40. Pytiak AV, Stearns P, Bastrom TP, et al. Are the Current Little League Pitching Guidelines Adequate? A Single-Season Prospective MRI Study. *Orthop J Sports Med.* 2017;5(5):2325967117704851.

41. Sakata J, Nakamura E, Suzukawa M, Akaike A, Shimizu K. Physical Risk Factors for a Medial Elbow Injury in Junior Baseball Players: A Prospective Cohort Study of 353 Players. *Am J Sports Med.* 2017;45(1):135-143.

42. Sasaki J, Takahara M, Ogino T, Kashiwa H, Ishigaki D, Kanauchi Y. Ultrasonographic assessment of the ulnar collateral ligament and medial elbow laxity in college baseball players. *J Bone Joint Surg Am.* 2002;84(4):525-531.

43. Shukla DR, Golan E, Nasser P, Culbertson M, Hausman M. Importance of the posterior bundle of the medial ulnar collateral ligament. *J Shoulder Elbow Surg.* 2016;25(11):1868-1873.

44. Slowik JS, Aune KT, Diffendaffer AZ, Cain EL, Dugas JR, Fleisig GS. Fastball Velocity and Elbow-Varus Torque in Professional Baseball Pitchers. *J Athl Train.* 2019;54(3):296-301.

45. Tajika T, Oya N, Ichinose T, et al. Relationship between the elbow joint valgus instability and forearm flexor muscle strength in high school pitchers with and without symptom. *J Orthop Surg (Hong Kong).* 2019;27(1):2309499019832664.

46. Tajika T, Yamamoto A, Oya N, et al. The morphologic change of the ulnar collateral ligament of elbow in high school baseball pitchers, with and without symptoms, by sonography. *J Shoulder Elbow Surg.* 2016;25(8):1223-1228.

47. Veeger HE, van der Helm FC. Shoulder function: the perfect compromise between mobility and stability. *J Biomech.* 2007;40(10):2119-2129.

48. Yoshida M, Goto H, Takenaga T, et al. Anterior and posterior bands of the anterior bundle in the elbow ulnar collateral ligament: ultrasound anatomy. *J Shoulder Elbow Surg.* 2017;26(10):1803-1809.

APPENDIX A: OFFICE OF RESEARCH INTEGRITY APPROVAL LETTER AND ANNUAL UPDATE LETTER

MARSHALL UNIVERSITY

March 16, 2020

Mark Timmons, PhD
School of Kinesiology

RE: IRBNet ID# 1566840-1
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title:	[1566840-1] Ultrasound Evaluation of the Elbows and Shoulders of Young Throwing Athletes.	
Site Location:	MU	
Submission Type:	New Project	APPROVED
Review Type:	Expedited Review	

In accordance with 45CFR46.110(a)(4),(6),&(7), the above study was granted Expedited approval today by the Marshall University Institutional Review Board #1 (Medical) Chair. An annual update will be required on March 13, 2021 for administrative review and approval. The update must include the Annual Update Form and current educational certificates for all investigators involved in the study. All amendments must be submitted for approval by the IRB Chair prior to implementation and a closure request is required upon completion of the study.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Bruce Day, ThD, CIP at 304 696-4303 or day50@marshall.edu. Please include your study title and reference number in all correspondence with this office.

Sincerely,

Bruce F. Day, ThD, CIP
Director, Office of Research Integrity

March 8, 2021

Mark Timmons, PhD
School of Kinesiology, Marshall University

RE: IRBNet ID# 1566840-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. timmons:

Protocol Title:	[1566840-2] Ultrasound Evaluation of the Elbows and Shoulders of Young Throwing Athletes.	
Next Annual Report Due:	March 13, 2022	
Site Location:	MU	
Submission Type:	Annual Update	APPROVED
Review Type:	Administrative Review	

The annual update report for the above listed study was approved today by the IRB Coordinator. The next annual report will be due on March 13, 2022. The annual report must be submitted prior to the due date in order to continue with the research. A closure package must be submitted upon completion of the study.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Margaret Hardy at (304) 696-6322 or hardyma@marshall.edu. Please include your study title and reference number in all correspondence with this office.

Sincerely,

Bruce F. Day, ThD, CIP
Director, Office of Research Integrity

APPENDIX B: PARENTAL CONSENT FORM

Marshall University
Parental Consent to Participate in a Research Study

Ultrasound Evaluation of the Elbows and Shoulders of Young Throwing Athletes.

Mark Timmons, PhD, Principal Investigator

Approved on:	3/13/20
Study number:	1566840

Marshall University IRB

Key Information

Your child is invited (with your permission) to participate in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. Your child may or may not receive any benefit from being part of the study. Your child's participation is voluntary. Please take your time to make your decision, and ask your research investigator or research staff to explain any words or information that you do not understand. The following is a short summary to help you decide why you may or may not want to allow your child to be a part of this study. Information that is more detailed is listed later on in this form. The purpose of the study is use ultrasound imaging to study the structure of the shoulders and elbows of young people that play baseball or softball. Your child will be asked to sit or lay down while several ultrasound images are taken of their shoulders or elbows. We expect that your child will be in this research study for about 30 minutes. The primary risk of participation is that the positions your child's arm will be placed in might be uncomfortable.

How Many People Will Take Part In The Study?

About 30 children will take part in this study. A total of 60 children are the most that would be able to enter the study.

What Is Involved In This Research Study?

Your child will be asked to complete (with your help if needed) a few short forms that will ask questions about your child's shoulders and arms. These form will not include your child's name, a number that we assign will identify your child's records. These forms will help us determine the level of function of your child's arm and if there are symptoms of elbow or shoulder injury. We will measure your child's height and weight. We will perform a test to assess the motion of your child's shoulder blade. Your child will raise and lower their arms several times while we watch the motion of their shoulder blade. We will then use small hand held devices to make several measurements of your child's arm length, wrist circumference, strength (arm, grip, and shoulder) and shoulder range of motion. After these measurements, we will use an ultrasound machine to make several images of the shoulder and elbow of both arms of your child.

Parent's Initials ________

What Are Your Rights As A Research Study Participant?

You may choose not to allow your child to take part or you may have your child 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 your child is entitled. If you decide to stop your child's participation in the study, we encourage you to talk to the investigators or study staff first.

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

Detailed Risks of the Study

There are minimal risks associated with this study. You child's arm will be placed in several different positions while the ultrasound imaging is completed. Their arm will be in these positions for a very short period (about 30 seconds). If the positon is, too uncomfortable, slight adjustments can be made to make it imaging more comfortable. During the strength, testing your child will be asked to perform, several maximum contractions of their arm muscles, these contractions might lead to feelings of slight muscle fatigue similar to the feelings during exercise. The feeling of fatigue will last only a few minutes.

What about Confidentiality?

We will do our best to make sure that your child's personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law says we must keep your child's study records private. Nevertheless, under unforeseen and rare circumstances, we may be required by law to allow certain agencies to view your child's records. Those agencies would include the Marshall University IRB, Office of Research Integrity (ORI) and the federal Office of Human Research Protection (OHRP). This is to make sure that we are protecting your child's rights and safety. If we publish the information, we learn from this study, your child 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 your child's participation in this study. All the study costs, including any study tests, supplies and procedures related directly to the study, will be paid for by the study.

Will You Be Paid For Participating?

You will receive no payment or other compensation for your child's participation in this study.

Parent's Initials ________

Who Is Sponsoring This Study?

The Marshall University School of Kinesiology is sponsoring this study. The sponsor is providing money or other support to help conduct this study. The researchers do not; hold a direct financial interest in the sponsor or the product being studied.

What About Identifiable Private Information or Identifiable Biospecimens?

Your child's information collected as part of the research, even if identifiers are removed, will not be used or distributed for future research studies.

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 Timmons 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 and/or your child's rights as a research participant, contact the Marshall University Office of Research Integrity (ORI) at (304) 696-4303. 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.

SIGNATURES

You grant permission for your child ________________________________take part in this study. You have had a chance to ask questions about this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you or your child are entitled.

____
Parent Name (Printed)

____ _________________
Parent Signature Date

____
Person Obtaining Consent (Printed)

____ _________________
Person Obtaining Consent Signature Date

Parent's Initials ________

APPENDIX C: MINOR ASSENT FORM

Marshall University
Child's Assent for being in a Research Study

Marshall University IRB

Approved on:	3/13/20
Study number:	1566840

Title: Ultrasound Evaluation of the Elbows and Shoulders of Young Throwing Athletes.

Why are you here?

We are asking you to take part in a research study because we are trying to learn more about the structure of the arms of young people that play baseball or softball. We are inviting you to be in the study because you play baseball or softball

Why are they doing this study?

The structure of the arm might have something to do with how the arms of throwers are injured.

What will happen to you?

You will be asked to fill out some forms with your parents help if you want. We will then measure your arm strength and motion of your arm. Then we will use an ultrasound, looks like a computer, to make images of your arm.

Will the study hurt?

When we take the images we will put your arm in different positions, some of these positions might hurt a little. If the positions hurts let us know. We can move your arm if it hurts too much. When we test your strength, your muscles might feel a little tried for a minute.

Will the study help you?

You will not be helped right away from this study. The information will help us know more about the arms of baseball and softball players.

Initials ________

<u>What if you have any questions?</u>

You can ask any questions that you have about the study. If you have a question later that you didn't think of now, you can call me (304) 696-2925 or ask me next time.

<u>Do your parents know about this?</u>

This study was explained to your parents and they said that you could be in it if you want. You can talk this over with them before you decide.

<u>Do you have to be in the study?</u>

You do not have to be in the study. No one will be upset if you don't want to do this. If you don't want to be in this study, you just have to tell them. You can say yes now and change your mind later. It's up to you.

Putting a checkmark by the word YES and writing your name after that means that that you agree to be in the study, and know what will happen to you. If you decide to quit the study, all you have to do is tell the person in charge.

You have talked to your parents and the researcher about the study. You have had all of your questions answered. You understand that you can withdraw from this study at any time and no one will be angry or upset with you. Indicate your choice below:
(Check One)

____**YES**, you want to be in the study. ____**NO**, you do not want to be in the study.

____________________________ ____________________________ ___________
Name of Child *(Print)* Signature of Child Date

____________________________ ____________________________ ___________
Name of Witness *(Print)* Signature of Witness Date

____________________________ ____________________________ ___________
Name of Researcher *(Print)* Signature of Researcher Date

Initials ________

APPENDIX D: DATA COLLECTION FORM

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

Data Collection Forms

Ultrasound Evaluation of the Elbows and Shoulders of Young Throwing Athletes.

Procedure Checklist

1. Inclusion & exclusion criteria
   a. Eligibility Screening exam
2. Subject Informed Consent
   a. Read, discuss, ask questions, sign
3. General Questions
   a. Intake information
   b. Patient reported outcomes (PASS)
   c. Height , Weight
   d. Arm length
   e. Wrist circumference
   f. posture assessment
4. Clinical Evaluation
5. Strength Procedure
   a. ER
   b. IR
   c. ABd
   d. Grip strength
6. Ultrasound Imaging

Inclusion Criteria

1. Active in organized youth baseball or softball
2. Less than 18 years of age
3. Ability to sit still for up to 5 minutes

Exclusion Criteria (Any 1 excludes)

1. Equal to or greater than 18 years of age.
2. Less than 6 years of age
3. Shoulder or elbow pain $\geq 7/10$
4. Shoulder or elbow surgery
5. Arm, rib and shoulder fractures within past year
6. Greater than 50% loss of shoulder or elbow range of motion

Participant meets inclusion/exclusion criteria (circle one):
1= Yes, continue **2= No**, stop

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

Research Study Questionnaire
Participant completes:

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

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

1. **Have you had a major injury in the past year?**

   (Circle One) 1 = Yes 2 = No

2. **Do you currently have shoulder pain?**

   (Circle One) 1 = Yes 2 = No

   If yes, how would you rate the pain?
   (0 = no pain at all, 10 = the worst pain) _________________

3. **Do you currently have elbow pain?**

   (Circle One) 1 = Yes 2 = No

   If yes, how would you rate the pain?
   (0 = no pain at all, 10 = the worst pain) _________________

4. **How old were you when you start playing softball or baseball? _______**

5. **Which hand do you use to throw a ball?**

   1 = Right
   2 = Left
   3 = Ambidextrous

6. **Which of the following best describes your sport?**
   1. I play softball
   2. I play baseball
   3. I play both baseball and softball

7. **Which of the following is your main fielding position?**
   1. Outfield
   2. Infield
   3. Catcher
   4. Pitcher
   5. I do not play the field

8. **Which of the following is your second fielding position?**
   1. Outfield
   2. Infield
   3. Catcher
   4. Pitcher
   5. I do not play the field

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

Screening Exam
Research Team completes

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

Posture assessment	measure 1	measure 2
T1-T3 angle	____________	____________
T10-T12 angle	____________	____________

Wrist Circumference	Right	Left
Trial 1 (cm)	____________	____________
Trial 2 (cm)	____________	____________

Arm Length

Upper arm	Right	Left
Trial 1 (cm)	____________	____________
Trial 2 (cm)	____________	____________
Lower arm	Right	Left
Trial 1 (cm)	____________	____________
Trial 2 (cm)	____________	____________

Shoulder PROM:	Right	Left
ER	____________	____________
IR	____________	____________
Abduction	____________	____________
Flexion	____________	____________
Hort. Flex	____________	____________

Elbow PROM:	Right	Left
Flexion	____________	____________
Extension	____________	____________
Pronation	____________	____________
Supination	____________	____________

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

Cervical motion reproduces shoulder pain: Yes No

Right lateral flex ____________
Left lateral flex ____________
Flexion ____________
Extension ____________
Right rotation ____________
Left rotation ____________

Force, Pain

Trial	LEFT		RIGHT	
	Pain (0-10)	Force (lbs.)	Pain (0-10)	Force (lbs.)
ER 1				
IR 1				
ABD 1				
SA 1				
ER 2				
IR 2				
ABD 2				
SA 2				
Grip 2_1				
Grip 2_2				
Grip 3_1				
Grip 3_2				
Wr ext 1				
Wr flex 1				
Wr ext 2				
Wr flex 2				
LT 1				
MT 1				
LT 2				
LT 2				

Scapular Dyskinesia Test, External load, 0 lbs. 3 lbs. (BW < 68.2kg, 150lbs), 5 lbs. (BW >68.2kg, 150)

<u>Left</u>

Flexion	Normal	Subtle	Obvious
Classification	Winging	Shrugging	Dumping

<u>Right</u>

Flexion	Normal	Subtle	Obvious
Classification	Winging	Shrugging	Dumping

US Imaging Shoulder & Elbow Characteristics

Right Shoulder File name (on US machine): ____________________________

Bicep tendon cross section (arm on thigh, mm) **Image 1** **Image 2**

Right shoulder, image# ________ ______ ______

Supraspinatus Tendon Images B-mode, modified Crass position

Tendon x-section thickness in mm (thickest portion): **Image 1** **Image 2**

Right shoulder, image# _______ ______ ______

Tendon longitudinal thickness in mm **Image 1** **Image 2**

Right shoulder, image# _______ ______ ______

Acromial Humeral Distance

Right shoulder (posterior, mm) **Image 1** **Image 2**

Arm at 0°, image# __________ ______ ______

Arm at 60°, image# _________ ______ ______

Image 1 **Image 2**

Right Humeral Torsion Angle, image# ________ ______ ______

Left Shoulder File name (on US machine): ______________________________

Bicep tendon cross section (arm on thigh, mm) **Image 1** **Image 2**

Left shoulder, image# ___ ______ ______

Supraspinatus Tendon Images B-mode, modified Crass position

Tendon x-section thickness in mm (thickest portion): **Image 1** **Image 2**

Left shoulder, image# _________ ______ ______

Tendon longitudinal thickness in mm **Image 1** **Image 2**

Left shoulder, image# _________ ______ ______

Acromial Humeral Distance

Left shoulder (posterior, mm) **Image 1** **Image 2**

Arm at 0°, image# _________ ______ ______

Arm at 60°, image# ________ ______ ______

Image 1 **Image 2**

Left Humeral Torsion Angle, image# _________ ______ ______

Right Elbow File name (on US machine): _______________________________

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

Stress Test (UNSTRESSED): **Image 1** **Image 2**

Joint Space Width (mm) ______ _____ ______ _____

Stress Test (STRESSED): **Image 1** **Image 2**

Joint Space Width (mm) ______ _____ ______ _____

Flexor Tendon Thickness **Image 1** **Image 2**

Thickness (mm) ______ _____ ______ _____

Left Elbow File name (on US machine): _________________________

Stress Test (UNSTRESSED): **Image 1** **Image 2**

Joint Space Width (mm) ______ _____ ______ _____

Stress Test (STRESSED): **Image 1** **Image 2**

Joint Space Width (mm) ______ _____ ______ _____

Flexor Tendon Thickness **Image 1** **Image 2**

Thickness (mm) ______ _____ ______ _____