SOFT TISSUE CHARACTERISTICS ASSOCIATED WITH REPETITIVE OVERHEAD THROWING IN AN ADOLESCENT POPULATION AND THEIR RELATION TO UPPER EXTREMITY COMPLAINTS

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YOUTH AND ADOLESCENT RISK FACTOR ANALYSIS THROUGH QUANTITATIVE ULTRASOUND AND THEIR RELATION TO UPPER EXTREMITY COMPLAINTS

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Shoulder and elbow pathology in the youth and adolescent pitcher has been a long standing and pervasive phenomenon. Recently there has been a dramatic rise in the incidence of adolescent throwing injuries as a result of the ever increasingly competitive environment of youth sports and the frequent involvement in year-round participation. Existing guidelines have not been universally accepted by all organizations and there are some who hold long standing beliefs on proper pitching practices that may or may not coincide with the current best evidence. Identification of real-time tendon characteristics using quantitative ultrasound (QUS) opens another avenue for discovery of specific tissue behaviors and risk factors based on objective data. This is a novel application of a technology that in the past for this population has only been used to identify existing abnormalities and bone structure but not real-time tendon changes in response to pitching. We developed a protocol to reliably measure the infraspinatus (INF) tendon that showed moderate to high intra-rater reliability and used an existing method to examine the LHB. Among healthy, uninjured youth and adolescent baseball pitchers we found significant tendon width changes that occurred within 50 pitches, with side to side differences noted in the INF tendon. No single QUS finding was significantly predictive of experiencing an upper extremity complaint, however strong trends were noted for having a larger LHB and INF tendons. Correlational analysis showed that specific strength

parameters were significantly related to having a larger LHB and may be used to identify those who are greater risk. Larger INF tendons showed a tendency to have a protective effect in terms of upper extremity complaints and were shown to be significantly related to physical maturation and ball velocity. Information related to normalized strength were also determined and can serve as comparative data in the clinical setting. Application of the QUS methods may help to identify early signs of upper extremity pathology, and along with other risk factor information may be applied at the individual level to reduce the incidence of throwing related injuries.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1.0 INTRODUCTION

1.1 MOTIVATION

Baseball is one of the most popular and widely participated in sports in the United States, with estimates of greater than 4.5 million participants between the ages of 5 and 14 yrs each year.[1] As with any sport or recreational activity, participation comes with risk of injury or harm. Although catastrophic injury rates in baseball are low, overuse injuries of the upper extremity are seen with alarming regularity. Shoulder and elbow pain in youth and adolescent baseball is a well-recognized phenomenon.[2-7] Since the establishment of organized youth baseball programs, young arms have been vulnerable to the risk for injury associated with excessive throwing. More recently, youth baseball has seen a striking rise in year-round participation, single-sport specialization, increased exposure from play in multiple leagues, and performances in showcases,[5,6] all of which may result in repetitive strain and overuse injuries.

Recommendations to limit pitching in youth baseball date back to the mid 1960's,[8] early rules and regulations were aimed at limiting the number of innings pitched per week. However, in 1977, Slager[9] suggested limiting pitches thrown rather than innings pitched. By the mid-1990's, most experts believed that limitations should be on the number of pitches, not the number of innings pitched.[10] The USA Baseball Medical & Safety Advisory Committee (USAB-MSAC) commissioned the American Sports Medicine Institute (ASMI) to investigate pitch limits along with additional risk factors with a survey to baseball experts.[10] Conclusions included that the number of pitches thrown is a more important risk factor than the number of innings pitched and that the maximum number of pitches allowed should increase with age.[10] Subsequent studies have come to similar conclusions[2-4,11] and identified the number of pitches thrown as the more important variable to limit. Today, the USAB-MSAC,[12] along with the ASMI,[13] Little League Baseball & Softball,[14] and Baseball Canada[15] all have recommendations on pitching limitations based on pitch counts.

The investigations to be presented have provided players, parents, coaches, and organizations with information on the most current safety recommendations. However, none of these studies reviewed have investigated the link between pitching and acute changes in the tendons of the throwing shoulder, nor do they contain clinical data showing the immediate effects of pitching on tendons in the shoulder. Quantitative ultrasound (QUS) will allow us to investigate this area and will likely lead to new insights as to risk factors for injury. If successful, QUS could be paired with biomechanics work, pre-season training work-load goal setting, or predictive study designs to most specifically provide guidelines for safe training and play. Improved injury prevention measures aimed at reducing the accumulated stress placed on the shoulder are desperately needed. They would allow safer participation with lower risk of pathology. The overall goal of this research study is to determine the changes within the tendons of the throwing shoulder during a pitching performance and to correlate the tissue changes to the volume of pitches thrown, participant characteristics, pitch speed and shoulder pain and injury. The proposed work is innovative in its use of QUS to provide immediate clinical information of a real sports activity. Greater knowledge of the acute effects on soft tissue will allow earlier identification of those most at risk leading to more appropriate restrictions on pitch counts and allowing safe participation in both the short and long term.

1.2 SHOULDER INJURIES IN PITCHERS

Recent epidemiological studies of American youth and high school baseball players have found an incidence of shoulder pain in anywhere from 26.5%[16] to 35%[2,3] of pitchers every season. In addition to the seasonal incidence of shoulder pain, another study reported individual pitching performances resulted in shoulder pain over 9% of the time.[2] Furthermore, serious injury resulting in surgery or retirement from baseball in those who start pitching at 9 – 14 years old when followed for a 10 year period was found to have an incidence of 5% in a prospective longitudinal study.[4] As pitchers age and develop, the risk for injury to the throwing shoulder increases,[17] and expert consensus opinion is that many of the pitching injuries that require surgery or medical attention at older, higher levels of competition result from cumulative microtrauma that initially started at the youth baseball level.[7] Injury data from multiple studies in college and professional baseball suggest that most shoulder and elbow injuries are related to throwing and, in particular, the act of pitching.[18]

Economically, injuries related to youth baseball are substantial.[19] When considering the economic burden secondary to both acute and overuse baseball injuries, costs include resources at the medical, financial, and human resource level[20] and can be examined as direct, indirect, and unquantifiable costs.[21] Miller et al[21] went on to delineate direct costs as those from emergency room services, hospital visits, physician visits, physical therapy, and medicine. Indirect cost were defined as those related to lost wages of parents, use of loss of benefits, and lost productivity at work. Unquantifiable costs can be considered related to the individual or the family's psychological well-being after an injury.[21] Additionally, the costs described may have long-term consequences on the musculoskeletal system, which can lead to reduced levels of physical activity as the child ages.[19] According to a critical review in 2006 by Caine et al,[19] youth baseball injuries, for those age 0 – 14 years, accounted for an average total cost, in 1998 United States Dollars, of $3,017,473,669 of which $476,281,548 (nearly 16%) was related to work loss.

1.3 RISK FACTORS FOR INJURY

1.3.1 Youth Pitchers Compared with Skeletally Mature Pitchers

Increasing age and skeletal development are associated with a shift in which anatomical structures in the throwing shoulder are at the greatest risk for injury. Traditionally, the youth and adolescent baseball pitcher has been at risk for pathologies related to the proximal humeral epiphyseal plate, the fusing medial epicondylar apophysis,[8,16,22-26] or the rotator cuff.[27,28] However, as the skeletal system matures and the pitcher advances through the high school and, possibly, the collegiate and professional ranks, pitchers become more at risk for pathologies, including disruption of the anterior glenohumeral labrum[29]; superior labrum anterior-posterior tears;[30] rotator cuff tensile failure leading to tearing, tendonitis, or abrasion;[29,31] injuries to the ulnar collateral ligament (UCL);[5,17,32] and issues related to the long head of the biceps tendon.[31,33,34] The use of various definitions of injury and reporting mechanisms (i.e., proportions and athlete exposures) makes a direct comparison between various levels of baseball difficult. However, regardless of the exact pathology and the reporting mechanism, the pitcher’s throwing arm seems to be at high risk for injury at all levels and ages of baseball, with younger, skeletally immature pitchers being more likely to encounter physeal injuries to the proximal humeral epiphyseal plate and medial epicondylar apophysis[35,36] as well as Osteochondritis Dissecan of the capitellum,[17] whereas further skeletal development leads to greater incidences of UCL, superior labrum anterior-posterior, and rotator cuff injuries.[17]

1.3.2 Pitchers Compared to Nonpitchers

Baseball pitchers of all ages experience a greater proportion of upper extremity injuries as compared with their position playing counterparts.[37,38] Shanley et al[38] examined the incidence of injuries in high school softball and baseball players. The incidence of injury for pitchers was found to be 37.4% and only 15.3% for position players.[38] They found that, overall, pitchers experienced 47.1% of all shoulder injuries and the risk for an upper extremity injury to a pitcher was 2.6 times greater than the risk to a position player, when considering both sports.[38] For baseball specifically, they found pitchers were especially at risk for sustaining an upper extremity injury, with pitchers found to be 3.6 times as likely to experience an upper extremity injury as a position player.[38] Similar findings have been reported in Major League Baseball,[37] which indicate that pitchers not only have a higher overall incident rate of injury but also experience a greater proportion of upper extremity injuries, specifically shoulder injuries, throughout their careers.

1.3.3 The Adolescent and Adult Shoulder and Pathology

The unique anatomic and physiologic alterations of the growing athlete, in combination with repetitive high velocity movements, are believed to be responsible for many of the adolescent upper extremity injuries experienced in baseball.[39] Furthermore, these anatomic and physiologic differences between the mature and developmentally immature skeleton, such as increased bone plasticity, ligamentous laxity, open epiphyseal growth plates, and under developed musculature,[40] are frequently cited as risk factors contributing to adolescent pitching injuries.

1.3.3.1 Bone Plasticity

The bone can undergo plastic deformation or remodeling as an applied tensile load exceeds its elastic limit, precluding its return to the original length.[41] The mineral content of the bone largely determines its tensile strength and, thus, its elastic and plastic properties.[42] The adolescent athlete has less mineralization of the cortical bone compared with more mature athletes[43], and although weaker in tensile strength, it has the ability to absorb more energy before fracture. Immature bone's ability to absorb increased energy results in an increased capacity to undergo bone remodeling when compared with mature bone,[44,45] examples of which include retroversion of the humeral head[46-51] and the scapular glenoid.[46,51,52] The repeated torsion in external rotation during the late cocking phase of throwing provides the energy to create such remodeling of immature bone.

1.3.3.2 Ligamentous Laxity

The shoulder, among other joints, has been shown to be quite lax in adolescents compared with adults.[53] The proportional difference of type I and type III collagen, the major structural protein in the supporting and connective tissues, has been proposed as the cause of this discrepancy in laxity between the two groups.[54] The amount of type III collagen, a protein responsible for providing structural integrity in distensible organs, produced in adolescents is proportionately greater than in adults,[54] and as children mature, they assume the adult, more rigid, tissue characteristics.[53] Increased laxity, along with significant anterior force of the humerus,[55] produced during arm cocking exposes the anterior glenoid labrum to potential tearing.[29] In addition, increased laxity and micro-instability has been implicated in pathology such as internal impingement.[55]

1.3.3.3 Physeal Plate of Ossification Maturation

Open growth plates pose a unique susceptibility to injury for young athletes. Found to be weaker than the surrounding joint capsule and supportive ligaments[56] and thus the weakest link in the kinetic transfer of energy through the shoulder, the epiphyseal growth plate remain open until late in the second decade, approximately 16-18 years in the glenoid and 17-18 years in the proximal humerus.[56] The epiphyseal growth cartilage is more vulnerable to injury from repetitive microtrauma and macro-trauma than adult cartilage,[57] often resulting in physeal injuries in adolescent pitchers that would otherwise yield ligamentous injuries in an adult.[40]

Structurally most resistant to tension and least resistant to torsion,[56] the epiphyseal plate poorly tolerates the biomechanical stress imposed by the high-velocity throwing motion,[58] particularly the rotational torque achieved during maximum external rotation in the cocking phase.[29,56] Supported by the finding that acute proximal humeral fractures are more likely to involve the epiphyseal growth plate in 13- to 16-year old athletes when compared with 5- to 12-year olds,[22] the relatively weak growth plate is particularly vulnerable during periods of long bone growth.[57]

In both the adolescent and adult throwing athlete, there is a well-documented difference between dominant and nondominant glenohumeral range of motion, characterized by increased humeral external rotation with an associated decrease in internal rotation.[46-48,53,59] In a large study of rotational stress fracture of the proximal epiphyseal growth plate, also known as Little Leaguer's shoulder, Carson and Gasser[22] proposed that these rotational motion changes were occurring secondary to bony remodeling through the proximal humeral epiphyseal growth plate itself via repeated torsion in external rotation. With continued maturity and mineralization of the cortical bone, the adolescent bone loses some capacity to plastically deform or remodel through this growth plate, potentially predisposing them to fracture with repetitive throwing.[53] In 2005, Meister et al.[53]

looked at glenohumeral rotation changes in 294 adolescent baseball players aged 8-16 yrs. They found that elevation and total range of motion, defined as external rotation at 90-degree abduction + internal rotation at 90-degree abduction, of the shoulder both decreased with increasing age. The most remarkable decline in the total range of motion was found between the 13- and 14-year olds, just before the peak incidence of Little Leaguer's shoulder, suggesting that the decreased rotational range of motion (internal rotation at 90 degrees, external rotation at 90 degrees) resulted in increased rotational stress or torsion at the growth plate as a potential cause.

1.3.3.4 Reduced Muscle Strength of Adolescents

Children differ from adults in many muscular performance attributes, such as size-normalized strength, power, endurance, and recovery from exhaustive exercise. It is hypothesized that, compared with adults, children are substantially less capable of recruiting or fully using their higher-threshold, type II motor units.[60] In addition, children have lower size-normalized maximal voluntary force, speed, and power than adults.[60] Age-related differences were found during elbow flexion, with both peak torque and peak rate of torque development being significantly lower in boys aged 9.7± 1.6 years than in men aged 22.1± 2.8 years.[61] Trakis et al.[62] examined muscle strength of adolescent pitchers with and without pain related to throwing. They found weakness in muscles of the posterior shoulder in the throwing arm compared with the nonthrowing arm in a those adolescents with pain, concluding that the inability of weakened posterior shoulder musculature to tolerate the stress of throwing, with adaptively stronger propulsive internal rotators, may contribute to pain in this group.[62] Likewise, Byram et al.[63] found a significant association for preseason weakness of external rotation and supraspinatus strength with throwing-related injury that required surgery in professional baseball pitchers. Weakness of the shoulder musculature associated with throwing seems to increase risk for injury in various ages and levels of competition. The neuromuscular makeup of adolescent muscle may amplify this risk in the young thrower.

1.3.3.5 Throwing Mechanics and Kinetics

The throwing sequence in baseball is an efficient and skilled pattern. Traditionally, the pitching motion has been divided into six phases:[29,63-65] windup, stride, arm cocking, acceleration, deceleration, and follow-through phase. Most biomechanical studies on pitching have focused on adult pitchers.[29,64,66-68] However, a few exceptions[2,56,69-72] have examined the kinematics and kinetics of the throwing motion in the adolescent baseball pitcher. The mechanics of the throwing motion have been shown to not change significantly despite the age or level of play;[69] however, joint forces and torques increase with age and levels of competition. In 1999, Fleisig et al.[69] examined a number of kinematic, kinetic, and temporal parameters across four levels of competition. None of the six temporal and 1 of the 11 kinematic parameters showed significant differences. However, all eight of the kinetic parameters increased significantly with competition level.[69] Maximum anterior force present during the cocking phase has been found to be approximately twice as high in professional pitchers (33.8 N/kg) as compared with youth pitchers (16.2N/kg).[55] In addition, shoulder distraction force just after ball release has been found to be approximately 50% of the pitcher's body weight.[56] Fleisig et al.[69] concluded that, because position and temporal differences were not observed, kinetic differences were most likely caused by increased muscle strength resulting in increased joint forces and torques in the higher level athlete.[69] With the exception of some data that indicate that youth pitchers have improper timing with trunk rotation,[70,73] most studies[56,70] have found that the kinematics of pitching are generally similar for both youth and elite adult pitchers.[56] The combination of kinetic differences and overall lack of position and temporal differences among adolescent and adult pitchers suggests that a pitcher should learn proper mechanics as early as possible[6] and focus on strength and power as the body matures.[69] In fact, Davis et al.[71] found youth pitchers with better mechanics generated lower torques and loads in the throwing shoulder. A reduction in the loads and stress placed upon the throwing arm may help prevent shoulder and elbow injuries in youth pitchers.

1.3.4 Pitch Type as it Relates to Injury

Controversy has long existed regarding pitch type in adolescents, specifically the risk associated with throwing breaking pitches too soon. Breaking pitches are those pitches that do not travel straight as a fastball does, with common examples including the curveball and slider. In 1996, Andrews and Fleisig[10] conducted a survey of baseball experts, orthopedic surgeons, and coaches about risk factors of young pitchers. Results of the survey suggested that a child could start throwing a fastball at 8 ± 2 years, a change-up at 10 ± 3 years, and a curve-ball at 14 ± 2 years.[10] This recommendation implied that experts felt there was an increased risk associated with throwing a curveball at too young of an age. Therefore, USAB-MSAC concluded the curveball should not be learned before the age of 14 years.[7] In 2002, Lyman et al.[2] evaluated pitch types for their relationship to both elbow and shoulder pain. The study had findings consistent with the USAB-MSAC's conclusions, suggesting that the use of breaking pitches presented a significant increased risk (curveball, 52% of increase; slider, 86% of increase) for elbow and shoulder pain in youth baseball pitchers. However, the use of the change-up was associated with 12% and 29% of reduction in the risk for elbow and shoulder pain, respectively.[2]

Despite differences in kinematics with various types of pitches, controversy continues to exist whether breaking pitches are more stressful than fastballs. Fleisig et al.[74] examined the kinetics among different pitches in collegiate pitchers. There were significant kinematic differences between the fastball and the curveball, but few kinetic differences were found concluding that, because the joint loads were similar between the fastball and the curveball, neither pitch was more stressful for the collegiate pitcher.[74] Dun et al.[75] conducted a study to examine the kinetics in adolescent throwers to determine whether the curveball was more dangerous for this level of pitcher. The study concluded that elbow and shoulder loads were greatest in the fastball and least in the change-up, indicating that the curveball may not be more potentially harmful than the fastball for youth pitchers.[75] In addition, Nissen et al.[76] examined adolescent pitchers with 2 years of experience to assess differences of various pitches and found that lower moments at the shoulder and elbow existed when throwing the curveball vs. the fastball. Therefore, the current scientific evidence seems to indicate that the curveball is no more dangerous of a pitch than the fastball in adolescents.[13,75] Despite the lack of existing evidence, the 2012 position statement for youth baseball from the ASMI expresses concern over throwing curveballs, or breaking balls of any type, too early secondary to a potential lack of physical development, neuromuscular control, proper coaching, and good mechanics in the youth pitcher, all of which may be counterproductive to mastering proper pitching mechanics.[13] However, given the kinetic data showing similar or lower moments at the shoulder and elbow when throwing the curveball,[74-76] further work is warranted to examine the influence that proper mechanics and physical development may have on the use of breaking pitches and injury risk in youth baseball.

1.3.5 Velocity as it Relates to Injury

Increasing pitch velocity has been identified as an independent risk factor at the adolescent,[11] high school,[5] collegiate,[77] and professional[32] levels of pitching. Pitchers acquire greater ball velocity by increasing torque of glenohumeral rotation in the late cocking and acceleration phases of throwing.

Greater torque places higher stress on the entire kinetic chain,[78] including the throwing arm. Overuse injuries, that occur from cumulative microtrauma and are commonly seen in pitchers, are related to high levels of stress placed on the weakest areas of the kinetic chain,[78] generally on the shoulder or the elbow. In fact, Petty et al.[5] noted that studies examining the kinetics of full-effort throwing[79] and injury mechanisms of throwing[29] and cadaveric studies examining tissue failure of the UCL[80,81] suggested that the UCL nears its failure point as pitch velocity exceeds 80 mph. Pitch velocity has been identified as a risk factor in youth and adult populations. In 2004, Petty et al.[5] performed a retrospective cohort study on a group of former high school baseball players after they had a UCL reconstruction performed. They evaluated six potential risk factors, including self-reported fastball velocity. The pitchers in the injured cohort had a mean self-reported pitch velocity of 83 mph, with some reporting that they were able to pitch as fast as 93 mph.[5] They concluded that special attention should be paid to high-level elite teenage pitchers who are able to achieve high pitch velocities, as high velocity compounds the risk for UCL injuries.[5] Olsen et al.[11] retrospectively examined risk factors associated with the need to undergo shoulder or elbow surgery in adolescent baseball players. Among other factors, pitching with higher velocity was shown to be present in the injured group. The mean self-reported fastball in the injured group was 88 mph compared with 83 mph in the uninjured group. Even more importantly, pitching with a fastball speed of greater than 85 mph increased the injury risk by 2.58 times.[11] Furthermore, evidence exists in the professional pitcher as well, which shows a significant association between higher pitch velocity and elbow injuries, especially injuries to the UCL.[32] Although other risk factors seemed to be more related to injury, higher maximum pitch velocity achieved is related to increased risk for shoulder or elbow injury in pitchers.

1.3.6 Fatigue as it Relates to Injury

The inherent instability from limited bony glenohumeral articulation, in combination with high-velocity movements, poses a challenge to the maintenance of shoulder integrity during the pitching motion. As such, the glenohumeral joint relies heavily on the dynamic stabilization provided by the rotator cuff and surrounding musculature.[82] The onset of muscular fatigue in addition to an already lax adolescent shoulder make stabilization even more difficult.[29] If compressive forces do not counteract the high distraction forces, injuries are more likely to occur.[30] Alterations in the pitching motion caused by improper mechanics or poor dynamic stability, as well as muscle fatigue attributed to high pitch counts and overuse, negatively influence performance[83,84] and have been cited as common reasons for shoulder injuries in the adolescent pitcher.[23,83,84]

Muscle fatigue has been postulated to lead to shoulder injury by disrupting the balance of compression and distraction forces, thus altering the normal pitching mechanics and/or impairing the proprioceptive system and the ability to respond to perturbations in the throwing motion. Deeper examinations of the effects of fatigue on the kinematic and kinetic parameters of the pitching motion show conflicting results. Parameters, including maximum shoulder external rotation and horizontal adduction, have been shown to change, either decreasing[85] or increasing,[86] with extended pitching under both actual and simulated game conditions.[85,86] However, these studies were unable to determine whether the changes occurred because of fatigue or secondary to adopted protective mechanisms to minimize the significant loads associated with throwing.[85,86] In 2007, Escamilla et al.[87] examined collegiate baseball pitchers, with extended pitch counts under simulated baseball game conditions. Contrary to the previous findings of Murray et al.[85] and Barrentine et al.[86] the study found that, aside from a decrease in ball velocity and a decrease in trunk flexion at foot strike, none of the shoulder and elbow kinematics or kinetics of a pitcher change significantly during the course of a simulated game.[87] However, they did acknowledge that they were many other factors to consider when determining injury risk. Mullaney et al.[88] examined the effects of extended throwing on muscular strength as a measure of muscular fatigue. They found that, of the 14 upper and lower extremity strength measurements taken before and after the simulated game, only three were significantly less after the game: shoulder flexion, adduction, and internal rotation. They also found 11% of reduction in shoulder external rotation strength, which did not reach statistical significance.[88] A study by Gandhi et al.[89] examined the voluntary activation and the maximum strength of external rotation before and after pitching in a simulated game. After the completion of the game, in which the uninjured high school participants pitched 75-90 pitches, voluntary activation was significantly lower than pre-throwing values (96% for pre-throwing to 89% for post-throwing), and the decrease in external rotation strength after the game approached statistical significance (peak volitional torque of 27.3 ft-lb before to 25.6 ft-lb after).[89] This study[89] was the first to show voluntary activation failure of the infraspinatus because of fatigue that occurred during pitching, with an accompanied 3% of drop in external rotation force. The studies examining fatigue in the rotator cuff were not designed to determine risk for injury. However, rotator cuff failure during pitching may have implications for shoulder injury, with maximum shoulder external rotation weakness having been associated with throwing-related injuries that may require surgery.[90]

Fatigue has also been shown to impair proprioception,[91-95] reducing the shoulder's capacity to respond to perturbations and possibly predisposing the athlete to injury. In 1996, Voight et al.[91] showed a decreased ability to actively and passively reproduce a specific shoulder position after fatigue, concluding that shoulder proprioception, specifically joint position sense, is diminished in the presence of shoulder muscle fatigue. Proprioception of the shoulder after fatiguing was tested by the ability to detect passive motion by Carpenter et al.[93] in 1998. After exercise, the threshold to detect passive motion had increased by 73%, indicating a decrease in proprioceptive sense with muscle fatigue. Studies examining proprioception of the shoulder and the throwing motion found similar results. In 1999, Myers et al.[92] showed a decreased ability to actively reproduce joint position in both midrange and end range of rotational motion of the abducted humerus after fatiguing the shoulder. Despite the reduction in proprioception as measured by an angle reproduction test, they found no significant effect on neuromuscular control as determined by sway velocity during a dynamic stability test. However, secondary to the reduction in proprioception, they concluded that, as joint position sense in reduced, injury risk may increase because of increased mechanical stress.[92] In 2004, Tripp et al.[95] examined the effects of functional fatigue on position reproduction in overhead throwing athletes. The study found a significant difference between pretest and posttest error scores in the fatigued condition, with more errors being made in the arm-cocked position than in the follow-through. Again, in 2007 Tripp et al.[94] examined the ability of healthy baseball players to reproduce the late-cocking and ball release positions of the pitching motion before and after a fatigue protocol. Fatigue was found to significantly decrease the joint position sense in both the late-cocking and ball-release positions for the shoulder, scapulothoracic, and elbow joints. Overall, fatigue has been shown to diminish position sense at the scapulothoracic and glenohumeral joints in positions throughout the throwing motion, namely maximum external rotation, that have implications for labral and internal impingement conditions commonly seen in throwing athletes,[94] and observation of acute fatigue is important in the prevention of injuries.[95]

1.3.7 Cumulative Microtrauma and Injury

Research has indicated that pitching injuries are attributed to a number of factors in the developing baseball player, most of which are related to overuse.[2-4,11,12] In addition, based on previous research and expert consensus opinion, the belief is that many of the pitching injuries that require surgery or medical attention at older age or higher levels of competition result from cumulative microtrauma that initially started at the youth baseball level.[7] Increased pitch count during the course of a game and season, in addition to an increased number of innings pitched during the course of a season, has been identified as a significant risk factor for adolescent shoulder injuries.[2-4,11] In 2001, Lyman et al.[3] conducted a prospective cohort study for two seasons to determine the frequency of elbow and shoulder complaints in youth pitchers and to identify associations to pitch types, volume, and other risk factors. They found that risk factors for shoulder pain included decreased self-satisfaction with performance, experiencing arm fatigue during the game pitched, and throwing more than 75 pitches per game. In fact, every ten pitches thrown in a game resulted in significantly increased odds of experiencing shoulder pain. Pitchers throwing in the highest category (>75 pitches) were 3.2 times more likely to experience shoulder pain than the lowest pitch category. Lyman et al.[2] followed up the previous study with a prospective cohort study examining the effect of pitch type, count, and mechanics on the risk for upper extremity pain in youth baseball pitchers. They found a significant association between the number of pitches thrown in a game and during the season and the rate of shoulder and elbow pain. In fact they noted that there was a 52% increase in the risk for shoulder pain at the 75-99 pitches per game level. In 2006, Olsen et al.[11] conducted a case-control study with 95 adolescent pitchers with a history of shoulder or elbow surgery and 45 adolescent pitchers with no history of surgery. They found a number of risk factors related to the group with the surgical history, all of which were related to more throwing and throwing despite fatigue. Four variables were identified as the risk factors with the most significant association: pitching greater than 8 months of the year (five times increase), throwing more than 80 pitches per game (four times increase), throwing faster than 85 mph (2.58 times increase), and regularity pitching despite the presence of arm fatigue (36 times increase).[11] In 2011, Fleisig et al.[4] conducted a prospective cohort study to quantify the cumulative incidence of throwing injuries in young baseball pitchers during a 10-year period. The study found that those pitching more than 100 innings a year were 3.5 times more likely to be injured and the overall risk of a youth pitcher sustaining a serious injury for 10 years was 5%.[4] Repetitive stress and a lack of adequate recovery, as highlighted by the previous studies, can lead to injury. Youth and adolescents exposed to repetitive stress are particularly vulnerable to overuse injuries in the shoulder and elbow especially given their unique anatomy and physiology.

1.4 PITCH COUNTS

Current pitch count recommendations, established by ASMI, through work commissioned by the USAB-MSAC, have been based on much of the work described throughout this review, especially through the work performed by Andrews and Fleisig,[10] Lyman et al.,[2,3] Olsen et al.[11] and Fleisig et al.[4] Secondary to the established link between excessive throwing and overuse injuries in adolescents, youth pitch counts limits are the primary means currently advocated for injury reduction.

1.4.1 Current Recommendations

1.4.1.1 Youth Baseball

The initial pitch count recommendations were based on a study examining the opinion of baseball experts, orthopedic surgeons, and coaches.[10] The results provided the initial recommendations of pitch count limitations per game.[10] After a further epidemiologic study by Lyman et al.[2] in 2002, modifications were made to the age-based pitch count recommendations. The current pitch count recommendations of USAB-MSAC[12,96] have not changed since the 2004 position statement.[97] (Table 1) In addition to pitch count limitations, USAB-MSAC makes additional recommendations against multiple pitching appearances in a single game, circumventing pitch count rules by pitching in multiple leagues, participation in year-round baseball, pitching at home after having pitched in a game, and throwing breaking pitches before puberty;[12,96,97] however these recommendations do not describe mandatory rest periods.

Table 1: USA Baseball pitch count recommendations, Ages 9 - 14 yrs

USAB-MSAC/ASMI (2004[97], 2006[96], 2008[12])				
Age	Pitches per game	Pitches per week	Pitches per season	Pitches per year
9-10	50	75	1000	2000
11-12	75	100	1000	3000
13-14	75	125	1000	3000

From its inception, Little League Baseball's pitching regulations were based on the number of innings pitched to determine pitcher eligibility.[98] Starting in 2007, Little League Baseball, in collaboration with ASMI and the USAB-MSAC, became the first national youth baseball organization to institute a pitch count based no age.[98] The pitch count limit for Little League Baseball restricted the number of pitches thrown in a game and also determined the amount of rest the pitcher must have before they are allowed to throw again.[98] The 2010 Regular Season Pitching Rules for Little League Baseball[14] added a younger age group, 7-8 years old, and adjusted the age ranges for the mandatory rest requirements (Table 2). Baseball Canada's Official Rules of Baseball[15] presented the organization's pitch count limitations and the rest day requirements for different age categories of play for the 2012 season. Maximum pitch count limitations and mandatory rest days were similar to that of Little League Baseball,[98] although the rest periods are more age specific than Little League Baseball.

Table 2: 2010 Little League Baseball, pitching rules, ages 7 - 18 yrs

2010 Little League Baseball	
Age	Pitches per game
7-8	50
9-10	75
11-12	85
13-16	95
17-18	105

Table 2 (continued)

Age	1-20 pitches	21-35 pitches	36-50 pitches	51-65 pitches	66 or > pitches
≤ 14	0 rest	1 day rest	2 days rest	3 days rest	4 days rest
Age	1-30 pitches	31-45 pitches	46-60 pitches	61-75 pitches	76 or > pitches
15-18	0 rest	1 day rest	2 days rest	3 days rest	4 days rest

1.4.1.2 Adolescent and High School Baseball

Once the younger baseball player is participating in high school baseball, different pitching restrictions, which aim to protect the young thrower from injury, are in place for school-sponsored baseball. Most states' interscholastic associations place a limitation on the number of innings that a high school pitcher can pitch, with only two states reporting that they count the number of pitches (South Dakota, maximum 106/day; Vermont, maximum of 120/day).[99,100] Review of each state's pitching limitations shows consistency between states in regards to items such as the use of mandatory rest periods and what constitutes a pitching appearance. The maximum inning allowance for pitching during a 1-week period ranges from 18 innings (New York) to 10 innings (Washington, DC),[99,100] with many states enacting additional limitations on the number of innings pitched every 4, 3, or 2 days. The maximum 4-, 3- ,2-, and single-day limitations vary slightly by state and can be found by researching the respective state associations.[99,100] As with the rules change in Little League

Baseball from innings limitations to pitch counts, many states are starting to question the long-held inning rules in place secondary to the accumulation of evidence and the amount of publicity and coverage the issue has received.

1.4.2 Compliance with Pitch Count Guidelines

Two studies were identified that aimed to detect knowledge of and compliance with youth pitch count guidelines.[101,102] In 2012, Fazarale et al.[101] conducted an internet-based survey to assess whether youth baseball coaches were aware of and followed the recommended guidelines set forth by the USAB-MSAC. Of the coaches who participated in the survey, 73% reported that they follow the recommendations. However, overall, only 43% of the questions regarding pitch count and rest periods were answered correctly, with the coaches of the 9- to 10-year age group answering 62% correct, coaches of the 11- to 12-year age group answering 35% correct, and coaches of the 13-to 14-year age group answering 42% correct.[101] In addition, only 53% of the respondents felt that the other coaches in the league abided by the recommendations, indicating that improved enforcement of the rules may be indicated.[101] There were limitations to this study, primarily that the survey used had unknown validity and reliability and the study population was limited to a single geographic region. However, the lack of knowledge and compliance indicated by this study may put youth pitchers at risk for upper extremity pain and injuries.[101] A similar study was performed the following year in Japan by Yukutake et al.[102] Their results showed that, overall, nearly 40% of the coaches had correct knowledge of the pitching guidelines as determined by the questionnaire, similar to the findings of Fazarale et al.[101], with a non-significant trend toward older coaches having better knowledge of the pitch count guidelines.[102] Unfortunately, only approximately 28% of the coaches reported that they routinely comply with the recommendations,[102] which is lower than the data from the study performed in the United States.[101]

1.5 CONCLUSIONS

Youth and adolescent pitching continues to result in a high prevalence of injury and pain in the upper extremity. Non-modifiable and modifiable risk factors have been identified and likely interact resulting in pain and injury. On the basis of the available research reporting numerous factors and mechanisms related to pitching injuries, there are a number of avenues for injury prevention. The most currently advocated method, and the strategy most easily applied, is limiting a young pitcher's pitch count. However, attention to other risk factors, such as proper mechanics, strength, and conditioning, and monitoring fatigue and performance habits also play a role in injury prevention. Greater education of coaches, parents, and players of known risk factors and warning signs of injury will likely assist in reducing the overall prevalence of youth and adolescent baseball pitching injuries. Continued work is warranted to assess the effectiveness of current guidelines and to provide additional methods of injury prevention for the youth and adolescent thrower.

2.0 QUANTITATIVE ULTRASOUND INTRA- AND INTER-RATER RELIABILITY FOR THE LONG HEAD OF THE BICEPS AND INFRASPINATUS TENDONS

2.1 INTRODUCTION

Ultrasound is a non-invasive method that can be employed to visualize and examine a variety of human tissues including musculoskeletal structures. The use of ultrasound to examine soft tissue structures of the shoulder, which includes the rotator cuff and the long head of the biceps (LHB)[103-110] has become a well-established, valid,[111] and reliable[112] method. Traditionally, ultrasound imaging has been used to qualitatively evaluate and confirm pathological conditions.[113] However, a qualitative approach is subjective and depends on the operator's ability, experience, and interpretation of the scan.[111,113] A quantitative approach to ultrasonography decreases the subjectivity of the interpreter. By applying first-order statistics and texture analysis, quantitative ultrasound (QUS) has been shown to characterize the microstructure of tissue.[114] Tendon thickness and echogenicity, the ability of the tissue to reflect the ultrasound wave resulting in lighter (hyperechoic) and darker (hypoechoic) areas in the image, along with grayscale values can describe the ultrasound image and texture as well as its overall health. Characteristics of pathology that can be identified by ultrasound include: hypoechoic tendon appearance[103,105,106] and increased thickness, particularly the long head of the biceps tendon (LHB).[107,108] Despite the validity of QUS and grayscale characteristics,[111] accurate, repeatable images must be obtained to apply the quantitative analysis, and this reliability is dependent on the examiner performing the examination.

The most well designed research study cannot overcome the problems associated with an unreliable measure. Reliable procedures to obtain a detailed image of the tendon of interests are vital to making any determination regarding tendon health and degeneration. Previous research has utilized specifically designed methods or markers to establish a reference to improve reliability[112,115] of the ultrasound measurement. Work in our lab[112] has utilized a standardized subject position, transducer placement based on specific orientation of images obtained, and an external reference marker to improve reliability of the measurement. Intra-rater reliability values, using this defined protocol,[112] have been reported as good for the biceps tendon in terms of thickness (0.90) and homogeneity (0.76) and moderate for echogenicity (0.74), variance, skewness, entropy, contrast, and energy.[112]

The main objective of this pilot study was to ensure that the examiners in this study could perform the ultrasound examination, using the established QUS protocol[112] for the LHB and a related but new protocol for the infraspinatus (INF) tendon, of the shoulder in an efficient, reliable manner. Through evaluation of tendon thickness, echogenicity, and additional grayscale variables, intra- and inter-rater reliability for the examiners of interest were established. We expected intra-rater reliability to be greater than inter-rater reliability for all measures and all measures would provide at least moderate reliability.

2.2 METHODS

2.2.1 Quantitative Ultrasound System

Ultrasound imaging was completed using a Philips HD 11XE ultrasound machine, with a 5 – 12 MHz linear array transducer (Philips Medical Systems, Bothell, WA). This ultrasound machine is able to freeze the image and allow visualization of the previous 5 seconds of imaging. The machine settings were kept identical across all examinations performed for all subjects, in particular the depth was set at 4 cm and the gain was set at 85 dBs Optimal images based on visualization of the tendon of interest with defined tendon borders, bone border, and reference marker were selected and saved for later analysis.

2.2.2 Participants

Six young adults (approximate age 18 -25 years) who were members of the Human Engineering Research Laboratory (HERL) during May through August of 2014 volunteered to participant in this reliability study. All six volunteers reported no history of shoulder injury or pain and were not actively involved in any aggressive sport or recreational activity that exposed the shoulder to increased forces. However, the volunteers were not screened through a physical examination prior to participation.

2.2.3 Ultrasound Examination

Two examiners conducted ultrasound examinations of each participant. Both examiners were trained in a specifically developed QUS protocol and had approximately 1 year of experience. The study examiners and investigators met frequently to refine the established protocol[112] to match the anatomical variation present with evaluating the INF tendon, which previously was not developed. The details of the specifically designed protocol for the LHB and the INF are described in detail below.

2.2.3.1 Testing Set Up

Participants were asked to wear a white tank top to allow full and complete visualization of the INF and LHB tendons. All subjects assumed a seated position in a standard chair. The arm being tested was kept adducted to the side of the thorax, with the elbow flexed to 90° and the forearm in full supination resting on a pad to assist in maintaining the position of the elbow. Participants were cued as needed to maintain an upright posture, reducing the amount of the thoracic flexion and an excessive anterior position of the glenohumeral joint associated with poor posture. This subject position was utilized for testing of both the LHB[112] and the INF[116] tendons (Figure 1).

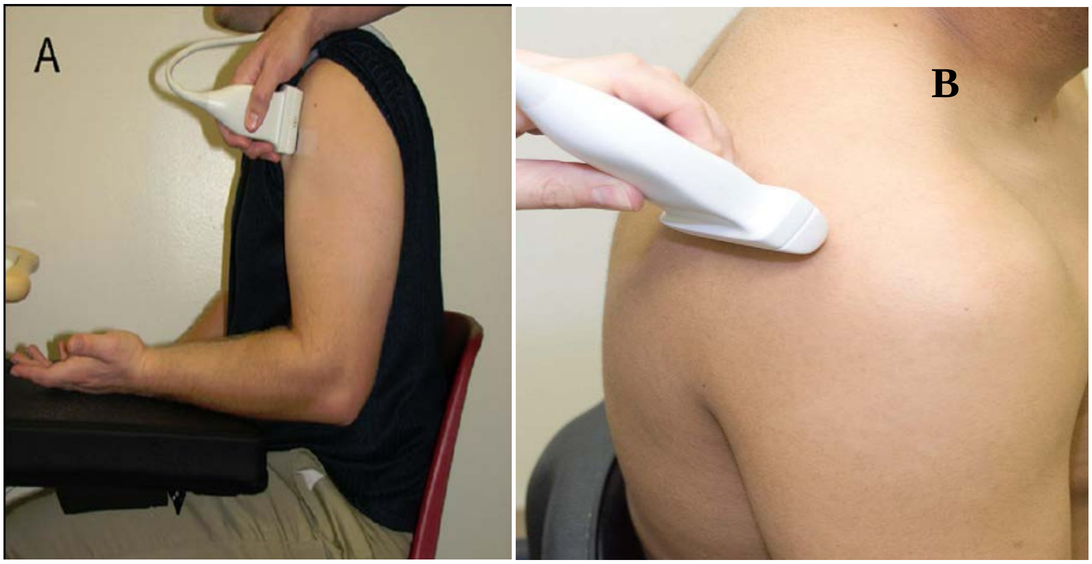

Figure 1: Testing Set Up:

A. Subject positioning with probe placement for LHB.

B. Probe placement for INF (modified from Jacobson, 2011)

2.2.3.2 QUS Imaging of the Infraspinatus Tendon

Ultrasound gel was applied to the probe and skin overlaying the spine of the scapula and the infraspinatus fossa. To establish consistent visualization of the INF tendon, the probe was initially run from lateral to medial along the spine of the scapula until it reached the medial border of the scapula. The probe was then lowered inferiorly approximately half of the width of the probe into the infraspinatus fossa. The probe was then slowly guided in a lateral direction until the insertion of the INF tendon onto the humeral head was visualized. In order to obtain the clearest image of the INF tendon, the probe was oriented at an angle with the medial aspect of the probe being slightly inferior to the lateral aspect of the probe to most accurately mimic the course of the INF from its origin to its insertion. Figure 2 illustrates the probe orientation (modified from Jacobson, 2011),[116] while Figure 3 is of the associated image of the INF tendon in the long axis view.

Figure 2: Probe Orientation – Infraspinatus

The surface of the humeral head appears semi-circular and bright white in the bottom right corner of the image. The maximum amount of the tendon able to be oriented in the longitudinal fashion over the bone edge, with a defined space between the tendon edge and bone edge was captured at the far right of the image.

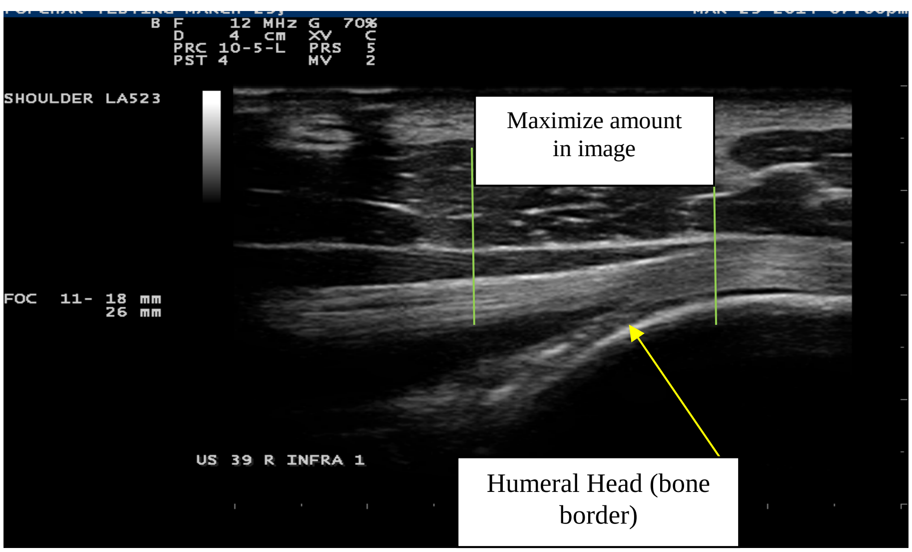

Figure 3: Infraspinatus tendon image obtained from probe placement

The transducer location that produced the most ideal image of the tendon was then traced on the skin, and a steel “A-shaped” reference marker was taped to the skin at the medial end of the transducer footprint (Figure 4). In order for the reference marker to not move during testing, tape was applied directly over the marker to hold the marker onto the skin. The transducer was

Figure 4: Reference marker location

then placed in a manner such that the medial portion of the transducer was directly over the crossbars of the reference marker (Figure 5).

Figure 5: Transducer placement with reference marker

The crossbars of the reference marker created an interference pattern in the ultrasound image (Figure 6), which was used to define the tendon region of interest (ROI) used during the image analysis.

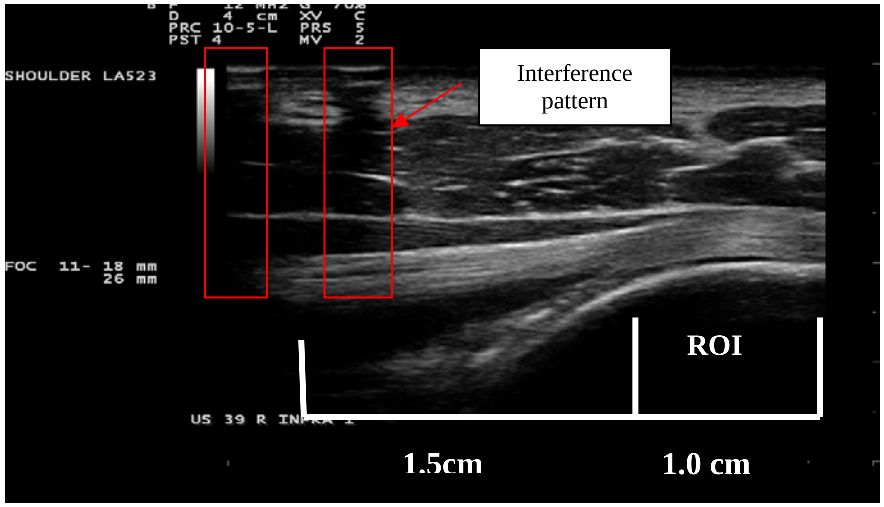

Figure 6: Interference Pattern & Region of Interest (ROI)

Four separate images were collected and analyzed. Images 1 and 2 were collected by examiner 1. The reference marker was then removed, the skin was cleaned to erase all marks, and the procedure was repeated by examiner 2. The reference marker was once again removed and the procedures were repeated by each examiner to collect images 3 and 4. No significant changes in the QUS outcomes were expected during the initial and final tests, as subjects did not perform any activity and were instructed to sit and rest between sets.

2.2.3.3 QUS Imaging of the Long Head of the Biceps

All general information regarding testing set up for the LHB imaging was similar to that of the INF tendon. To establish consistent visualization of the LHB tendon, the probe was initially placed on the anterior aspect of the humeral head in a transverse direction. Once visualization of the bicipital groove and the greater and lesser tubercle of the humerus were obtained, the probe was rotated 90° to the longitudinal direction along the anterior humeral head and proximal humerus. Figure 7 illustrates the probe orientation along the anterior humerus, while Figure 8 is of the associated image of the LHB tendon in the longitudinal view.

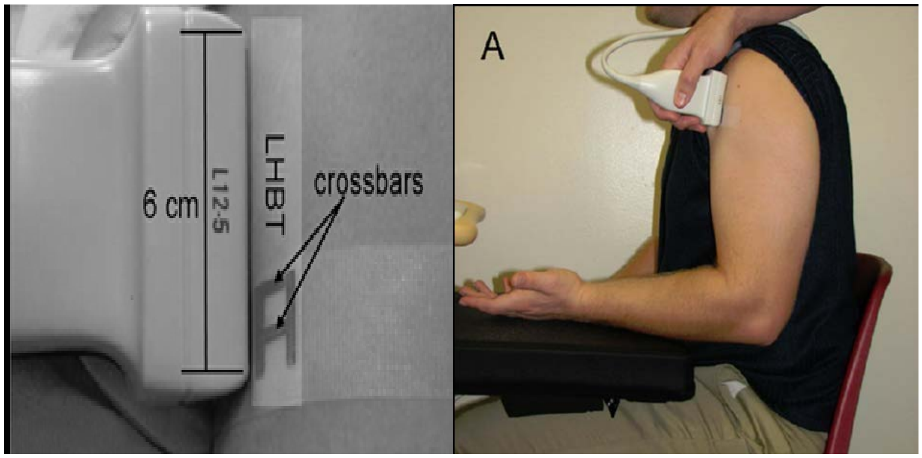

Figure 7: Probe orientation along anterior humerus

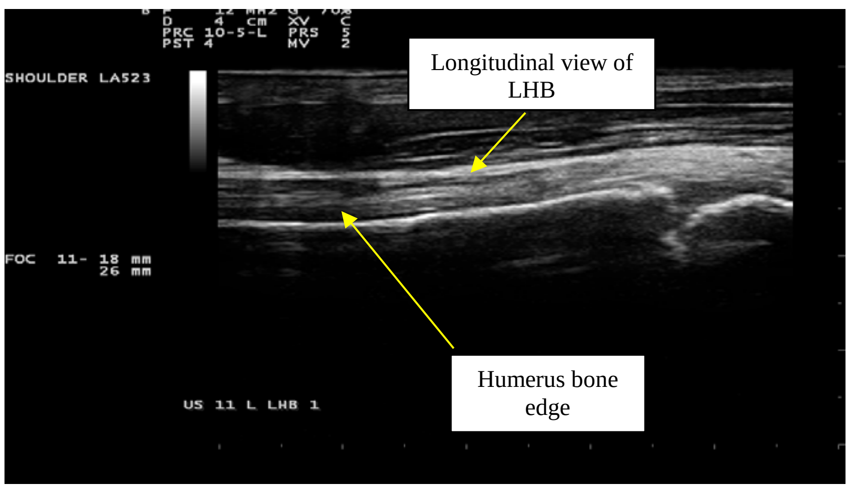

Figure 8: LHB tendon in longitudinal view

The surface of the humeral bone edge appears as a bright white border, with a potential opening where the proximal humeral physis is located. The probe is oriented such that the LHB tendon as parallel to the bone edge as possible with defined tendon borders. The transducer location determination, reference marker, and transducer placement (Figure 7), resultant interference pattern in the ultrasound image (Figure 9), and definition of the ROI were similar in methodology to that of the INF. A similar testing protocol was followed for the LHB tendon. However, secondary to known inter-rater reliability for the LHB,[112] only examiner 1 (AP) performed the reliability testing to establish operator intra-rater reliability.

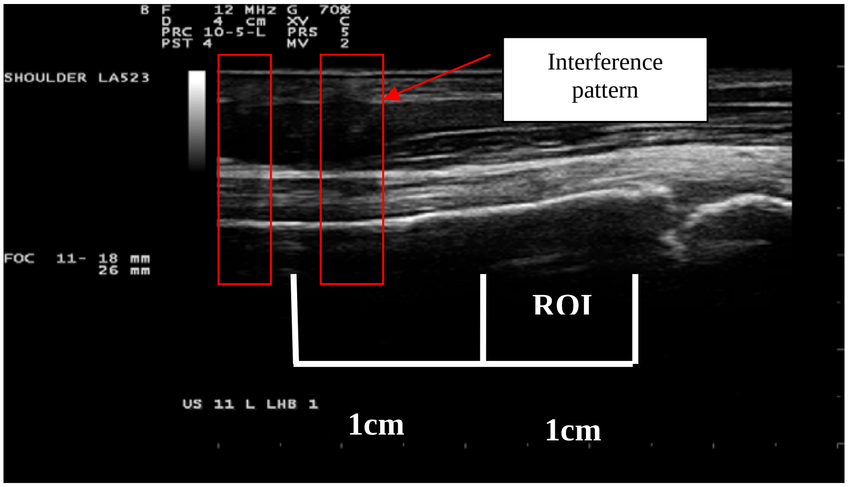

Figure 9: Interference Pattern & ROI LHB

2.2.4 Image Analysis

Each pixel in the ultrasound image represents a grayscale value ranging from 0 (black) to 255 (white).[112] Collagen will reflect ultrasound waves back to the transducer and appear hyperechoic (closer to 255), whereas the waves pass through fluid that appears darker (closer to 0) on the resultant image.[112] The ROI for each tendon was defined in relation to the center of the interference pattern created by the externally placed reference markers, as shown in Figures 6 & 9 using an interactive MATLAB function (The MathWorks, Natick, MA). The following features were calculated for the tendon ROI: tendon thickness, echogenicity, variance, skewness, kurtosis, entropy, contrast, homogeneity, and energy.[112,117,118]

The upper and lower boundaries of the ROI were determined by manually clicking the top and bottom boarders of the tendon and fitting a 200-point spline to each line. Each spline was converted to 10 cords. The MATLAB function then calculated the minimum distance between cords

1 through 10 and averaged the distance data to yield the average tendon diameter.[112,119] To minimize inter-trial variance due to transducer pressure and inter-variability not corresponding to activity related change, such as probe orientation or signal variation with depth, a regression equation was developed and utilized that determined tendon ROI echogenicity (grayscale) from the distance from skin surface to the middle of the tendon ROI and averaged the soft tissue (region of muscle and fat above the tendon ROI) grayscale, creating a tendon to reference echogenicity ratio.[112,119] Previous intra-rater reliability of shoulder ultrasound measures exceed 0.8 for diameter measures and 0.7 for echogenicity.[112] Established inter-rater reliability was lower for all QUS measures, with tendon thickness and echogenicity achieving the highest reliability (> 0.75), with all other measures falling below that level.[112]

First-order statistics of the variance, skewness, kurtosis, and entropy are derived from all available pixels in the region of interest (ROI).[112,114] Respectively, the variance, skewness, kurtosis, and entropy describe the spread, symmetry, peakedness and uniformity of the greyscale histogram. Second-order statistics provide additional information about the texture of the ROI. MATLAB texture coefficients (contrast, energy, and homogeneity) are derived from the ROI and describe the spatial dependence of the pixels.[112,120] Contrast measures the intensity difference between pixels oriented next to one another over the entire image and is zero when the image is constant and increases for a heterogeneous image.[112] Energy is equal to the sum of squared elements along the diagonal of the matrix in the ROI, and is equal to 1 for a constant image and decreases with the presence of spatial grayscale texture.[112] Homogeneity equals 1 for a diagonal co-occurrence matrix and gets closer to 0 as the spatial texture increases. Therefore, a healthy tendon should appear to have highly aligned collagen fibers, with a striped appearance of light and dark bands, with the grayscale histogram wider (increased variance), more symmetrical (less skewed), flatter (less kurtosis), more heterogeneous (increased entropy), with higher contrast, and lower energy and homogeneity than a tendon with signs of degeneration.[112]

2.2.5 Statistical Analysis

The intra-rater reliability of repeated QUS measurements of the INF and LHB (for examiner 1) were tested on 6 subjects, with 4 measurements and was determined through the Intraclass Correlation Coefficient (ICC) single measures value, ICC(1,1). The reliability analysis was completed using IBM SPSS Statistics, version 21.

Minimal detectable change (MDC) for each of the QUS variables was determined for each examiner using the formula MDC = 1.96*SEM*√2. The standard error of the measurement (SEM) was determined by using the formula SEM = standard deviation from the initial measurement*(√(1-ICC).

Inter-rater reliability was determined for each repeated measure through the ICC(2,1) (i.e. each variable at time-point 1 between examiners, time-point 2 between examiners, etc.) was utilized to determine inter-rater reliability at each step. Additionally each QUS variable was averaged for each examiner and inter-rater reliability was determined through ICC(2,4), using a two-way random model in SPSS statistics.

We hypothesized that the reliability measure for intra-rater reliability of the both tendons for all QUS variables would meet or exceed 0.50 indicating moderate reliability and that inter-rater reliability of the INF tendon would be no less than 0.40 indicating fair reliability.

2.3 RESULTS

2.3.1 Intra-Rater Reliability & Minimal Detectable Change

The results of this study showed intra-rater reliability of the LHB tendon (examiner 1) to be fair for tendon width (ICC = 0.48), skewness (ICC = 0.58), just below the criteria for echogenicity (ICC = 0.39), and low for variance (ICC = 0.22). The remaining grayscale values showed poor reliability for the biceps tendon with ICC(1,1) < 0.20 (Table 3). Utilizing the reliability measure (ICC), the MDC was calculated for each QUS variable of interest for the primary examiner (AP) and can be found in Table 3.

Table 3: Intra-Rater Reliability - LHB (examiner 1)

LHB Intra-Rater Reliability (Examiner 1, AP)		
Variable	***ICC(1,1)***	***MDC***
Width	0.48	0.80
Echogenicity	0.39	49.88
Variance	0.22	2224.73
Skewness	0.58	0.43
Kurtosis	<0.35	7.99
Entropy	<0.20	1.08
Contrast	<0..20	5.70
Energy	<0..20	0.57
Homogeneity	<0.20	0.48

Intra-rater reliability results for the INF tendon were much higher, with fair to excellent ICC(1,1) values (> 0.48) for all QUS variables (Table 4). Of particular interest, tendon width (0.58) and echogenicity (0.85) were both acceptable, achieving at least 0.40. Examiner 2 (NH) had slightly higher ICC(1,1) values for most QUS variables, indicating fair to excellent reliability, in particular for width (0.96) and echogenicity (0.85). MDC was calculated in a similar manner to above for each examiner using the ICC value (Table 4).

Table 4: INF Intra-Rater Reliability (Both Examiners)

INF Intra-Rater Reliability				
	Examiner 1 (AP)		Examiner 2 (NH)	
Variable	***ICC(1,1)***	***MDC***	***ICC(1,1)***	***MDC***
Width	0.58	0.43	0.96	0.24
Echogenicity	0.85	23.50	0.85	26.27
Variance	0.63	883.21	0.78	1143.79
Skewness	0.48	0.96	0.61	1.13
Kurtosis	0.63	2.68	0.53	4.58
Entropy	0.66	0.78	0.67	0.78
Contrast	0.72	2.38	0.74	2.77
Energy	0.68	0.80	0.62	0.82
Homogeneity	0.76	0.41	0.76	0.45

2.3.2 Inter-Rater Reliability

Inter-rater reliability testing using the averaged values for each QUS variable across four time-points, ICC (2,4) was moderate to high for all but one QUS variable. ICC (2,4) was high for echogenicity (0.97), variance (0.89), entropy (0.91), contrast (0.93), energy (0.95), and homogeneity (0.93). Moderate reliability (> 0.50 - < 0.75) was determined for skewness (0.63) and kurtosis (0.70). Tendon width showed the lowest inter-rater reliability (0.23) (Table 5).

Table 5: INF - ICC (2,4) values with associated 95% CI

Variable	ICC(average measures)	95% CI	Significance
Tendon width	0.23	(-.44 - .82)	0.29
Echogenicity*	0.97	(.24 - .10)	<0.001
Variance*	0.89	(.35 - .99)	0.01
Skewness	0.63	(-.36 - .94)	.051
Kurtosis	0.70	(-.39 - .96)	.074
Entropy*	0.91	(.45 - .99)	0.01
Contrast*	0.93	(.52 - .99)	0.003
Energy*	0.95	(.63 - .99)	0.001
Homogeneity*	0.93	(.24 - .99)	0.001

Inter-rater reliability determined for each repeated measure, ICC (2,1) values were lower than above, likely due to using single measures and not average measures as previous. Moderate to high (> 0.70) ICC's were found for the single time points between examiners as shown in Table 6 below. All four time points for echogenicity and 3/4 time points for variance, skewness, entropy, contrast, energy, and homogeneity had at least moderate reliability.

Table 6: INF - ICC (2,1) Values with associated 95% CI

Variable	ICC	95% CI	Significance
Echogenicity 1	0.98	(.85 - 1.00)	0.001
Echogenicity 2	0.99	(.91 - .100)	0.001
Echogenicity 3	0.78	(-.27 - .97)	0.011
Echogenicity 4	0.90	(.15 - .99)	0.004
Variance 1	0.81	(-.17 - .97)	0.015
Variance 2	.079	(-.26 - .97)	0.013
Variance 4	0.85	(-.29 - .98)	0.038
Skewness 1	0.77	(-.21 - .97)	0.004
Skewness 3	0.75	(-.48 - .97)	0.074
Kurtosis 3	0.75	(-.26 - .96)	0.057
Kurtosis 4	0.78	(-.13 - .97)	0.037
Entropy 1	0.85	(.15 - .98)	0.024
Entropy 2	0.81	(-.12 - .97)	0.045
Entropy 4	0.76	(-.24 - .96)	0.054
Contrast 1	0.93	(.44 - .99)	0.009
Contrast 2	0.91	(.41 -.99)	0.011
Contrast 4	0.73	(-.30 - .96)	0.019
Energy 1	0.84	(-.17 - .98)	0.041
Energy 2	0.85	(.13 - .98)	0.026
Energy 3	0.73	(-.27 - .96)	0.013
Homogeneity 1	0.94	(.51 - .99)	0.007
Homogeneity 2	0.95	(.64 - .99)	0.004
Homogeneity 3	0.81	(-.20 - .97)	0.012

2.4 DISCUSSION

The objective of this study was to establish the intra- and inter-rater reliability for the INF tendon using a specific QUS protocol and to determine the intra-rater reliability for the primary examiner(s) involved in testing participants in the upcoming study. Furthermore, we aimed to determine the MDC that each QUS variable would have to undergo in future testing to establish a real change had occurred in response to activity.

The results of this pilot study indicates that the use of a specifically designed QUS procedure for the INF tendon produced fair to excellent reliability (> 0.40) for all variables measured. With no previous reliability values reported for the INF tendon, comparison must be made to established reliability values for the supraspinatus and LHB tendons.[112] The intra-rater reliability values for the INF tendon are similar or slightly higher than reported by Collinger et al[112] for other tendons of the shoulder, and were achieved by both operators whom had less than two years of experience.

Intra-rater reliability, using the protocol outlined above, has previously been reported as good for tendon thickness and echogenicity for the LHB.[112] The intra-rater reliability of the LHB of the primary examiner (AP) in this study was determined to be fair[121] (≥ 0.40) for the primary variables of interest, tendon width (0.48) and just below that criteria for echogenicity (0.39). Secondary grayscale variables were of poor or unacceptable reliability for the LHB in this pilot study. This was likely due to abnormal values seen for many of the grayscale variables in time-point one for the third subject and / or due to the small sample size. ICC (1,1) values determined from a larger sample of participants in the acute tendon changes chapter (Chapter 4) revealed substantially improved reliability for the LHB: width (0.91), echogenicity (0.87), variance (0.74), skewness (0.82), kurtosis (0.75), entropy (0.63), contrast (0.75), energy (0.64), and homogeneity (0.73), with all achieving at least moderate reliability.

As expected, inter-rater reliability was generally lower than intra-rater reliability for both tendons examined. This finding is in agreement with previous studies that suggested ultrasound is an operator-dependent modality.[112,122,123] Inter-rater reliability is improved when following the standardized procedures for testing and when average values of the repeated measurements are analyzed. Using this method of inter-rater reliability, ICC (2,4), six of nine QUS variables (echogenicity, variance, entropy, contrast, energy, and homogeneity) had high reliability values (> 0.89). Two QUS variables, skewness (0.63) and kurtosis (0.70) had moderate reliability, and tendon width had low / unacceptable reliability (0.23). We hypothesize that the low reliability value for tendon width, with higher reliability for all other variables, indicates that slightly different portions of healthy tendons were being analyzed by each examiner. If separate examiners are performing testing, it would be vital that set-up and ROI determination based on the location of the humeral head on the image screen be more exact between the operators. However, grayscale values have moderate to high reliability indicating the protocol is able to consistently measure these factors found in the length of the INF tendon. ICC (2,1) values were less reliable and highlight the operator dependency that is found with QUS imaging. Primarily for this reason and to make use of the moderate to high intra-rater reliability of QUS found in this pilot study, the upcoming investigations in this dissertation utilized only one examiner (AP) to record images, with the exception of the first 3 subjects tested, whom were tested by examiner 2 (NH) . However, at no point, was one participant tested by more than one examiner, ensuring that the high intra-rater reliability was utilized for all subjects tested.

The values of the MDC shown in Tables 3 and 4 provide a guideline for interpreting changes within a single subject or a group of subjects as the minimum amount of change in a patient's score that ensures the change is not the result of measurement error. Therefore, observed changes greater than the MDC in an individual can be considered significantly different. This may be helpful in the future if further testing would reveal a link between the amount of change that occurs in response to throwing and the prevalence of pain or injury.

2.4.1 Limitations

The results of this current pilot study are based on a small sample of volunteers (*n* = 6). Six young adults were studied secondary to a sampling of convenience within the testing center at HERL. Reliability measures for the QUS protocols for the LHB and the INF for two specific examiners were established. However, the age and body morphology of the young participants in the proceeding chapters may not allow direct generalization of these reliability measures. No volunteers had a history of pathology in the shoulder in this reliability study. This could potentially inflate the reliability measures secondary to the lack of anatomical variation seen in healthy tendons of young adults. Additionally, no activity was allowed between measurements during this trial. Future studies will likely involved measuring QUS variables pre- and post-activity to assess for differences secondary to use of the tendons. Potential image variations as well as acute body changes (i.e. perspiration, excessive skin tension with extreme range of motion, and potentially acute muscle hypertrophy) are all issues that may need to be considered in future testing. Manners in which to maintain the reference marker location will have to be examined and refined as needed during upcoming trials.

2.5 CONCLUSIONS

Although the intra-rater reliability measures for the first-order statistics and grayscale variables of the LHB for examiner one were lower than hypothesized, QUS testing of the INF and LHB, using the defined protocols, resulted in generally fair to good reliability for each examiner for tendon width and echogenicity. The results of this pilot study are encouraging and suggest that future QUS testing for the INF and LHB tendon are reliable when performed by a single evaluator. Lower inter-rater reliability values would discourage the use of multiple examiners for recording repeated measurements. Use of an external reference marker allowed consistent visualization of a defined ROI throughout repeated measurements and further use of this technique is encouraged in future studies. Tendon thickness and echogenicity were found to have higher, more consistent intra-rater reliability for both tendons of interest and can serve as primary outcomes in future testing. The determined SEM and MDC values can serve as a guide for interpreting results of QUS imaging in response to activity. Upcoming studies utilizing the protocol in this pilot study should display the reliability and consistency necessary to identify acute changes in tendons.

3.0 PHYSICAL CHARACTERISTICS OF A YOUTH AND ADOLESCENT BASEBALL POPULATION AND RELATION TO COMPLAINTS

3.1 INTRODUCTION

The throwing motion in overhead sports, such as baseball, is an efficient and skilled pattern, which places extreme demands on the shoulder girdle and elbow. In particular, the shoulder joint must be able to achieve extreme ranges of motion, while at the same time have the propulsive muscles achieve maximum limb acceleration and the passive and dynamic structures of the shoulder achieve stability of the glenohumeral joint.[30,124] This range of motion (ROM) and strength / stability phenomenon has been referred to as the "thrower's paradox."[30,125] The repetitive nature, along with the extreme demands, of overhead throwing can lead to alterations in this mobility-stability relationship and lead injury.[30,124]

Upper extremity injuries are prevalent in youth and adolescent baseball[2-7,11] and have been linked to many of pitching injuries that require surgery or medical attention at older, higher levels of competition.[7] Many risk factors have been proposed and studied for young throwing athletes, with most of the work showing factors related to overuse throughout the course of a single game, season, or year[2-4,12] to be the most significant. However, factors not related to cumulative microtrauma have also been identified. Demographic variables such as height and weight in children have been found to be associated with increased risk of injury to the elbow and the shoulder.[3,11,126] Alterations in

ROM from soft tissue changes or osseous adaptations of the developing humerus, have also been found to be risk factors,[127] while modifications in muscular strength of the shoulder muscles have also been associated with increased risk of upper extremity injuries.[62,90,127] Due to the critical function of the shoulder joint and the rotator cuff in relation to individual risk factors, such as muscular imbalances, as well as cumulative microtrauma, it is clinically important to detect modifiable risk factors that can be addressed with rehabilitative interventions.

Despite the amount of literature devoted to upper extremity injuries in overhead athletes, we were unable to find any study that provided a descriptive profile, including body weight normalized strength data of the uninjured, healthy youth and adolescent baseball players (≤ 14 years) that could be used as a reference in the clinical setting. The purpose of this investigation was two-fold: first, to provide data on baseball participation characteristics, ROM, and upper extremity strength and second, to relate these variables to the presence of shoulder and elbow complaints experienced over the course of one season.

3.2 METHODS

3.2.1 Participants

Subjects were eligible to participate in this study if they were a youth or adolescent baseball player, 9 – 14 years of age, were currently playing baseball in an organized league, and reported pitching as either their primary or secondary position. Subjects were excluded if they had a history of shoulder injury or elbow injury that resulted in surgery, injury to the throwing arm that resulted in a loss of playing time within the last year, or if they had shoulder or elbow pain at the time of testing. Female gender was not excluded if present on a team or in a league that was recruited to participate in the study.

3.2.2 Testing Procedure

3.2.2.1 Demographic and Physical Examination

Basic demographic and physical examination forms can be found in Appendix B. All physical examination procedures were performed on the throwing and non-throwing arms. Subjects were asked to complete a basic information questionnaire. The primary information derived from this questionnaire was: age, height, weight, throwing arm dominance, and information related to their pitching or baseball history. The questionnaire was designed specifically to obtain information on known risk factors for injury in this population.

Each participant also underwent physical measures testing to quantify characteristics of the throwing and non-throwing shoulders. The physical examination focused on basic characteristics of the shoulders including ROM and strength of the rotator cuff.

Standard goniometry of the glenohumeral joint was performed to measure the amount of ROM of internal rotation (IR) and external rotation (ER) of the shoulders, ER at 0°, ER at 90°, and IR at 90° were measured. For all measurements, the participants were lying supine with a towel roll under their arm to maintain the arm aligned with the body and their elbow flexed to 90°. ER at 0° was measured by keeping the arm at the side of the participant's body and externally rotating their arm until motion was no longer available.[128] ER at 90° was measured with the participant's arm abducted 90° away from the body in the frontal plane. In this position, the arm was externally rotated until motion was no longer available in the shoulder.[128] Finally, IR at 90° was measured with the arm abducted 90° away from the frontal plane.[128] The arm was internally rotated, with pressure maintained on the anterior shoulder to prevent scapular rotation, until motion was no longer available in the shoulder. A standard goniometer (Baseline™) with 10 inch moveable arms was used to obtain the ROM measurements.

Strength testing of muscle-tendon units in the shoulders was performed to quantify the strength of the rotator cuff and biceps. Muscle testing was executed with a hand-held dynamometer (Lafayette Manual Muscle Tester, Model 01163) to obtain all strength data. The following test positions were utilized to assess the rotator cuff. Scapular plane abduction was tested at 90° of forward elevation of the humerus in the scapular plane at 45° abduction.[129] The participant was instructed to raise their arm up into the dynamometer as hard as they could, while the examiner resisted with an equal amount of downward pressure applied to the participant's wrist. The external rotators of the shoulder were tested in two positions, at 0° abduction and at 90° of abduction. External rotation at 0° abduction was tested with the participant's arm against the body and the elbow flexed to 90° of flexion and the humerus slightly internally rotated.[129] The participant exerted a maximum force into external rotation, while the examiner resisted with an equal and opposite force into internal rotation. The force from the examiner through the dynamometer was applied proximal to the wrist. External rotation at 90° was tested with the participant sitting upright and with the arm abducted 90° from the body in the frontal plane with the elbow flexed 90°. With the humerus in approximately 45° of ER, the participant exerted a maximum force in the posterior direction into external rotation. The examiner applied equal and opposite resistance to the proximal wrist into internal rotation. Strength of the humeral internal rotators was also assessed in full internal rotation with the participant's arm placed behind the back. The participant lifted their hand off their back with maximum force, while the examiner applied an equal and opposite force proximal to the wrist in the direction of the participant's back.[129] To assess the force generation in the acceleration phase of throwing, internal rotation in the 90/90° position was tested with the participant in the seated position and the arm placed in 90° abduction, 90° elbow flexion, and 90° external rotation.[130] The participant was not strapped in to a seat secondary to the environment and seating options available, however, the opposite hand was utilized to hold the chair for stabilization. The seated position was utilized in this study to more specifically address the functional position of the upper extremity during overhead throwing.[130] The participant exerted a maximum force into internal rotation, while the examiner resisted with an equal and opposite force into external rotation. The force of the examiner through the HHD was applied proximal to the wrist of the participant, while the examiner provided stabilization to the upper extremity at the lateral epicondyle of the elbow. The final motion assessed for strength was elbow flexion, with the participant holding their arm at their side of their body with their elbow flexed to 90°. The participant flexed their elbow with maximum force, while the examiner applied an equal and opposite force, delivered at the wrist, into elbow extension. All strength testing was performed three times in each test position, with the average of the three trials being used for data analysis.

3.2.2.2 Performance / Velocity

Performance variables related to the perceived exertion with which the participants pitched as well as pitch velocity during a practice session were recorded. The OMNI-RES[131] scale required the participants to rate their perceived level of exertion from 0 to 10, where 0 represented working extremely easy and 10 represented working extremely hard. Participants completed this scale before they commenced pitching and at the conclusion of pitching. Pitch velocity was recorded using the Bushnell® speedster™ III that was positioned behind home plate while each participant pitched during practice. Five pitch velocities were recorded for each subject as they pitched during a practice or training session.

3.2.2.3 Follow-up Questionnaires

End of season follow-up interviews were conducted at the conclusion of the summer season and looked to identify the presence of arm pain or injury that was experienced at any point through-out the season. The measures derived from the follow-up questionnaires included the presence of pain in the throwing shoulder, injury to the throwing shoulder, any other injury to the throwing arm, and any issues overall related to throwing. The follow-up interview ended with open-ended questions that provided the respondents the opportunity to discuss additional problems or issues experienced throughout the season. No other testing procedures took place during the end of season interviews.

3.2.2.4 Statistical Analysis

Basic descriptive statistics (means, standard deviations, frequencies) were calculated for all participants as well as the throwing and non-throwing arms. Discrepancies between the throwing and non-throwing shoulders were determined through a paired t-test, when assumptions of normality were met, or a Mann-Whitney U test when a normal distribution was not assumed, for all continuous variables. Differences between the 3 age groups (9-10yrs; 11-12yrs; & 13-14yrs) were tested with analysis of variance (ANOVA) comparing group means of each age level and a Kruskal-Wallis H test when normality was not assumed. For instances were significant differences were found in the ANOVA, post-hoc comparisons with a Bonferroni correction were used to locate the differences. For instances where differences were identified in mean ranks, individual comparisons were run with an alpha level adjusted for multiple comparisons. For categorical variables that could vary between the throwing and non-throwing shoulders, the proportion in each category was calculated and the overall difference between the two sides was tested with a McNemar test at $\alpha = 0.05$ significance level. In instances where an overall difference between groups existed, post-hoc analysis was conducted using a Bonferroni correction in order to correct for multiple comparisons.

Further analyses were performed, on a subset of this sample, to determine the predictive ability of demographic information, ROM, and strength variables on the presence of shoulder or arm pain throughout the subsequent baseball season, as determined by the end of season follow-ups, using a binary logistic regression and between group differences using standard t-tests to compare the group that experienced a complaint versus the group that did not.

3.3 RESULTS

3.3.1 Demographics

Fifty-three healthy, male, uninjured individuals (age = 11.53 years, height = 156.09 cm, weight = 49.28 kg, BMI = 19.83) (*n* of each age: 9 y/o = 4; 10 y/o = 7; 11 y/o = 19; 12 y/o = 7; 13 y/o = 12; 14 y/o = 4) participated in this study, which was approved by the Institutional Review Board of the University of Pittsburgh. No participants of female gender were enrolled. Consent of each participant and parent or guardian was obtained prior to the study. Basic demographic information for the entire sample (*n* = 53) can be found in Table 7 along with similar information for each age group.

Age categories for analyses were grouped as follows: age category 1 = 9 & 10 y/o; age category 2 = 11 & 12 y/o; and age category 3 = 13 – 14 y/o. As expected, the oldest age category was found to be significantly taller; $F(2, 50) = 49.47$, $p < .001$ and weigh more; $F(2, 50) = 23.65$, $p < .001$ than both of the younger age categories, and had a higher BMI; $F(2, 50) = 4.33$, $p = .02$ than the 11 – 12 y/o. The median value for the number of leagues that each age group participated in was 2 and there was no significant difference between the age groups; $\chi^2(2) = 5.29$, $p = 0.07$. Additionally, there was no group difference in the proportion of: right-handed throwers $\chi^2(2) = 0.35$, $p = 0.84$, primary position of pitcher $\chi^2(2) = .573$, $p = 0.75$, and secondary position of pitcher $\chi^2(2) = .011$, $p = 0.99$. However, there was a difference between groups in the number of years pitched $\chi^2(2) = 20.20$, $p < 0.001$, with post-hoc testing with Mann-Whitney U tests with corrected α to 0.0167, revealing differences between each age category (9 -10 median = 2; 11 -12 median = 3; and 13 -14 median = 5.5 years) (Table 7).

Table 7: Demographic Information, entire sample & each age group

Variable	Total Sample (n = 53) Mean ± (SD)	Freq.	Perc.	9 - 10 y/o (n = 11) Mean ± (SD)	Freq.	Perc.	11 - 12 y/o (n = 26) Mean ± (SD)	Freq.	Perc.	13 - 14 y/o (n = 16) Mean ± (SD)	Freq.	Perc.
Age (years)	11.53 ± 1.38			9.64 ± 0.50			11.27 ± 0.45			13.25 ± 0.45		
Height (cm)	156.09 ± 13.21			142.24 ± 8.87			152.69 ± 7.16			171.13 ± 8.08		
Weight (kg)	49.28 ± 14.71			39.13 ± 10.16			44.24 ± 9.05			64.44 ± 13.42		
BMI (kg/m^2)	19.83 ± 3.44			19.18 ± 3.49			18.89 ± 3.25			21.82 ± 3.05		
No. of Leagues	2.0* ± 0.81			2.0*			2.0*			2.0*		
Yrs. Pitched	3.0* ± 1.76			2.0*			3.0*			5.5*		
Throw. Arm Right		42/53	79.2		8/11	73.0		21/26	80.8		13/16	81.3
1° Position Pitcher		22/53	41.5		5/11	45.5		11/26	42.3		6/16	37.5
2° Position Pitcher		31/53	58.5		6/11	54.5		15/26	57.7		10/16	62.5

***Median value**

Table 8: Age Group Comparisons on Demographic Data; 1= 9/10 y/o; 2 = 11/12 y/o; 13/14 y/o

	Test Statistic F or χ^2*	p-value	Post-hoc Groups and p-value	Groups and CI's
Height (cm)	49.47	<.001**	2 vs. 1 = .002 3 vs. 1 < .001 3 vs. 2 < .001	1 vs. 2 = (3.50 - 17.41) 1 vs. 3 = (21.32 - 36.47) 2 vs. 3 = (12.29 - 24.59)
Weight (kg)	23.65	<.001**	3 vs. 1 < .001 3 vs. 2 < .001	3 vs. 1 = (14.87 - 35.74) 3 vs. 2 = (11.73 - 28.70)
BMI (kg/m^2)	4.33	0.02**	3 vs. 2 = .019	3 vs. 2 = (.38 - 5.48)
Years Pitched	20.20*	<.001**	1 = 2.0 2 = 3.0 3 = 5.5	1 vs. 2 = .009 1 vs. 3 < .001 2 vs. 3 < .001
# of leagues	5.29*	0.07	-	-
Throwing arm Right	0.353*	0.84	-	-
1 ° position pitcher	.573*	0.75	-	-
2° position pitcher	.011*	0.99	-	-

3.3.2 Range of Motion

Physical examination of ROM of the dominant and non-dominant shoulders for the entire sample and for each age group can be found in Table 9. Comparisons between age groups revealed no significant differences in ROM values (Table 10).

Table 9: ROM dominant and non-dominant arms

	n = 53	9 - 10 y/o	11 - 12 y/o	13 - 14 y/o
Variable	**Mean ± (SD)**	**Mean ± (SD)**	**Mean ± (SD)**	**Mean ± (SD)**
IR @ 90° Dominant	46.26 ± 11.28	47.60 ± 9.71	47.29 ± 13.08	44.06 ± 9.89
IR @ 90° Non-Dom.	52.11 ± 10.02	53.70 ± 10.50	52.71 ± 9.68	50.31 ± 10.54
ER @ 90° Dominant	114.83 ± 12.76	112.7 ± 12.57	117.48 ± 12.56	112.69 ± 13.30
ER @ 90° Non-Dom.	109.32 ± 9.47	106.80 ± 8.79	111.95 ± 10.99	107.44 ± 7.05
ER @ 0° Dominant	89.06 ± 14.04	90.90 ± 11.40	91.00 ± 13.94	85.38 ± 15.65
ER @ 0° Non-Dom	87.09 ± 11.84	86.1 ± 11.37	88.86 ± 12.46	85.38 ± 11.70
Total Rot. Motion Dom	161.09 ± 15.40	160.30 ± 18.22	164.76 ± 13.89	156.75 ± 15.22
Total Rot. Motion Non-Dom	161.43 ± 12.89	160.50 ± 15.64	164.67 ± 10.94	157.75 ± 13.17

Table 10: ROM compared by age groups

	Test Statistic	
	F or χ^2 *	**P - Value**
IR @ 90° Dominant	.980*	0.61
IR @ 90° Non-Dominant	0.41	0.67
ER @ 90° Dominant	0.81	0.45
ER @ 90° Non-Dominant	2.606*	0.27
ER @ 0° Dominant	.923*	0.81
ER @ 0° Non-Dominant	.426*	0.63
Total Rot. Motion Dominant	1.259	0.29
Total Rot. Motion Non-Dominant	1.361	0.27

Comparisons of the dominant to non-dominant shoulder were carried out for the entire group, regardless of age (Table11) and by age group (Table 12). When examining the participants as one group, on average, participants showed significantly less IR @ 90° in the throwing arm (Mdn =

45.0°) than in the non-throwing arm (Mdn = 51.0°), U = 1,477.00, $p = 0.005$; and greater ER @ 90° in the throwing arm (M = 114.83) than the non-throwing arm (M = 109.32), $t(92) = 2.38$, $p = 0.02$ (Table 11). Total Rotational Motion (TRM), was determined through the addition of the IR @ 90° and ER @ 90° ROM. Despite side to side differences in both IR @ 90° and ER @ 90°, there was no difference in TRM between sides (mean difference 0.34, *p*-value = 0.91). ER @ 0° was not significantly different between throwing and non-throwing arms at $\alpha = 0.05$ level (Table 11).

Table 11: Dominant vs. Non-dominant shoulder ROM comparisons, entire group

	Test	t or u	*p*-value	Mean difference	Confidence Interval	Standard error
ER @ 0°	t-test	0.739	0.46	1.98	(-3.34 - 7.30)	2.68
IR @ 90°	M-WU	1,477.00	0.005**	5.85	(-10.00- -2.00)	
ER @ 90°	t-test	2.377	0.02**	5.51	(0.91 - 10.12)	2.32
TRM	t-test	-0.116	0.908	0.34	(-6.16 – 5.48)	2.93

Investigation of the same variables for each age group revealed significantly less IR @ 90° in the throwing arms of the 11 – 12 y/o (Mdn = 45.0°) than the non-throwing arms (Mdn = 52.0°), U = 1.53, $p = 0.03$. There was a trend towards significance for the 13 – 14 y/o age group in regards to IR ROM @ 90° with the throwing arm (M = 44.06°) showing a tendency to have less ROM than the non-throwing arms (M = 50.31°), $t(30) = -1.73$, $p = 0.09$ (Table 12) but the trend did not reach the $\alpha = 0.05$, with calculated post-hoc power of 0.53.

Table 12: Dominant vs. Non-dominant shoulder ROM comparisons, by age group

			9 - 10 y/o Age Category 1			
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
ER @ 0°	M-WU	53	0.85		(-7.00 - 20.00)	
IR @ 90°	t-test	-1.35	0.19	-6.1	(-15.60 - 3.40)	4.52
ER @ 90°	t-test	1.22	0.24	5.9	(-4.29 - 16.09)	4.85
TRM	t-test	-0.03	0.98	-0.20	(-16.15 – 15.75)	7.59
			11 - 12 y/o Age Category 2			
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
ER @ 0°	t-test	194	0.6	2.14	(-6.11 - 10.39)	4.08

Table 12 continued

IR @ 90°	M-WU	1.53	$\boxed{0.03*}$		(-12.00 - (-)1.00)	
ER @ 90°	t-test	1.52	0.14	5.52	(-1.84 - 12.89)	3.64
TRM	t-test	0.03	0.98	0.10	(-7.70 – 7.89)	3.86
13 - 14 y/o Age Category 3						
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
ER @ 0°	t-test	113.5	1.00	0.00	(-9.98 - 9.98)	4.89
IR @ 90°	t-test	-1.73	0.09	-6.25	(-13.63 - 1.13)	3.61
ER @ 90°	M-WU	1.4	0.29		(-4.00 - 13.00)	
TRM	t-test	-0.20	0.84	-1.00	(-11.28 – 9.28)	5.03

3.3.3 Strength variables

Physical examination information for strength of the dominant and non-dominant shoulders for the entire sample and for each age group can be found in Table 13. All strength values are normalized to body weight (kg force / kg body weight).

Table 13: Normalized Strength Data

	n = 53	**9 - 10 y/o**	**11 - 12 y/o**	**13 - 14 y/o**
Variable	**Mean ± (SD)**	**Mean ± (SD)**	**Mean ± (SD)**	**Mean ± (SD)**
Elevation @ 90° Dominant	0.13 ± 0.03	0.13 ± 0.05	0.12 ± 0.02	0.14 ± 0.04
Elevation @ 90° Non-Dom	0.12 ± 0.03	0.12 ± 0.03	0.12 ± 0.02	0.13 ± 0.04
ER @ 0° Dominant	0.14 ± 0.03	0.14 ± 0.03	0.14 ± 0.03	0.15 ± 0.03
ER @ 0°Non-Dom.	0.14 ± 0.04	0.13 ± 0.03	0.14 ± 0.04	0.14 ± 0.04
ER @ 90° Dominant	0.12 ± 0.04	0.11 ± 0.04	0.12 ± 0.04	0.14 ± 0.04
ER @ 90° Non-Dom.	0.12 ± 0.04	0.11 ± 0.04	0.12 ± 0.04	0.14 ± 0.04
IR behind back Dominant	0.14 ± 0.06	0.11 ± 0.04	0.17 ± 0.08	0.11 ± 0.04
IR behind back Non-Dom.	0.14 ± 0.06	0.11 ± 0.03	0.16 ± 0.08	0.13 ± 0.03
IR @ 90° Dominant	0.18 ± 0.06	0.15 ± 0.07	0.18 ± 0.05	0.19 ± 0.06
IR @ 90° Non-Dom.	0.17 ± 0.05	0.15 ± 0.07	0.18 ± 0.05	0.18 ± 0.05
Elbow flexion Dominant	0.25 ± 0.06	0.24 ± 0.08	0.25 ± 0.05	0.26 ± 0.07
Elbow flexion Non-Dom.	0.24 ± 0.07	0.24 ± 0.08	0.24 ± 0.06	0.26 ± 0.08
ER 90 post Dominant	0.14 ± 0.05	0.15 ± 0.05	0.14 ± 0.07	0.14 ± 0.05
ER 90 post Non-Dom.	0.14 ± 0.05	0.15 ± 0.05	0.14 ± 0.06	0.13 ± 0.06
ER @ 90°/ IR @ 90° Dom.	0.73 ± 0.23	0.75 ± 0.24	0.68 ± 0.27	0.78 ± 0.13
ER @ 90°/ IR @ 90° Non-Dom.	0.75 ± 0.20	0.79 ± 0.21	0.67 ± 0.17	0.83 ± 0.21

No significant differences existed between the age groups in body weight normalized strength values (Table 14).

Table 14: Normalized Strength variables compared by age groups

	Test Statistic F or χ^2*	*p* - Value
Elevation @ 90° Dominant	5.147*	0.08
Elevation @ 90° Non-Dominant	1.51	0.23
ER @ 0° Dominant	0.43	0.66
ER @ 0° Non-Dominant	0.45	0.64
ER @90° Dominant	5.29	0.07
ER @ 90° Non-Dominant	2.80	0.07
IR behind back Dominant	4.49	0.11
IR behind back Non-Dominant	5.83	0.05
IR @ 90° Dominant	1.25	0.30
IR @90° Non-Dominant	2.95	0.23
Elbow flexion Dominant	0.34	0.71
Elbow flexion Non-Dominant	0.29	0.75
ER @ 90°/ IR @ 90° Dom.	0.93	0.40
ER @ 90°/ IR @ 90° Non-Dom.	3.21	0.05

Comparisons of the dominant to non-dominant shoulder were carried out for the entire group, regardless of age (Table 15) and by age group (Table 16).

Table 15: Dominant vs. Non-dominant shoulder strength comparisons, entire group

	Test	t or u	p-value	Mean difference	Confidence Interval	Standard error
Elevation @ 90°	t-test	1.679	0.10	0.0111	(-.0020 - .0241)	0.0066
ER @ 0°	t-test	0.793	0.43	0.0054	(-.0082 - .0191)	0.0069
ER @ 90°	M-WU	1,110.00	0.97	0.0001	(-.017 - .018)	
IR behind back	M-WU	1067.5	0.94	0.0024	(-.022 - .025)	
IR @ 90°	t-test	0.793	0.43	0.0094	(-.0141 - .0331)	0.0119
Elbow flexion	t-test	0.247	0.56	0.0079	(-.0191 - .0349)	0.0136
ER @ 90°:IR @ 90°	t-test	-0.880	0.38	-0.0379	(-.1233 – .0476)	0.0430

Table 16: Dominant vs. Non-dominant shoulder strength comparisons, by age group

9 - 10 y/o Age Category 1						
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
Elevation @ 90°	t-test	0.65	0.53	0.01	(-.03 - .05)	0.02
ER @ 0°	t-test	0.8	0.43	0.01	(-.02 - .04)	0.01
ER @ 90°	t-test	-0.26	0.85	0.00	(-.04 - .03)	0.02
IR behind back	M-WU	58	0.58		(-.02 - .02)	
IR @ 90°	M-WU	42	0.58		(-.04 - .05)	
Elbow flexion	t-test	0.07	0.95	0.00	(-.07 - .08)	0.03
ER @ 90°/IR @ 90°	t-test	-0.64	0.53	-0.06	(-.27 - .15)	0.10
11 - 12 y/o Age Category 2						
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
Elevation @ 90°	M-WU	1.39	0.11		(-.00 - .02)	
ER @ 0°	M-WU	-0.06	0.86		(-.02 - .02)	
ER @ 90°	t-test	0.15	1.00	0.00	(-.03 - .03)	0.01
IR behind back	t-test	190	0.8	0.01	(-.04 - .06)	0.02
IR @ 90°	t-test	209	0.65	0.01	(-.03 - .04)	0.02
Elbow flexion	t-test	0.71	0.48	0.01	(-.02 - .05)	0.02
ER @ 90°/IR @ 90°	t-test	-0.21	0.83	-0.01	(-.15 - .12)	0.07
13 - 14 y/o Age Category 3						
	Test	**t or u**	**p-value**	**Mean Diff.**	**CI's**	**St'd error**
Elevation @ 90°	M-WU	0.99	0.13		(-.00 - .03)	
ER @ 0°	t-test	0.77	0.45	0.01	(-.02 - .03)	0.01
ER @ 90°	M-WU	0.27	0.72		(-1.34 - 1.77)	
IR behind back	t-test	132.5	0.91	0.00	(-.03 - .03)	0.01
IR @ 90°	t-test	116	0.54	0.01	(-.03 - .05)	0.02
Elbow flexion	t-test	0.22	0.83	0.01	(-.05 - .058)	0.03
ER @ 90°/IR @ 90°	t-test	-0.87	0.39	-0.05	(-.18 - .07)	0.06

All normalized strength values were not significantly different at $\alpha = 0.05$ between the throwing and non-throwing shoulders in the entire sample and in all age groups.

3.3.4 Performance / velocity

Performance variables related to pitch velocity and the ratings of perceived exertion for the entire group and for each age category are shown in Table 17 below.

Table 17: Velocity (mph) and RPE, entire group and by age group

Variable	n = 53 Mean ± (SD)	9 - 10 y/o Mean ± (SD)	11 - 12 y/o Mean ± (SD)	13 - 14 y/o Mean ± (SD)
Max. Pitch Velocity	56.75 ± 9.72	45.75 ± 5.99	54.91 ± 7.82	65.93 ± 4.86
Ave. Pitch Velocity	54.54 ± 10.11	43.28 ± 6.04	52.80 ± 8.75	63.71 ± 4.56
Change in Velocity	1.57 ± 2.71	2.52 ± 1.38	0.89 ± 3.48	2.09 ± 1.42
RPE at end of throwing	6.24 ± 2.45	3.00 ± 2.11	6.54 ± 1.88	7.87 ± 1.36

There was a significant effect of maximum velocity on the age groups F(2,41) = 24.73, *p* =0.00, with post-hoc comparisons revealing each older age group having higher maximum pitch velocities than the younger age groups (Table 18). There was also a significant effect of average pitch velocity on the age groups F(2,41) – 21.70, *p* = 0.00 with post-hoc comparisons revealing each older age group having higher average pitch velocities than the younger age groups (Table 18). Ratings of Perceived Exertion (RPE) at the end of throwing also showed a significant effect on the three age groups, $\chi^2(2) = 50.46$, $p < 0.001$, with examination of the group medians showing RPE at the end of the throwing performance for the 11 – 12 y/o (Mdn = 7.00) and the 13 – 14 y/o (Mdn = 8.00) significantly higher than the 9 – 10 y/o (Mdn = 2.50).

Table 18: Performance variables compared by age groups

	Test Statistic F or Chi-Square*	*p* - Value	Post-hoc groups and p-value	Groups and CI's
Max. Pitch Velocity	24.73	<.001**	2 vs. 1 = .006 3 vs. 1 < .001 3 vs. 2 < .001	2 vs. 1 = (2.25- 16.07) 3 vs. 1 = (12.76 - 27.59) 3 vs. 2 = (5.30 - 16.74)
Ave. Pitch Velocity	21.70	<.001**	3 vs. 1 < .001 3 vs. 2 = .004	2 vs. 1 = (2.09 - 16.96) 3 vs. 1 = (12.45 - 28.41) 3 vs. 2 = (4.75 - 17.07)
Change in Velocity	4.38	0.11	-	-
RPE at end of throwing	50.46*	<.001**	2 vs. 1 < .001 3 vs. 1 < .001	-

3.3.5 Predictors of Shoulder or Arm Pain in Proceeding Baseball Season

Of the 53 subjects who underwent physical examination testing, 37 performed season long tracking of the presence of any symptoms experienced in the upper extremity of the throwing arm. This subset of participants was contacted at the end of the season. Two analyses were performed to determine significant variables from their physical examination data, t-tests when the sample was grouped by the presence of pain, and logistic regression when testing for predictors of pain.

3.3.5.1 Demographic and Physical Examination of Subset

The 37 participants that were able to be reached for follow-up had a mean age of 11.68 ± 1.53 years, height = 157.07 ± 14.78 cm, weight = 51.05 ± 16.41 kg, and BMI of 20.21 ± 3.76. The median number of leagues participated in was 2.0 ± 0.78 leagues, range 1 – 4; years pitched = 3.00 ± 1.95 years, range 1- 8; 28 / 37 (75.7%) were right hand dominant throwers; 19 / 37 (51.4%) were primarily pitchers; and 18 / 37 (48.6%) reported pitching as their secondary position. No differences were noted in demographic information between the group with follow up and the entire group,($p > 0.05$), and only the proportion of those who reported pitching as either their primary or secondary position varied between the subset available for follow-up and the 16 subjects not available for follow up, ($p = 0.03$) (Table 19).

Table 19: Demographic Information of n = 37 subset of follow up participants

	n = 53			n = 37 (F/U)			n = 16 (No F/U)			n = 53 vs. 37	n = 37 vs. 16
Variable	**Mean ± SD**	**Freq.**	**Percent**	**Mean ± SD**	**Freq.**	**Percent**	**Mean ± SD**	**Freq.**	**Percent**	***p*-value**	***p*-value**
Age	11.53 ± 1.38			11.68 ± 1.53			11.19 ± 0.91			0.63	0.24
Height	156.09 ± 13.21			157.07 ± 14.78			153.83 ± 8.55			0.74	0.42
Weight	49.28 ± 14.71			51.05 ± 16.41			45.19 ± 8.80			0.59	0.19
BMI	19.83 ± 3.44			20.21 ± 3.76			19.0 ± 2.46			0.62	0.23
No. of Leagues	2.0* ± 1.76			2.0* ± 0.78			1.0* ± 0.73				
Yrs. Pitched	3.0* ± 1.76			3.0* ± 1.95			3.5 ± 1.26				
Throw. Arm Right		42/53	79.2%		28/37	75.70%		14/16	87.50%	0.69	0.33
1° Position Pitcher		22/53	41.5%		19/37	51.40%		3/16	18.80%	0.36	0.03
2° Position Pitcher		31/53	58.5%		18/37	48.60%		13/16	81.30%	0.36	0.03

Dominant and non-dominant shoulder ROM was determined, from the baseline testing, for the n = 37 subset of participants. Values can be found in Table 20 below.

Table 20: ROM, dominant & non-dominant arms (n = 37 subset)

Variable	Mean ± SD
ER @ 0° Dominant	89.05° ± 13.75
ER @ 0° Non-dominant	87.35° ± 11.60
IR @ 90° Dominant	46.03° ± 11.81
IR @ 90° Non-dominant	52.27° ± 9.85
ER @ 90° Dominant	113.89° ± 12.53
ER @ 90° Non-dominant	107.95° ± 8.75
TRM Dominant	159.92° ± 15.92
TRM Non-Dominant	160.22 ± 12.57

Strength of the dominant and non-dominant shoulder was also assessed for the subset of 37 participants who completed follow-up. Values for both shoulders can be found in Table 21 below.

Table 21: Strength, dominant & non-dominant arms (n = 37 subset)

Variable	Mean ± SD
Elevation @ 90° Dominant	0.13 ± 0.04
Elevation @ 90° Non-dominant	0.12 ± 0.03
ER @ 0° Dominant	0.14 ± 0.03
ER @ 0° Non-dominant	0.13 ± 0.04
ER @ 90° Dominant	0.13 ± 0.04
ER @ 90° Non-dominant	0.13 ± 0.04
IR behind back Dominant	0.12 ± 0.05
IR behind back Non-dominant	0.12 ± 0.04
IR @ 90° Dominant	0.17 ± 0.06
IR @ 90° Non-dominant	0.17 ± 0.06
Elbow flexion Dominant	0.25 ± 0.07
Elbow flexion Non-dominant	0.25 ± 0.08
ER @ 90° post Dominant	0.14 ± 0.06
ER @ 90° post Non-dominant	0.14 ± 0.06
ER/IR @ 90° ratio Dominant	0.78 ± 0.20
ER/IR @ 90° ratio Non-Dominant	0.78 ± 0.19

Performance variables of maximum velocity achieved while pitching and average velocity were also determined for the subset. Values can be found in Table 22 below.

Table 22: Pitch velocity (n = 37 subset)

Variable	Mean ± SD
Max. velocity	55.23 ± 10.22
Ave. velocity	52.65 ± 10.38

3.3.5.2 Seasonal Complaint of Arm Symptoms

Of the 37 subjects who were eligible to be contacted for testing / interviewing at the conclusion of their baseball season, 33 (89.2%) completed follow up assessments. Season complaints of any upper extremity (shoulder or elbow) symptoms (pain, soreness, stiffness with throwing, or injury) were present in 15 / 33 (45.5%) of the participants.

Table 23: Participants with seasonal c/o pain

Seasonal c/o symptoms		Frequency	Percent
Yes	15	15/33	45.50%
No	18	18/33	54.50%

3.3.5.3 Comparison between group with pain and group without pain

All t-tests using ROM and strength values were conducted using the data from the dominant arm only. Individual t-tests revealed a significant difference in the values of IR @ 90° strength in the dominant arm between the group with ($M = 0.20 \pm 0.05$) and without ($M = 0.15 \pm 0.06$) a seasonal complaint, $t(31) = -2.439$, $p = 0.021$. External rotation @ 90° to internal rotation @ 90° ratio (ER/IR ratio) was also significantly different between the group with pain ($M = 0.71 \pm 0.14$) and the group without pain ($M = 0.87 \pm 0.23$), $t(31) = 2.343$, $p = 0.026$. All other comparisons were not significant at the $p = 0.05$ level (Table 24).

Table 24: t-tests results between group with c/o pain and group without c/o pain

Variable	C/O group	No C/O group	t-score	df	*p*-value
Age	11.67 ± 1.45	11.83 ± 1.58	0.313	31	0.76
Height	158.33 ± 13.83	158.33 ± 15.39	0.000	31	1.00
Weight	52.37 ± 17.94	52.21 ± 16.41	-0.027	31	0.98
BMI	20.37 ± 4.47	20.36 ± 3.55	-0.009	31	0.993
ROM:					
ER @ 0°	91.47 ± 13.70	89.78 ± 13.69	-0.353	31	0.73
IR @ 90°	43.93 ± 8.58	48.22 ± 14.53	1.005	31	0.32
ER @ 90°	113.73 ± 10.80	113.72 ± 13.18	-0.003	31	1.00
TRM non-dom. – dom.	-0.20 ± 12.81	3.00 ± 14.98	0.652	31	0.52
Strength:					
Elevation @ 90°	0.14 ± 0.04	0.13 ± 0.04	-0.52	31	0.61
ER @ 0°	0.15 ± 0.04	0.14 ± 0.03	-1.054	30	0.3
ER @ 90°	0.14 ± 0.04	0.13 ± 0.04	-0.874	31	0.39
IR behind back	0.13 ± 0.05	0.11 ± 0.05	-0.823	30	0.42
IR @ 90°	0.20 ± 0.05	0.15 ± 0.06	-2.439	31	0.02
ER/IR ratio	0.71 ± 0.14	0.87 ± 0.23	2.343	31	0.03
Elbow flexion	0.26 ± 0.06	0.25 ± 0.07	-0.743	31	0.46
ER @ 90° post	0.17 ± 0.06	0.12 ± 0.05	-1.914	21	0.07
Max. velocity	55.57 ± 9.99	55.41 ± 11.48	-0.041	29	0.97

3.3.5.4 Logistic Regression with dependent variable of seasonal c/o

Binary logistic regression of the natural log (ln) of IR @ 90° strength of the dominant arm produced a statistically significant result, model $\chi^2(1) = 5.890$, $p = 0.015$, $R^2 = 21.9\%$, Wald = 4.626 , $p = 0.031$, Odds Ratio = 14.80(1.270 – 172.506). In addition, the ratio of the ln ER/IR strength @ 90° also produced a statistically significant result, model $\chi^2(1) = 4.936$, $p = 0.026$, $R^2 = 18.6\%$, Wald = 3.862, $p = 0.049$, Odds Ratio = 0.032 (0.001 – 0.991). No other variables were found to be significant predictors of the presence of upper extremity symptoms experienced throughout the proceeding season (Table 26).

Table 25: Logistic regression, Predictors of seasonal complaints

Variable	Model χ^2	*p*-value	R^2	B	Wald	*p*-value	Odds Ratio	95% CI for OR
Age	0.104	0.747	0.004	-0.076	0.104	0.747	0.926	0.582 - 1.475
Height	0.000	1.00	0.000	0.000	0.000	1.000	1.000	0.953 - 1.049
Weight	0.001	0.978	0.000	0.001	0.001	0.978	1.001	0.960 - 1.043
BMI	0.000	0.993	0.000	0.001	0.000	0.993	1.001	0.838 - 1.195
No. of Leagues	0.649	0.421	0.026	0.424	0.627	0.428	1.528	0.535 - 4.366
Years Pitched	0.25	0.617	0.01	-0.092	0.247	0.619	0.912	0.634 - 1.312
ROM ER @ 0°	0.132	0.716	0.005	0.01	0.132	0.717	1.01	0.959 - 1.063
ROM IR @ 90°	1.11	0.292	0.044	-0.033	0.968	0.325	0.967	0.905 - 1.034
ROM ER @ 90°	0.000	0.998	0.000	0.000	0.000	0.998	1.000	0.944 - 1.060
TRM non-dom.-dom	0.447	0.504	0.018	-0.017	0.442	0.506	0.983	0.934 – 1.034
Elevation @ 90°	0.318	0.573	0.013	0.677	0.309	0.578	1.969	0.181 - 21.423
ER @ 0°	0.769	0.38	0.032	1.309	0.732	0.392	3.703	0.184 - 74.346
ER @ 90°	0.585	0.444	0.024	0.74	0.562	0.453	2.097	0.303 - 14.514
IR behind back	1.19	0.275	0.049	0.964	1.14	0.286	2.621	0.447 - 15.374
IR @ 90°	5.89	0.015	0.219	2.695	4.626	0.031	14.803	1.270 - 172.506
Elbow flexion	0.741	0.389	0.03	1.132	0.679	0.41	3.102	0.210 - 45.802
ER @ 90° post	2.856	0.091	0.156	1.821	2.37	0.124	6.181	0.608 - 62.825
ER/IR ratio	4.936	0.026	0.186	-3.439	3.862	0.049	0.032	0.001 - 0.991
Max. Velocity	0.002	0.966	0.000	0.001	0.002	0.966	1.001	0.936 - 1.071

3.4 DISCUSSION

Examination of the entire group revealed a deficit in IR @ 90° ROM and an increase in ER @ 90° ROM in the dominant arm when compared to the non-dominant arm, with a mean difference of approximately 5 – 6° in each motion, with a non-significant difference in side to side TRM of 1°. No significant differences were found between age groups in regards to ROM findings, suggesting that the overall ROM profile was similar across all age groups. However, there was a trend to have less dominant arm TRM in the 13 – 14 y/o group, which did not reach statistical significance. Numerous studies have shown that a typical thrower's ROM profile, with decreased IR @ 90°, increased ER @ 90°, and equivalent TRM, exists in adult baseball players.[46,47,132-137] Additional works on youth and adolescent baseball players have reported similar findings of ROM adaptations.[53,62,138] The results of this study support the previous findings[53,62,138] showing alterations in ROM are evident in youth and adolescent baseball players by the age of 14. Levine et al[50] found increasing degrees of variation between the dominant and non-dominant shoulder with increasing age, where participants in the groups that corresponded to ages 8 – 14 years experienced a difference in IR @ 90° ranging from 4.6° - 8.4°, which are similar with the results of this study. Trakis et al[62] investigated ROM in 23 adolescent baseball pitchers with a mean age of 15.7 years. They found pitchers had a loss in dominant arm IR @ 90° of 13°, a gain in ER @ 90° of 11°, with no difference in TRM between sides.[62] Our results showed a more moderate departure in side to side differences for ER and IR @ 90°, but likewise found nearly no difference (1°) in TRM. It is possible that the slightly increased mean age of the participants in the study by Trakis et al[62] was the main cause of the larger side to side variations, as age related changes in bone morphology, i.e. humeral retro-torsion, have been found to increase with age in youth and adolescent baseball players.[139] Meister et al[53] examined the dominant and non-dominant shoulders of 294 baseball players age 8 – 16 years. Significant differences were found between the dominant and non-dominant arms for both IR @ 90° and ER @ 90°, with the data suggesting that TRM decreases as age increases.[53] The results of this study correspond with the results of Meister et al[53], with the 13 – 14 year old age group having the lowest mean TRM for both the dominant and nondominant arms. Meister et al[53] did find that ROM varied amongst age groups, whereas the result of this study found no significant differences in the ROM in either arm across all age groups. This is potentially due to the difference in sample size between the studies, with Meister et al[53] being over 5 times larger. Activity specific adaptations in rotational ROM in the arms of healthy, uninjured youth and adolescents baseball players were further supported in this study. This study, however, was unable to determine the cause of the ROM adaptations, but a combination of osseous and soft tissue changes likely contribute.[140,141].

To the best of our knowledge, this is the first study looking at the rotator cuff and body weight normalized shoulder strength in healthy, uninjured youth and adolescent baseball players. We found strength of the dominant and non-dominant shoulder ranged from 12 – 14% of body weight for positions typically described to primarily test the rotator cuff and up to 18% and 25% for the composite motion of IR @ 90° and isolated elbow flexion, respectively. Unilateral ER/IR ratios were 73% for the dominant and 75% non-dominant shoulder. There was no main effect of age on the values of the body weight normalized strength for all test positions, nor were there any statistically significant differences in strength between the dominant and non-dominant shoulder. A number of studies have examined the shoulder strength profile of professional[90,142-144], high-school[145-150] and collegiate[151,152] baseball players, with most focusing on rotational strength in the abducted shoulder. Wilk et al[144] and Ellenbecker et al[143] examined shoulder external and internal rotation isokinetically in professional pitchers. Wilk et al[144] concluded that there was no significant difference between the dominant and non-dominant arm in IR and ER muscle strength and that the ER/IR ratio of the throwing arm was significantly lower than the non-throwing arm, ranging from 61% - 65% depending on the testing speed.[144] Ellenbecker et al[143] also found no significant difference between the dominant and non-dominant shoulder for ER. However, they found that the dominant shoulder IR was significantly greater. Also, the ER/IR ratio of the dominant arm was approximately 7% lower than the non-dominant arm, indicating a relative decrease in ER strength compared to IR strength on the dominant side.[143] Donatelli et al[142] also quantified the shoulder girdle strength of professional baseball pitchers, however, a hand-held dynamometer (HHD) was used instead of isokinetic testing. Similar strength patterns emerged, with relative weakness of the dominant arm ER and increase strength of the dominant arm IR compared to the non-dominant arm.[142] They reported a unilateral ER/IR ratio of 83.9% for the dominant arm and 93.3% for the non-dominant arm, when using a HHD.[142] The unilateral ER/IR ratios reported by Donatelli et al[142] are substantially higher than those reported by Wilk et al[144] and Ellenbecker et al[143] results likely display a discrepancy between isometric testing with a HHD and isokinetic testing when evaluation shoulder strength in overhead athletes. Unilateral ER/IR ratios are higher when using HHD testing and must be considered when referring to population-specific normative data.[143] Our results were more similar to Donatelli et al[142] and reflect the differences in testing devices. In 2011, Hurd et al[149] published data describing rotator cuff strength of uninjured high school pitchers, through isometric testing using a HHD. The mean age of the participants were 16 ± 1 years[149], closer approximating the mean age of the subjects in this study. Hurd et al[149] found side-to-side differences in ER, IR, and the unilateral ER/IR ratio of the abducted shoulder. In this study on youth and adolescent baseball players age 9 – 14 years, no side-to-side differences in ER, IR, or the unilateral ER/IR ratio were found. Hurd et al[149] noted that ER and the ER/IR ratio increased with age in the dominant limb. Though not statistically significant, the results of our study did show a trend to have the greatest mean dominant shoulder ER strength (14%) and ER/IR ratio (78%) in the 13 -14 year old group. However, it is possible that the younger throwers comprising the group examined in this study had not yet undergone strength profile changes seen in adolescent groups of an older mean age. Hurd et al[149] provided strength data normalized to body mass and showed the dominant shoulder mean ER strength was 17.5%, IR strength was 18.7% and the ER/IR ratio was 96%, with a 9% deficit from the non-dominant shoulder ratio. The results of our study, with a mean subject age of 11.5 years, revealed lower percentages of strength per body mass in dominant ER strength (12%), IR strength (18%), and ER/IR ratio (73%), with a more modest 2% deficit from the non-dominant shoulder ratio.

Additional studies of high school baseball pitchers[145,147], using isokinetic testing, revealed bilateral differences in IR @ 90° strength and lower ER/IR ratios than reported in this study. It is possible that the lower mean age resulted in less exposure to unilateral overload that leads to the adaptive increases in IR @ 90° strength and a lower ER/IR ratio in the dominant arm.

In 2014, Brochard et al[153] examined the shoulder strength profiles in children with and without a brachial plexus palsy. In the group of children with typical development, they found no significant differences in ER and IR and reported a dominant shoulder ER/IR ratio of 76.7% and non-dominant ratio of 76.8%.[153] It is likely that the shoulder strength profile of this group of uninjured, healthy, youth and adolescent baseball players reflects that of typical development and maturation. The findings of other studies examining shoulder strength in older baseball players would suggest that extended exposure to overhead throwing will eventually lead to adaptive changes in the shoulder strength profile.

Follow up questioning at the end of the season revealed 15/33 (45.5%) of the participants experienced some amount of pain, soreness, stiffness, or injury in the throwing upper extremity; shoulder 12/33 (36.4%), elbow 6/33 (18.2%), or both 3/33 (9.1%). These incidence findings are consistent with previous epidemiological reports in youth and adolescent baseball.[2,3,154-156] Investigations dating back to the mid 1970's have shown an incidence of elbow symptoms in 17%[154] to 20%[155] of Little League participants, with more recent data suggesting that elbow symptoms are present in 26% to 28% of youth and adolescent baseball players.[2,3] Two reports by Lyman et al[2,3] have reported incidence of shoulder symptoms to be between 32% and 35% in this population, and young throwers experiencing symptoms in either the elbow or the shoulder during a season have been reported to be has high as 47% to 51%[2,3,156]. The results of our study show similar incidence values for shoulder and upper extremity symptoms and a slightly lower percentage for elbow symptoms compared to the more recent data. The consistency of the high level of incidence is of particular concern given the amount of attention the condition has received as well as the institution of rules changes[96-98] that have been implemented and that have been based off of well-done risk factor work.[2-4,10,11]

Comparisons using t-tests identified two strength variables in the dominant arm that were significantly different between the groups with and without pain. Elevated levels of IR @ 90° strength (mean difference = .047) (p = 0.02) and a reduced ER/IR ratio (mean difference = .158) (p = 0.03) were found in the group that experienced pain. Results of the logistic regression analysis revealed similar findings, confirming the outcomes. Throwing shoulder IR @ 90° strength was found to explain nearly 22% of the variance in the presence of a seasonal complaint and had an odds ratio of 14.8, while the dominant shoulder ER/IR ratio explained nearly 19% of the variance in the presence of a seasonal complaint and had an odds ratio of 0.03. These significant predictors of a seasonal complaint, and their associated change in odds, suggest that increases in the strength of IR @ 90° and decreases in the ER/IR ratio, in the throwing shoulder, increase the odds of having a complaint throughout the season.

During pitching, the internal rotators are the primary accelerators of the throwing arm.[157,158] Pitchers acquire greater ball velocity by increasing torque of glenohumeral rotation in the late cocking and acceleration phases of throwing. Overuse injuries, that occur from cumulative microtrauma and are commonly seen in pitchers, are related to high levels of stress placed on vulnerable areas of the kinetic chain.[78] Trakis et al[62] suggested that adaptively stronger propulsive internal rotators, along with weakened or overloaded posterior cuff muscles, may contribute to pain in those adolescents fitting this profile. In a group of 9 to 12 year old baseball players, Harada et al[127] found that there was increased strength of external and internal rotation of the shoulder in a group with elbow injuries compared to those with no injury. Hurd et al[150] found that internal rotator strength was associated with peak external-rotation moment, suggesting increases in internal rotator strength escalate the demand on the posterior shoulder muscles to counteract limb acceleration. However, they questioned if the increased moments associated with the internal rotator strength represented any actual increase in risk of injury, especially at the elbow, as they found no relationship between IR strength and elbow adduction moment.[150] Likewise, in a prospective study of professional pitchers, Byram et al[90] found no association between internal rotator strength and injury that required surgical intervention. Therefore, conflicting evidence exists regarding the risk associated with increased IR strength. Our results most closely match that of Harada et al[127] with significantly higher IR @ 90° strength scores ($p = 0.02$) found in the group with pain (0.20 ± 0.05 vs. 0.15 ±0.06) despite the lack of any side to side differences in strength being present. It is possible that the conflicting results are related to the age of the participants and the amount of physical maturation that has occurred. Though the mean age of the participants in the study by Hurd et al[150] was only approximately 5 years older than this study, the differences in the unique anatomy and physiology of the growing athlete[40,159] may account for the conflicting results.

Decreases in unilateral ER/IR ratios are reported to have clinical implications secondary to the disruption of important rotator cuff force couples resulting in muscular imbalances.[90,143,144,160,161]. Trakis et al[62] examined 23 adolescent pitchers, 12 of whom had throwing-related pain in the prior season and 11 which had no such history. They found that the ER/IR ratio was no different for the group that had the history of pain compared to the group without. Conversely, Byram et al[90] prospectively found an association between the ER/IR ratio and the likelihood of throwing injury in a group of professional baseball players. The results of this study concur with Byram et al[90] indicating that a relative decrease in the unilateral ER/IR ratio of the throwing shoulder is predictive of upper extremity complaint in the ensuing season. We found that the ER/IR ratio of the dominant shoulder for those who did not experience pain was 0.87 ± 0.23 while those who experienced complaints was 0.71 ± 0.14. Unfortunately, the results of this study were unable to identify a critical ratio, but the nearly approximately 16% difference between the groups highlights the importance of the protective function of the posterior rotator cuff to offset the potentially over-developed propulsive muscles.

Performance enhancement training for baseball players often focus on the strength and power of the internal rotators, as increases in strength can produce greater limb acceleration[162] and ball velocity. The results of this study highlight the importance of properly training the external rotators not only in functional positions but in an appropriate manner of muscle activation. Maximizing the protective effect of the external rotators, while enhancing performance through strengthening of the internal rotators, would promote a more balanced ER/IR ratio potentially allowing safer, yet enhanced performance.

3.4.1 Limitations

There were several limitations to this study. The overall sample size was much smaller than many of the descriptive studies in baseball players. Despite the study being prospective in nature, the smaller sample size may have led to reduced power to identify other significant differences or predictors. In regards to the strength testing, external rotation strength was measured through maximal volitional isometric contractions in a concentric manner. However, during pitching the posterior rotator cuff's main function is to eccentrically decelerate the humerus. Potentially, a more exact or important ER/IR ratio would include eccentric testing of the external rotators. Additionally during strength testing, methods were used to best isolate specific muscles and actions. However, none of the participants were tested while strapped in or stabilized through external means. This may have allowed some degree of muscular substitution that could have affected the results. Finally, the analyses relating the ROM and strength data and the presence of a seasonal complaint of pain did not account for participant variations in other known risk factors, such as number of pitchers per game or total number of pitches for the season or year,[3,4] though independent t-tests revealed no group differences in seasonal pitch count, average pitches per game, single game high pitches, and the frequency of pitching while fatigued.

3.5 CONCLUSION

Demographic information in regards to average body morphology and participation habits as well as rotational ROM, isometric shoulder strength, pitch velocity, and predictors of seasonal complaints of upper extremity symptoms were determined for a group of youth and adolescent baseball players. Two strength variables, both of the dominant arm, IR @ 90° and the unilateral ER/IR ratio were found to be predictive of having a upper extremity throwing related compliant throughout the season. To our knowledge, the results of this study are the first to identify specific strength variables that relate to pain in this population, and warrant further investigation with a larger sample size. Additionally, the results of this study emphasis the importance of enhancing the strength and performance of the posterior rotator cuff as well as provide a general goal for the ER/IR ratio. The data also suggests that activity related adaptations begin to manifest as early as 9 – 14 years of age, though do not appear to be as advanced as they eventually become in teenage and adults years with continued baseball exposure.

4.0 ACUTE CHANGES IN THE INFRASPINATUS AND LONG HEAD OF THE BICEPS TENDONS IN ADOLESCENT BASEBALL PLAYERS IN RESPONSE TO A PITCHING PERFORMANCE

4.1 INTRODUCTION

Youth baseball has become increasingly competitive and frequently involves year-round participation[5,6,163] and high volume of play, which many times results in repetitive strain injuries. Additionally, baseball is a sport that exposes the upper extremities of youth athletes to high levels of stress, which can often result in pain, overuse injuries, and can lead to future surgical interventions or early retirement from the sport. Likely due to the interaction of the frequency and duration of participation as well as the inherent stress associated with throwing, there has been a dramatic rise in adolescent throwing injuries.[164]

While catastrophic injury rates in baseball are low, overuse injuries of the upper extremity are seen with alarming regularity. Shoulder and elbow pain in youth and Little League Baseball is a well-recognized phenomenon[1-7,11,24,163,165-168] and is an increasing concern of parents, coaches, and medical professionals. Epidemiological studies examining overuse injuries in youth baseball date back to the mid 1970's and initially focused on elbow pain alone.[154,155] In the years that followed, epidemiological studies also began to include the shoulder. In 1978, Albright et al[156] fount that upwards of 50% of Little League pitchers experienced shoulder or elbow pain during the course of one season and noted that the incidence of disability was related to the duration of exposure. More recent epidemiological studies of American youth and high school baseball players have found an incidence of shoulder pain was demonstrated in up to 35%[2,3] of pitchers every season. Another perspective of the incidence of shoulder pain with pitching can be viewed at the level of individual pitching performances, which have been shown to result in shoulder pain in over 9% of the time.[2] Furthermore, serious injury resulting in surgery or retirement from baseball in those who start pitching at 9 – 14 years old, when followed for a 10 year period, was found to have an incidence of 5% in a prospective longitudinal study.[4]

As pitchers age and develop, the risk for injury to the throwing shoulder increases.[17,168] Previous research has shown that pitching injuries are related to a number of factors[169], the most of which are associated with overuse through the course of a single game, season, or year[2-4,12] and pitching despite fatigue.[11] Based on previous research as well as expert consensus opinion, the belief is that many of the pitching injuries that require surgery or medical attention at older and higher levels of competition result from accrued microtrauma that initiates in youth baseball.[2,7] However, due to the nature of cumulative microtrauma accumulating over a number of years it is difficult to carry out a study in which a definitive cause and effect relationship can be determined.[2] Therefore, much of the established risk factor information available has not been able to include clinical data showing the physical association between a pitching performance, along with the number of pitches thrown and acute changes in tendons of interest in the throwing shoulder.

Traditional imaging methods have drawbacks such as the exposure to radiation found in x-ray and the large cost and time involved with magnetic resonance imaging. Ultrasound provides an imaging method that involves no radiation, is relatively inexpensive, and provides the ability to identify acute markers of tendon change that may relate to risk of pathology in the future.[170] The portability of ultrasound offers the ability to evaluate subjects during real-time pitching performances at the field of play. Previous research has utilized specifically designed methods and markers to establish a reference to improve reliability[112,115] of the ultrasound measurement (see Chapter 2). Work in our lab[112] has utilized a standardized protocol for more precise repeatability, resulting in intra-rater reliability from good to moderate for various aspects of quantitative ultrasound (QUS). Through gray-scale based QUS, objective, reliable measurements of tendon appearance can be obtained and may provide greater information about the etiology of injuries related to accrued microtrauma.[112,170]

Based on previous work, guidelines have been established[12,14,96,98] to help pitchers reduce the risk of injury. However, a total and complete understanding of the nature of the cumulative microtrauma as it applies to youth and adolescent pitching has not yet been obtained. Additionally, complete knowledge of and compliance with such guidelines appears to be low, placing youth pitchers at risk for upper extremity pain and injuries.[101,102] The purpose of this study was to investigate acute changes within tendons of the throwing shoulder during a pitching performance in adolescent baseball players (9 – 14 years of age). Acute changes in the infraspinatus (INF) and the long head of the biceps (LHB) tendons were examined and compared to the non-throwing shoulder to determine the effect of the pitching performance through real-time QUS imaging. We hypothesized that the INF and LHB tendons will exhibit an increased diameter and decreased echogenicity after completing the pitching performance and that the tendons of the pitching arm will show greater changes than the non-throwing arm. The results of this investigation could provide quantitative, clinical data to the risk factor work already completed, and could provide an objective explanation of the tissue changes with pitching. These findings could aid in decision making, safe play practices, and provide greater insight into the prevalent issue of throwing injuries in youth and adolescent baseball.

4.2 METHODS

4.2.1 Quantitative Ultrasound System

Ultrasound imaging was completed using a Biosound MyLab25 Gold ultrasound system, with a 4.0 – 13.0 MHz linear array transducer[1] (Esaote, North American, Inc., Indianapolis, IN). This ultrasound machine is able to freeze the image and allow visualization of the previous 5 seconds of imaging. Optimal images based on the visualization of the tendon of interest with defined tendon borders, the bone border, and the reference marker were selected and saved. The MyLab 25 Gold was easily portable and was able to be transported to the various baseball training facilities and fields.

4.2.1.1 Quantitative Ultrasound Reliability

Please see Chapter 2 for details regarding QUS reliability and methods to enhance reliability used in this study.

Prior to this study, the primary examiners underwent at least 1 year of instruction and practice with the protocol and were shown to have no less than good reliability with the variables of interest (See Chapter 2.) Secondary to lower reported inter-rater reliability[112] than intra-rater

[1] Bio Sound Esaote Inc., Indianapolis, IN

reliability (also see Chapter 2) and to make use of the high intra-rater reliability of QUS, one examiner (AP) was utilized to record images in this study.

4.2.2 Participants

Subjects were eligible to participate in this study if they were a youth or adolescent baseball player, 9 – 14 years of age, were currently playing baseball in an organized league, and reported pitching as either their primary or secondary position. Subjects were excluded if they had a history of a shoulder injury or elbow injury that resulted in surgery, an injury to the throwing arm that resulted in a loss of playing time within the last year, or if they had shoulder or elbow pain at the time of testing.

4.2.3 Testing Set Up

Intense throwing or physical activity may cause changes in the musculature that could affect baseline testing. Therefore, each subject was asked to refrain from any throwing activities in the hours prior to coming to the testing session. They were encouraged to perform the typical routines they would follow prior to a game or practice. Baseline images were collected prior to the participant warming up for their throwing activity. All images were collected bilaterally to allow comparison between dominant (throwing) and non-dominant (non-throwing) arms.

During testing, participants were asked to either wear a white tank top, a sleeveless athletic shirt, or to fold their sleeve up enough to allow full and complete visualization of the INF and LHB tendon. All subjects assumed a seated position in a standard chair. The arm being tested was kept adducted to the side of the thorax, with the elbow flexed to 90° and the forearm in full supination resting on a pad to assist maintaining the position of the elbow. Participants were cued as needed to maintain an upright posture, reducing the amount of the thoracic flexion and an excessive anterior position of the glenohumeral joint associated with poor posture. This subject position was utilized for testing of both the LHB[112] and the INF tendons.[116] (Figure 12)

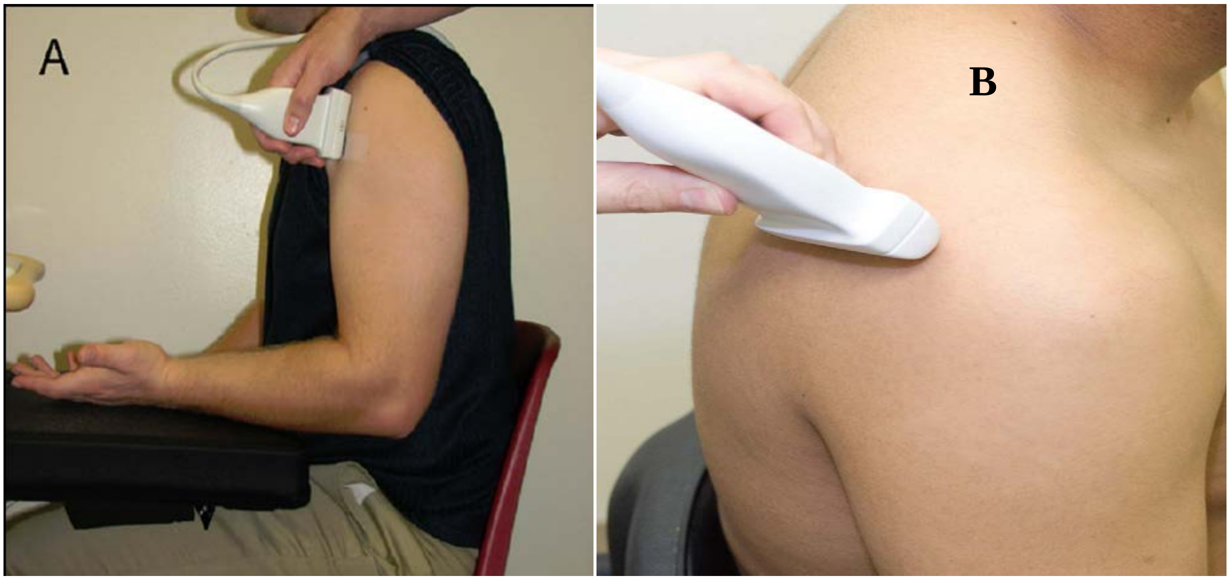

Figure 10 – QUS Testing Setup

A - Subject positioning for QUS the LHB and the INF imaging, with probe placement for LHB

B - Probe Placement for INF (modified from Jacobson, 2011[116])

Ultrasound set up was kept consistent throughout testing and across all participants. Shoulder tendon presets present in the ultrasound unit were utilized, with a depth of 4cm and a gain of 70 for the Bio Sound Esaote ultrasound machine used in the study.

4.2.4 Testing Procedure

4.2.4.1 Demographic Information

Baseline testing and examination included gathering information on basic demographics and a physical examination (Appendix B). Subjects were asked to complete a basic information questionnaire. The primary information derived from this questionnaire was: age, height, weight, throwing arm dominance, and information related to their pitching or baseball history. The questionnaire was designed specifically to obtain information on possible risk factors for injury in this population.

4.2.4.2 QUS Image of Infraspinatus tendon:

One operator (AP) performed the QUS imaging on all 50 participants. The examiner was trained in a specifically developed QUS protocol, had at least 1 year of experience, and followed the established protocol described previously by Collinger et al[112] and in Chapter 2 of this dissertation. All images were then saved for later analysis.

To establish a consistent visualization of the INF tendon, the methods utilized in Chapter 2 were performed in this aspect of the study.

4.2.4.3 QUS Image of Long Head of the Biceps

All general information regarding testing set up for LHB imaging was similar to that of the INF tendon. The examiner was trained in a specifically developed QUS protocol for the LHB tendon, had at least 1 year of experience, and followed the established protocol described in Chapter 2. All images were saved for later analysis and were presented to the investigator randomly.

The transducer location determination, reference marker and transducer placement, resultant interference pattern, and definition of ROI were similar in methodology to that of the INF.

Images before (baseline), during (at 20-25 pitches), and after (50-55 pitches) throwing were collected while ensuring that the marker was visible in the left hand aspect of the image to enhance the reliability of the serial image collection.

4.2.4.4 Pitching Protocol

All participants engaged in a standard pitching performance. Attempts were made to replicate normal game play, including use of a pitching mound set to the distance that corresponded with the age and level of play of the participant, a catcher, and use of verbal encouragement to pitch with intensity and exertion as in game play. In some of the pitching performances a batter was in place during live batting and pitching practice, however in many cases no batter was in place. Attempts were made to standardize the length of pitching, with the first pitching exposure lasting approximately 20 – 25 pitches and the second exposure lasting 25 – 30 pitches. Due to restrictions in practice schedule and time constraints the length of each pitching exposure was slightly longer than the proposed 15 pitches prior to resting. Secondary to what would be considered a long inning (>25 pitches), the participant was encouraged to pace himself as he approached 20 pitches. At the end of both pitching exposures, the pitcher reported any discomfort in the shoulder and or elbow region and the perceived level of exertion during the preceding pitching performance. Serial QUS images took place after the first and second pitching performance. The testing session / pitching performance ended for a pitcher when he achieved one of the following conditions: reached the final time-point (50 pitches) (48/50 subjects) or if they reported any pain with throwing (2/50). The original proposal was for participants to continue pitching for an additional 25 pitches to a final limit of 75 pitches. However, having participants pitch to the 75 pitch limit, while within the age-adjusted guidelines set by American Sports Medicine Institute (ASMI) and the USA Baseball Medical & Safety Advisory Committee[12,96] and Little League Baseball[14] was not allowed by the involved coaches. All coaches involved stated that they did not have their pitchers pitch to the point of 75 pitches in the pre-season or early in the season, when testing was taking place. Therefore, all pitching exposures were limited to 50 pitches.

A numeric rating scale of pain intensity and a perceived exertion scale were utilized before, during, and after the pitching performance. The Numeric Rating Scale (NRS)[171-173] required the participant to rate their pain from 0 to 10 (11 point scale), with the understanding that the 0 represented the absence or null end of the pain intensity continuum (i.e. no pain) and the 10 represented the other extreme of pain intensity (i.e. pain as bad as it could be). The number that the participant selected represented their pain intensity score. Participants completed this scale at baseline and at the time of the serial ultrasounds. The OMNI-RES[131,174] scale contains both a verbal and pictorial description of effort along a response range of 0 to 10. The scale required the participant to rate their perceived level of exertion from 0 to 10 (11-point scale), with the understanding that the 0 represented working extremely easy and the 10 represented the other extreme of perceived exertion (i.e. perceived effort is deemed extremely hard). The number that the participant selected represented his ratings of perceived exertion score. Participants completed this scale at baseline and at the time of the serial ultrasound.

4.2.4.5 Analysis of the Tendon Images

Images were analyzed using an interactive Matlab program developed by researchers at the Human Engineering Research Laboratory (HERL) at the University of Pittsburgh. The analysis of the images was described in detail in Chapter 2. Please refer to Chapter 2, section 2.2.4 for details.

4.2.5 Data Processing

Please see Appendices C and D for a detailed description of the protocol for image and data processing.

4.2.5.1 Statistical Analysis

Intraclass correlation coefficient (ICC) (model = one way, average measures) were determined from the measurements of the non-dominant tendon for the LHB and the INF tendons. Standard error of the measurement (SEM) and minimal detectable change (MDC) were then calculated using the following formulas: SEM = SD from 1st measure * (√(1-ICC) and MDC = 1.96 * SEM * √2.

Basic descriptive statistics (means, standard deviations, frequencies) were calculated for all participants as well as the throwing and non-throwing arms. Discrepancies between the throwing and non-throwing shoulders were determined through a paired t-test, when assumptions of normality were met, or a Mann-Whitney U test when a normal distribution was not assumed, for all continuous variables. Differences between the 3 age groups were tested with an analysis of variance (ANOVA) comparing group means of each age group when a normal distribution was assumed and a Kruskal-Wallis H test when normality was not assumed. For instances were significant differences were found in the ANOVA, post-hoc comparisons with a Bonferroni correction were used to locate the differences. For instances of where differences were identified in mean ranks, individual comparisons were run with an alpha level adjusted for multiple comparisons. For categorical variables that could vary between the throwing and non-throwing shoulders, the proportion in each category was calculated and the overall difference between the two sides was tested using a McNemar at $\alpha = 0.05$ significance level. To perform analysis between the proportions in three age groups, a Pearson Chi-Square test was performed on all categorical variables to determine if an overall difference was present between the groups. In instances where an overall difference between groups existed, post-hoc analysis was conducted using a Bonferroni correction in order to correct for multiple comparisons.

The primary statistical analysis in this aspect of the study related to the status of the QUS measures, specifically tendon width and echogenicity, of the LHB and the INF tendons of each participant. Repeated-measures analyses of variance (RM-ANOVA) were performed to test the main effect of pitch count (0, 20 – 25, and 50) on each descriptor of the LHB and INF tendons. Each pitch count number corresponded with a specific time-point for the analysis (i.e. 0 pitches was time-point 1, 20-25 pitches was time-point 2, and 50 pitches was time-point 3). The analysis was run with no modifiers or covariates. When appropriate, post-hoc analyses were performed to determine if baseline and serial QUS measures were significantly different from one another. Post-hoc testing compared all possible combinations for within subject changes in the throwing and the non-throwing shoulders. Pairwise t-tests were performed to determine differences within both the throwing and non-throwing shoulder at multiple time-points (time 0 vs. time 1), (time 0 vs. time 2), (time 1 vs. time 2) with the use of a Bonferroni correction to control multiple comparisons.

A between factor analysis was performed to investigate for differences between effects in the throwing versus non-throwing shoulders over the 3 time-points. A two-way repeated measures ANOVA was performed to compare the mean difference between the pitching shoulder and the non-throwing shoulder in terms of acute changes in tendon seen with pitching from baseline to 50 pitches. If significant differences were found, post-hoc analyses were conducted using pair-wise independent t-tests, and a Bonferroni correction to adjust for multiple comparisons. All statistical analyses were completed with IBM SPSS Statistics Software, version 22 (Armonk, NY: IBM Corp.)

4.3 RESULTS

4.3.1 Intra-rater reliability, SEM, and MDC

Reliability statistics were re-run with our larger sample size as compared to Chapter 2. Results showed high intra-rater reliability for the QUS variables, in particular tendon width and echogenicity for the LHB (> 0.87) and the INF (> 0.82). SEM for the LHB tendon width (0.207) and INF tendon width (0.155) was determined as was their respective MDC's 0.57 and 0.43). All other statistics related to intra-rater reliability and the QUS variables can be found below.

Table 26: ICC, SEM, MDC of QUS

Variable	ICC(1,1)	SEM	MDC
LHB width	**0.91**	**0.204**	**0.565**
LHB echogenicity	**0.86**	**7.988**	**22.143**
LHB Variance	0.73	242.863	673.182
LHB Skewness	0.80	0.233	0.645
LHB Kurtosis	0.75	0.520	1.441
LHB Entropy	0.60	0.133	0.368
LHB Contrast	0.75	0.875	2.425
LHB Energy	0.62	0.068	0.188
LHB Homogeneity	0.73	0.078	0.216
INF width	**0.94**	**0.152**	**0.421**
INF echogenicity	**0.80**	**10.241**	**28.387**
INF Variance	0.37	280.987	778.855
INF Skewness	0.74	0.398	1.102
INF Kurtosis	0.61	1.049	2.908
INF Entropy	0.41	0.215	0.596
INF contrast	0.24	0.968	2.682
INF Energy	0.50	0.141	0.392
INF Homogeneity	0.42	0.114	0.317

4.3.2 Differences in Demographics Between Age Groups

Fifty healthy, male, uninjured individuals (age= 11.60 years, height= 156.67cm, weight= 49.38 kg, BMI= 19.71) (n of each age: 9 y/o =4; 10 y/o =5; 11 y/o =18; 12 y/o =7; 13 y/o =12; 14 y/o =4) participated in this study, which was approved by the Institutional Review Board of the University of Pittsburgh. No participants of female gender were enrolled. Consent of each participant and parent or guardian was obtained prior to the study. Basic demographic information for the entire sample (n = 50) can be found in Table 27 along with similar information for each age group. Two participants were unable to continue pitching and further testing secondary to the following reasons: pain in the throwing arm (1) and time-constraint (1). Therefore, 48 complete pitching performances and data sets were available for QUS analysis.

Table 27: Basic Demographic Information

	9 - 10 y/o			11 - 12 y/o			13 - 14 y/o		
Variable	**Mean ± (SD)**	**Freq.**	**Perc.**	**Mean ± (SD)**	**Freq.**	**Perc.**	**Mean ± (SD)**	**Freq.**	**Perc.**
Age	9.56 ± 0.53			11.28 ± 0.46			13.25 ± 0.45		
Height	141.96 ± 9.37			152.70 ± 7.31			171.13 ± 8.08		
Weight	38.05 ± 9.72			43.82 ± 8.97			64.44 ± 13.42		
BMI	18.77 ± 3.42			18.70 ± 3.17			21.82 ± 3.05		
No. of Leagues	2.0* ± 0.87	Range (1.0 – 4.0)		2.0* ± 0.74	Range (1.0 – 3.0)		2.0* ± 0.86	Range (1.0 -4.0)	
Yrs. Pitched	2.0* ± 0.78	Range (1.0 – 3.0)		3.0* ± 1.07	Range (2.0 – 6.0)		5.5* ± 1.92	Range (1.0 -8.0)	
Throw. Arm Right		6/9	66.7		20/25	80.0		13/16	81.3
1° Position Pitcher		5/9	55.6		11/25	44.0		6/16	37.5
2° Position Pitcher		4/9	44.4		14/25	56.0		10/16	62.5

Table 27 (continued)

	Total Sample (n = 50)		
Variable	**Mean ± (SD)**	**Freq.**	**Perc.**
Age	11.60 ± 1.39		
Height	156.67 ± 13.29		
Weight	49.38 ± 14.94		
BMI	19.71 ± 3.44		
No. of Leagues	2.0* ± 0.82	Range (1.0 – 4.0)	
Yrs. Pitched	3.0* ± 1.78	Range (1.0 – 8.0)	
Throw. Arm Right		39/50	78.0
1° Position Pitcher		22/50	44.0
2° Position Pitcher		28/50	56.0

As expected, the oldest age category was found to be significantly taller F(2, 47) = 45.11, $p < .001$ and weigh more F(2,47) = 24.24, $p < .001$ than both of the younger age categories, and had a higher BMI F(2, 47) = 5.18 $p = .01$ than the 11 – 12 y/o. The median value for the number of leagues that each age group participated in was 2 and there was no significant difference between the age groups $X^2(2) = 3.91$, $p = 0.14$. Additionally, there was no group difference in the proportion of: right-handed throwers $X^2(2) = 0.83$ $p = 0.66$, primary position of pitcher $X^2(2) = 3.75$, $p = .99$, and secondary position of pitcher $X^2(2) = 10.98$, $p = 0.81$. However, the was a difference between groups in the number of years pitched $X^2(2) = 20.51$, $p < .001$, with the 13 – 14 year old group having a median of 5.5 years pitched compared to a median of 2 years pitched for the 9 – 10 and 3 years pitched for the 11 -12 year old group. Post-hoc tests between groups using the Mann-Whitney U tests were significantly different at an adjusted alpha level of 0.017 (Table 28) between the oldest age category and the younger age groups.

Table 28: Age group comparisons on baseline demographic data

	Test Statistic F or χ^2*	p-value	Post-hoc Groups and p-value	Groups and CI's
Height	45.11	<.001**	2 vs. 1 = .003 3 vs. 1 < .001 3 vs. 2 < .001	2 vs. 1 = (3.08 - 18.41) 3 vs. 1 = (20.96 - 37.39) 3 vs. 2 = (12.11 - 24.74)
Weight	24.24	<.001**	3 vs. 1 < .001 3 vs. 2 < .001	3 vs. 1 = (15.31 - 37.46) 3 vs. 2 = (12.11 - 29.13)
BMI	5.18	0.01**	3 vs. 2 = .019	3 vs. 2 = (.59 - 5.64)
Years Pitched	20.51*	0.00**	3 vs. 1 < .001 3 vs. 2 = .002	**Medians** 1 = 2.0 2 = 3.0 3 = 5.5
# of leagues	3.91*	0.14	-	-
Throwing arm Right	0.830*	0.66	-	-
1 ° position pitcher	3.750*	0.99	-	-
2° position pitcher	10.98*	0.81	-	-

4.3.3 Acute Changes in the LHB and INF Tendons in Response to Pitching

The mean, standard deviation, and change values (difference when time-point 2 or time-point 3 was subtracted from time-point 1) were determined for echogenicity and tendon width at each of the three time points in the LHB and the INF tendons (Tables 29, 30).

Table 29: Echogenicity - Mean, Standard Deviation, Change values

Tendon	Arm side	n	Echo. Time 1 mean ± (SD)	Echo. Time 2 mean ± (SD)	Echo. Time 3 mean ± (SD)	Change Time 1 - 2	Change Time 1 - 3
LHB	Dominant	48	125.85 ± 19.83	125.20 ± 16.56	124.82 ± 19.60	-0.64	-1.03
LHB	Non Dominant	44	125.56 ± 21.49	129.13 ± 16.62	127.32 ± 16.48	3.57	1.72
INF	Dominant	50	128.65 ± 23.03	130.83 ± 2.56	129.76 ± 21.96	2.88	1.81
INF	Non-Dominant	46	129.86 ± 22.81	131.12 ± 17.98	127.86 ± 18.27	2.18	-1.08

Table 30: Tendon Width - Mean, Standard Deviation, Change values

Tendon	Arm side	n	Width Time 1 mean ± (SD)	Width Time 2 mean ± (SD)	Width Time 3 mean ± (SD)	Change Time 1 - 2	Change Time 1 - 3
LHB	Dominant	48	4.05 ± 0.78	4.03 ± 0.76	4.24 ± 0.71	-0.03	0.18
LHB	Non-Dominant	44	4.41 ± 0.68	4.28 ± 0.87	4.42 ± 0.81	-0.13	-0.00
INF	Dominant	50	4.40 ± 0.63	4.51 ± 0.34	4.60 ± 0.65	0.13	0.21
INF	Non-Dominant	46	4.45 ± 0.63	4.43 ± 0.59	4.40 ± 0.63	-0.02	-0.05

4.3.3.1 Within-Subject Changes in Dominant and Non-Dominant Shoulders

The primary aim of this study was to determine acute QUS changes in response to pitching. Repeated Measures ANOVA (RM-ANOVA) were performed on the INF and LHB tendons and examined QUS variables of echogenicity and tendon diameter of the throwing and non-throwing arm separately. Echogenicity of the LHB, $F(2, 94) = 0.10$, $p = .91$, and the INF, $F(2, 94) = 0.66$, $p = 0.52$, tendons in the throwing arm were not significantly different throughout the three time points. Similar results were found in the non-throwing arm for both the LHB, $F(2, 86) = 1.37$, $p = 0.26$, and the INF, $F(1.72, 77.28) = 0.54$, $p = 0.56$, tendons. We accepted the null hypothesis that the echogenicity in the tendons were essentially equal throughout the pitching protocol (Table 31).

Table 31: Within-subject effects of Echogenicity (RM-ANOVA)

Within subjects effects of Echogenicity (RM-ANOVA)				
	F-value	**Sig.**	**Effect size (ηp2)**	**Obs. Power**
LHB (Dominant)	0.10	0.91	0.002	0.06
LHB (Non Dom)	1.37	0.26	0.031	0.27
INF (Dominant)	0.66	0.52	0.014	0.16
INF (Non Dom)	0.54	0.56	0.012	0.13

Within-subject analysis of tendon diameter revealed statistically significant differences in both tendons of the throwing shoulder. RM-ANOVA of the dominant LHB, $F(2, 94)= 6.53$, $p = 0.002$, was significant, with post-hoc comparisons revealing a difference between the baseline (Time-point 1) diameter value and the value at the completion of 50 pitches (Time-point 3) (Mean difference = 0.18, $p = 0.03$), Cohen's d effect size = 0.25, 95% confidence interval (0.02 – 0.35). A larger post-hoc difference was found between time-point 2 and time-point 3 for the LHB (Mean difference = 0.21, $p = 0.00$, Cohen's d effect size = 0.29, 95% confidence interval (0.08 – 0.35). RM-ANOVA of the INF was shown to violate the assumption of sphericity, $X^2 (2) = 6.122$, $p = 0.047$. Therefore, the more conservative correction of the f-value, the Greenhouse-Geisser correction was used. This correction resulted in a significant within-subjects effect for tendon diameter of the INF, F(1.78, 83.58) = 4.85, *p* = 0.01 of the dominant shoulder. Post-hoc comparisons revealed a significant difference between the baseline (Time-point 1) diameter value and the value at the completion of 50 pitches (Time-point 3) (Mean difference = 0.22, *p* = 0.03, Cohen's *d* effect size = 0.31, 95% confidence interval (0.02 – 0.41)

Table 32: Within-subjects effects of Diameter (RM-ANOVA)

Within subjects effects of Diameter (RM-ANOVA)					
	n	**F-value**	**Sig.**	**Effect size (η_{p2})**	**Obs. Power**
LHB (Dominant)	48	6.53	0.002*	0.12	0.90
LHB (Non Dom)	44	1.70	0.19	0.04	0.35
INF (Dominant)	48	4.85	0.01**	0.09	0.75
INF (Non Dom)	46	0.38	0.65	0.01	0.11
Post-hoc comparisons with Bonferroni Correction					
Pairwise comp.	**mean diff.**	**St'd. error**	**Sig.**	**Effect size (*d*)**	**95% CI**
1 – 3* (LHB)	0.18	0.07	0.03	0.25	(0.02 – 0.35)
2 – 3*(LHB)	0.21	0.06	0.00	0.29	(0.08 – 0.35)
1 – 3**(INF)	0.22	0.08	0.03	0.31	(0.02 – 0.41)

4.3.3.2 Two-way RM-ANOVA with Comparison of Pitching and Non-pitching Shoulders

The two-way RM-ANOVA for the LHB revealed no statistically significant effects for either the main effect of pitch count F(2, 84) = 0.77, *p* = 0.47 or the interaction of pitch count and throwing arm side F(1.66, 69.69) = 0.44, *p* = 0.61 for the QUS variable of echogenicity. Two-way analysis of tendon diameter for the LHB was not significant for the interaction of pitch count and throwing arm side F(2, 84) = 0.88, *p* = 0.42. However, the main effect of pitch count was statistically significant F(1.60, 67.62) = 5.96, *p* = 0.01) for the LHB tendon. Post-hoc analysis of pairwise comparison adjusted for multiple comparisons, showed a significant difference between pitches 20-25 (time-point 2) and 50 (time-point 3) for LHB tendon diameter (mean difference = 0.17, *p* = 0.001, Cohen's *d* effect size = 0.26, 95% CI (0.06 – 0.28)). A simple contrast, with no adjustment for multiple corrections, verged on significance for pitch count between the baseline (time-point 1) value and 50 pitches (time-point 3), F(1,42) = 3.60, p = 0.07, effect size r = 0.28 (Table 33).

Table 33: LHB: Two-way RM-ANOVA

Biceps: Two-Way RM-ANOVA (IV's pitch count & throwing side)					
	n	**F-Value**	**Sig.**	**Effect size ($\eta_{p}2$)**	**Obs. Power**
Echogenicity	43				
Pitch count		0.77	0.47	0.02	0.08
Pitch count * throwing side		0.44	0.61	0.01	0.11
Tendon Diameter	43				
Pitch count		5.96	0.01	0.12	0.81
Pitch count * throwing side		0.88	0.42	0.02	0.20
Post-hoc comparisons with Bonferroni Correction (Dominant Shoulder, Diameter)					
Pitch count	**mean diff.**	**St.'d error**	**Sig.**	**Effect size (*d*)**	**95% CI**
1 -2	0.09	0.06	0.418	0.05	(-.059 - .241)
1 -3	0.08	0.042	0.194	0.21	(-.025 - .184)
2 -3	0.17	0.044	0.001	0.26	(0.06 – 0.28)
Simple Contrasts without correction for multiple comparisons (Dominant Shoulder, Diameter)					
Pitch count	**F-value**	**sig.**		**Effect Size (*r*)**	**Obs. Power**
1 - 3	3.60	0.07		0.28	0.46

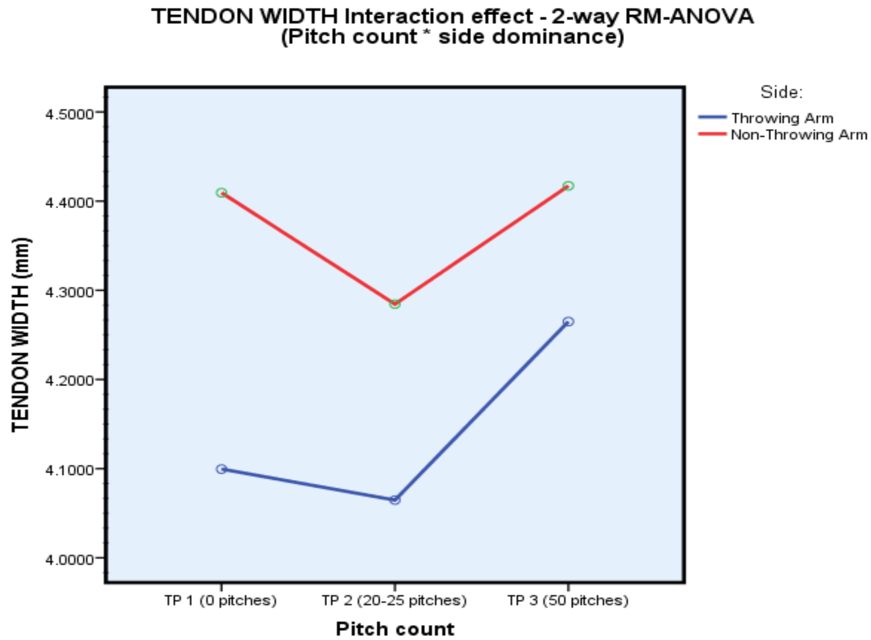

Figure 11: LHB interaction of pitch count and arm side

The two-way RM-ANOVA for the INF tendon also revealed no statistically significant effects of either pitch count $F(2,86) = 0.75$, $p = 0.48$ or the interaction of pitch count * throwing side $F(2, 86) = 0.28$, $p = 0.76$ for the QUS variable of echogenicity. Two-way analysis of tendon diameter for the INF was not significant for the main effect of pitch count $F(2, 86) = 1.83$, $p = 0.17$. The interaction of pitch count * throwing arm side showed a significant effect of the interaction, $F(2, 86) = 4.94$, $p = 0.01$. This indicates that pitch count had different effects on the diameter of the INF depending on which shoulder was measured. To further investigate the interaction, contrasts were performed comparing pitch counts at time-points 2 and 3 to the baseline tendon diameter when differentiated by arm side. These contrasts revealed an effect that was significant for the baseline value compared to time-point 2 (20-25 pitches), $F(1, 43) = 4.10$, $p = 0.049$, $r = 0.30$ and a significant interaction when comparing baseline to time-point 3 (50 pitches), $F(1, 43) = 7.84$, $p = 0.01$, $r = 0.39$(Table 34).

Table 34: INF Two-way RM-ANOVA

Infraspinatus: Two-Way RM-ANOVA (IV's pitch count & throwing side)					
	n	**F-Value**	**Sig.**	**Effect size (ηp2)**	**Obs. Power**
Echogenicity	44				
Pitch count		0.75	0.48	0.02	0.17
Pitch count * throwing side		0.28	0.76	0.01	0.09
Tendon Diameter	44				
Pitch count		1.83	0.17	0.04	0.37
Pitch count * throwing side		4.94	0.01	0.10	0.80

Tests of Within-Subjects Contrasts / Pitch count * side (Diameter)				
Pitch count * Throwing side	**F-value**	**sig.**	**Effect Size (*r*)**	**Obs. Power**
1- 2	4.10	0.05	0.30	0.51
1 - 3	7.84	0.01	0.39	0.78

Looking at the graph of the interaction, the effect of pitch count on the non-dominant shoulder was negligible (change score TP1 – TP3 = -0.05, SEM = 0.152). However, the dominant arm showed a significant divergence from the non-dominant arm in the direction of increased tendon width (change score TP1 – TP3 = 0.21, SEM = .152) (Figure 28).

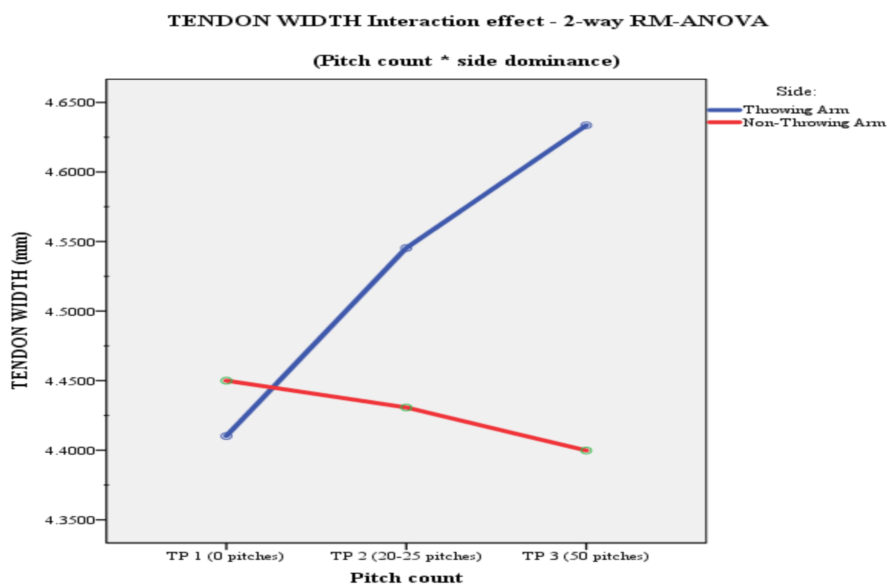

Figure 12: INF interaction of pitch count and arm side

The amount of change in the dominant shoulder LHB (Figure 29) and INF (Figure 30) tendons for each subject are shown below. Mean change experienced in the LHB was determined to be 0.18mm and ranged from -1.06mm to 1.50mm. Mean change in the dominant INF tendon was 0.21mm, with a range of -1.48mm to 1.24mm.

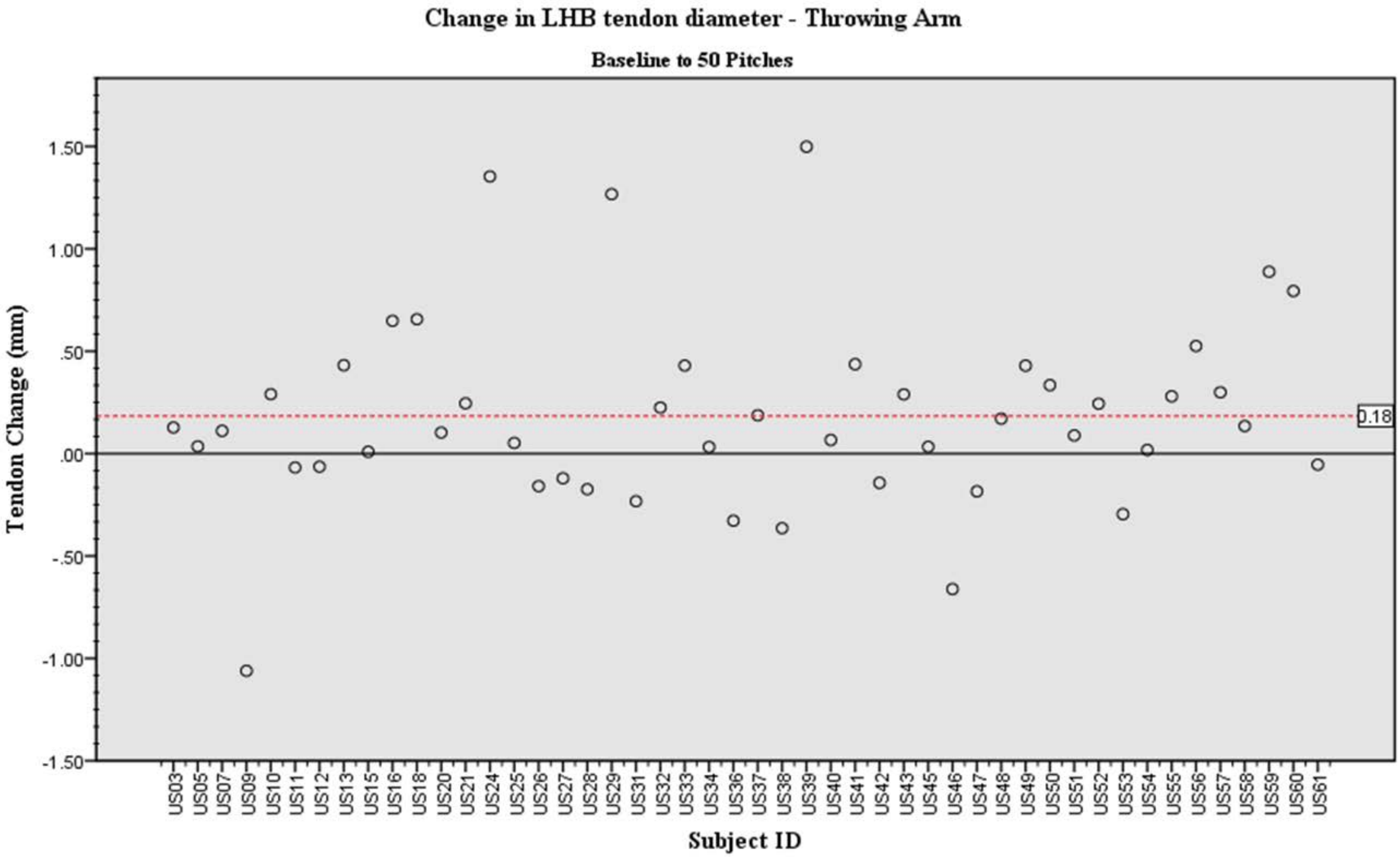

Figure 13: Individual Change in LHB with Pitching

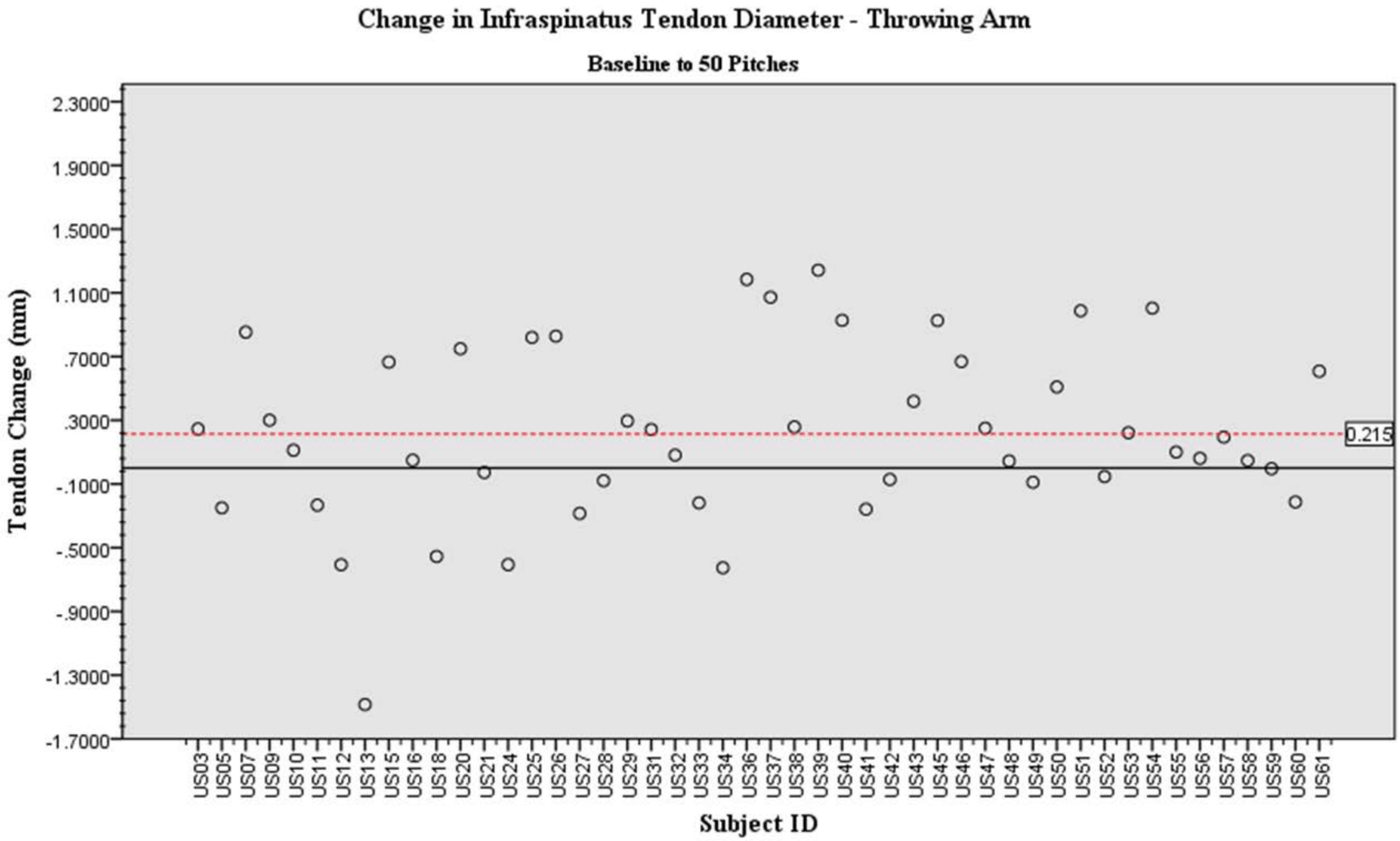

Figure 14: Individual Change in INF with Pitching

4.4 DISCUSSION

There were no unexpected findings in the baseline demographic or physical examination data in our sample. When examining for difference between the age groups that comprised the entire sample, expected differences were found that were consistent with physical maturation and were not used as covariates in the RM-ANOVA analysis. Intra-rater reliability statistics determined with a sample size of 50 showed an improvement over the limited sample reported in Chapter 2. In particular, improvements in reliability of the LHB tendon analyses were seen and further confirm the reliability of the protocol and the examiner.

The main objective of this study was to determine if changes occurred in tendons of the shoulder during a pitching exposure. Further, this study also sought to compare the effects of pitching on the throwing versus the non-throwing shoulders. Acute changes in tendons of the shoulder have been shown to occur in response to other upper extremity activities[170], however, such changes have yet to be documented in youth and adolescent pitchers. The results of this study indicate acute changes occur in the LHB and INF tendons of the throwing shoulder in response to pitching. Tendon diameter of the LHB was shown to increase 0.18mm and 0.21mm from baseline and time-point 2 to time point 3 (50 pitches) respectively, with the amount of change exceeding the standard error of the measurement (SEM) for LHB, suggesting the throwing arm experienced a statistically significant change in tendon diameter that exceeded the error of measurement. Tendon diameter of the INF was shown to increase 0.21mm from baseline to time-point 3 (50 pitches), with the amount of change exceeding the SEM, again suggesting the throwing arm experienced not only a statistically significant change in tendon diameter, but also one that exceeded measurement error.

No differences were noted in tendon diameter in the non-throwing arm when compared at any time-points. Exercise or high intensity loading and activity can stimulate adaptations in tendons that can be positive, but also may play a role in development of tendon injuries.[175,176] In a systematic review published in 2012, Tardioli, Malliaras, and Maffulli[176] concluded that exercise leads to acute responses in the loaded tendon which include collagen turnover, increased blood flow, and in influx of inflammatory products. Mechanical property changes such as these are influenced by both the activity duration and intensity and may lead the tendon to resemble one in a pathological state.[176] An association between thickened tendons and tendonopathy has been established in a more chronic state.[177] In regards to acute effects, additional studies have shown a non-significant trend toward increased tendon thickness with activity.[178,179] The investigation by van Drongelen et al[179] examined acute changes of the biceps tendon after a high-intensity wheelchair sport activity. They found an increase in tendon diameter of 0.22mm post activity, (Cohen's d = .24) that was positively correlated with the duration of play, suggesting the duration of exposure may be an important determinant.[179] However, a noted limitation of the study was that not all subjects were tested immediately post-activity and some were not tested for up to 30 minutes after the event,[179] while Fredberg, et al's[178] investigation of acute changes in Achilles tendon thickness post activity took place after 20 minutes of rest. The changes in tendon thickness in this study were based off of measurements taken immediately (within 5 minutes) after the completion of the throwing activity. The timing of the ultrasound measurement may account for some of the difference noted in tendon thickness significance between the studies. Interestingly however, the investigation by van Drongelen,[179] which most closely resembles this study in terms of tendon of interest and sport activity, had a very similar effect size (Cohen's d = .24 vs. .26). Our investigation did not account for factors outside of pitching that may have contributed to change seen in the tendons. High metabolic activity is present in human tendons and allows the tendon to adapt to changing demands.[180] Factors such as the history and rate of mechanical loading, temperature fluctuations, and fluid shifts have been proposed to stimulate changes in tendon properties.[180,181] Additionally, human tendon tissue has been reported to be composed of approximately 62% water,[182] but ranges from 60 – 80%, suggesting that fluid status could also vary amongst participants. However, we believe that the relative stability of echogenicity, both across participants and within the tendons during pitching, is a reflection of the fluid status in the tendon and would not suggest that the changes seen were secondary to fluid status or other factors outside of the mechanical loading with pitching.

When the throwing and non-throwing arms were compared, the INF tendon of the dominant, throwing arm experienced an acute change in tendon diameter that was significantly different from the non-dominant arm in response to pitching. These acute changes to the tendon may be part of a continuum that leads to pain and more chronic pathology over time,[179] however, this study does not provide proof of this relationship. Traditionally, there has been consensus that tendons endure subclinical, but cumulative damage, over a period of time prior to identified pathology.[183] The tendinosis continuum is generally believed to begin with mechanical overloading that surpasses the repair mechanisms.[183,184] Cook and Purdham[185] proposed a model of tendinopathy, based on clinical and basic science evidence, that presents along a continuum. They suggested 3 stages that begin with a reactive tendinopathy, in which there is a non-inflammatory proliferation response in the tendon that occurs in response to acute overload. This non-inflammatory proliferation results in a short-term thickening of the tendon. Cook and Purdham put forward that the short-term thickening acts to reduce stress by increasing cross-sectional area or by allowing adaptation to compressive forces that increases the stiffness of the tendon. Thickening of the tendon has been shown on both MRI and US scans, clinically as being seen in an acutely overloaded tendon most commonly in younger persons.[185] They describe continued or chronic overload leading to tendon disrepair and degenerative tendinopathy.[185] It is important to stress, that this model is mostly supported by cross-sectional studies and animal models and requires scientific and clinical evaluation to further validate. If this model were to be supported, the acute tendon thickening in response to pitching seen in this study may be described as a reactive tendinopathy, however, further investigations would be required to determine any relationship between the acute response and pathology. Adding or removing the load on the tendon, in this case pitching, would then drive the tendon further down the continuum or allow it to revert back closer to its original state, especially in the early stages.[185,186] Applying this principle to the tendons of youth and adolescent pitchers, would suggest that it is vital to monitor for acute overload that would proceed further down the continuum and that adequate rest and recovery should be utilized to allow the tendon to return to its original state.

The results occurred as early as the 50 pitch mark. Additionally, the upward trajectory of the graph of tendon width for both the LHB and the INF tendons would suggest that continued pitching beyond this point might result in continued acute changes in tendon diameter (Figures 13 & 14). The link between increased pitching and shoulder pain and pathology has been documented.[2-4,12] However, due to the slow development of cumulative trauma over a number of years, it has been difficult to carry out a study in which a definitive cause and effect relationship could be determined.[2] To our knowledge, this is the first study to show clinical data that suggests pitching at least 50 pitches results in acute changes in tendon architecture, however whether these changes are normal or potentially related to pathology could not be determined by this study, nor could the effects of the individual variations seen in tendon diameter changes.

Multiple organizations have established and implemented guidelines and pitching rules in attempts to prevent youth pitching injuries.[13,14,187] Lyman et al[3] found that risk for shoulder pain increased with throwing more than 75 pitches per game. In fact, every 10 pitches thrown in a game resulted in significantly increased odds of experiencing shoulder pain. Pitchers throwing in the highest category (>75 pitches) were 3.2 times more likely to experience shoulder pain than the lowest pitch count category (< 25 pitches). They concluded that to lower the risk of injury, young pitchers should not throw more than 75 pitches per game.[3] Lyman et al[2] followed up the previous study with a prospective cohort study examining the effect of pitch type, count, and mechanics on risk of upper extremity pain in youth baseball pitchers. They found a significant association between the number of pitches thrown in a game and during the season and the rate of shoulder and elbow pain. In fact, they noted that there was a 52% increase in the risk of shoulder pain at the 75-99 pitches per game level. The investigation by Lyman et al[2] represented the strongest evidence at that time to limit pitchers to 75 pitches per game. In 2006, Olsen et al[11] found a 4 fold increase in risk for having a surgical history with throwing more than 80 pitches per game. The results found by Olsen et al[11] were significant in that this was the first study to be able to show an association between overuse and actual serious injury as opposed to only arm complaints. The results of this study correspond with the findings above. In fact, the acute change in tendon thickness was seen approximately 25 pitches sooner than the current guidelines recommend as a single exposure limit. We are unable to determine if the detected acute change in tendon thickness represents an increased risk of pain or pathology from these results. Based on the evidence available it is possible that the observed changes noted in this study fall on the tendinopathy scale, most likely at the earliest, reversible stages. Conversely, the changes could merely represent a normal response for a single pitching exposure, with the accrued effects during a season or year being more representative of cumulative microtrauma. Though we could not determine the exact effect the changes seen in this study have on injury, the individual variation in response to pitching could be a predictor of injury.

Further work investigating individual acute responses and their relation to pain is needed to make this determination.

4.4.1 Limitations

The results of this study are based on a relatively small and homogenous group of youth and adolescent pitchers with no previous history of throwing injury over the past year and no current complaints with throwing. To determine if individuals with a relatively recent history of pathology react differently to pitching, it is also important to evaluate the acute effects on other populations. Some of the pitchers were tested while they were throwing in a competitive situation, i.e. pitching to a batter. However, when such a practice situation was not available, pitchers threw to a catcher, coach, or net with no batter. Without a batter being in place, intensity and effort may not have reached maximum levels. Exactly which pitchers threw to a batter was not recorded. However, review of the data showed the amount of change in tendon diameter was not significantly correlated with post-throwing ratings of perceived exertion. Testing took place at team facilities, during practice activities. The actual live practice setting was preferable to recreate a game-like environment, however lacked in the ability to provide high levels of control of extrinsic factors. We performed QUS imaging on an aspect of the LHB with an orientation to optimally image the widest part of the tendon, while maximizing collagen fiber reflection. This resulted in imaging an aspect of the LHB that was located in the approximately inferior one-third of the bicipital groove. We acknowledge that there are likely limitations in imaging the LHB tendon in this location as opposed to the proximal origin on the surpaglenoid tubercle and superior glenoid labrum. Significant biceps activity occurs in the follow-through phase and to a lesser extent the late cocking phase of throwing. The eccentric loading of the LHB during follow-though transfers large forces to the biceps anchor at its proximal insertion and the torsional force associated with the abducted and externally rotated position has been shown to cause a peeling back of the biceps anchor at it proximal insertion.[188,189] It is possible that our QUS analysis would have provided more information if we were to image the location of the tendon that is most frequently involved in pathology secondary to repetitive mechanical loading. However, a compromise was made in order to obtain reliable images of healthy tendons during a sports activity as a representation of overall tendon behavior, leading to the decision to image the widest part of the tendon. Finally, and most notably, the coaches and parents who participated in the study were not willing to pitch beyond 50 pitches, especially during pre-season practices. We believe that with continued pitching beyond this point would have resulted in greater acute changes in the tendons of interest. We recommend future testing on acute tendon changes with pitch count progressing to at least the 75 pitch amount to further demonstrate the changes that occur during extended pitching performances.

4.5 CONCLUSION

QUS immediately before, during, and after a pitching exposure was able to identify an acute increase in tendon diameter in both the LHB and the INF tendons. There was no associated decrease in echogenicity. Within-subject testing was significant for the throwing shoulder in both the LHB and the INF tendons and was non-significant for the non-throwing shoulder. A detected increase in tendon diameter as early as 50 pitches could indicate a reactive response of the tendon in response to the overload experienced during pitching, which is visible 25 pitches sooner than the current upper limits of the pitch count recommendations for this age group. Our results agree with previous risk factor work found in other studies expressing the importance of limiting potentially damaging cumulative overload to the tendon and allowing adequate rest that permits more complete tendon recovery. QUS shows promise in identifying potentially pathological conditions in tendons of the throwing shoulder however, additional work is needed to identify the effects at higher pitch counts and its correlation to the development of pain or pathology as well as the factors related to individual variations in tendon response.

5.0 QUANTITATIVE ULTRASOUND PREDICTORS OF THE PRESENCE OF SEASONAL UPPER EXTREMITY PAIN IN A YOUTH AND ADOLESCENT BASEBALL POPULATION

5.1 INTRODUCTION

Youth and adolescent baseball pitchers, as well as pitchers of all ages, are at increased risk for shoulder and elbow injuries compared to their non-pitching counterparts.[37,38] Over the past approximately 15 years, there has been a dramatic rise in the number of surgical and medical interventions performed in older, high school and collegiate baseball players[11,74], leading to the belief that many of these procedures are the result of cumulative microtrauma that initially started in at the youth level.[7] However, due to the slow development of the cumulative microtrauma over a number of years, it has been difficult to carry out a study in which a definitive cause and effect relationship can be determined.[2]

Previous research has identified multiple risk factors that were related to increases in either shoulder or elbow pain in a youth and adolescent population.[2-5,11] Many risk factors have been found to be related to the quantity of pitching, the amount of baseball played during the year, and unilateral overuse.[2-5,11,190] Pitching while fatigued or while experiencing arm fatigue,[3] a pitcher's maximum velocity achieved,[5,11] biomechanical deficiencies,[190] and demographic such as age, increased weight, and decreased height[3] have also all been identified as variables that can increase the risk of upper extremity complaints. Alterations in range of motion (ROM) from soft tissue changes or osseous adaptations of the developing humerus, have also been found to be risk factors,[127] while modifications in muscular strength of the shoulder muscles have also been associated with increased risk of upper extremity injuries in both older and younger baseball players.[62,90,127]

Despite the abundance of identified risk factors, very few studies[5,11] have linked such factors to actual objective findings or pathology. Traditional imaging methods have drawbacks such as the exposure to radiation found in x-ray and the large cost and time involved with magnetic resonance imaging. Ultrasound provides an imaging method that involves no radiation, is relatively inexpensive, and provides the ability to identify acute markers of tendon change that may relate to risk of pathology in the future.[170] Additionally, the portability of ultrasound offers the ability to evaluate participants during real-time pitching performances at the field of play, while providing a reliable image.[112]

Through collection of demographic, strength, ROM, and performance data, along with quantitative (QUS) imaging collected during a pitching exposure, correlations can be made that connect known risk factors with clinical imaging. The purposes of this investigation are to identify baseline characteristics of the long head of the biceps (LHB) and infraspinatus (INF) tendons, along with their response to a pitching performance, determine if any other baseline data predict the QUS findings, and to identify the QUS findings' predictive ability to determine the presence of an upper extremity complaint during the preceding season. Secondary analyses will then be conducted to establish correlations between those QUS variables that are most related to upper extremity complaints and easily identifiable demographic or physical examination findings.

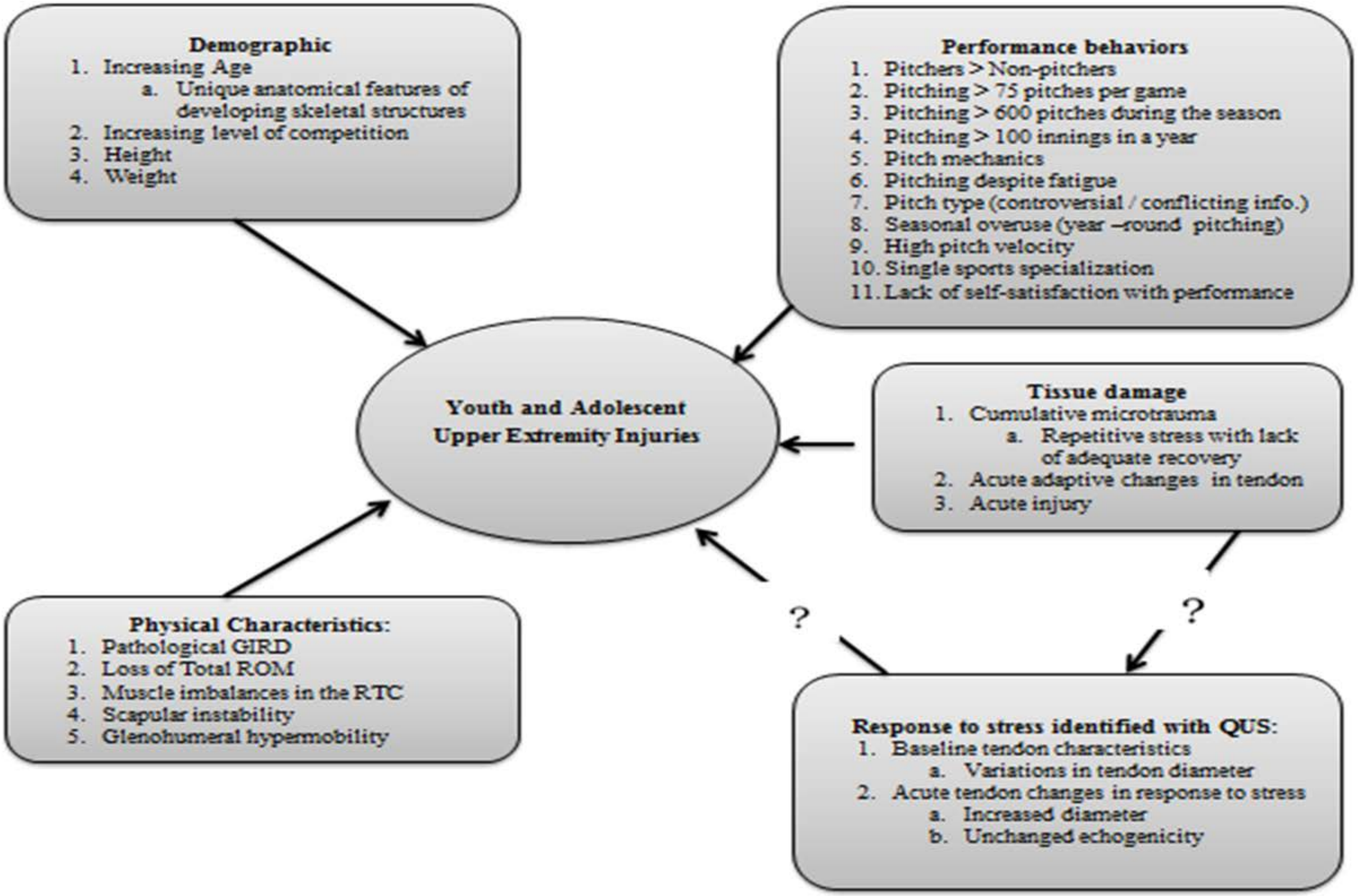

Figure 15: Conceptual Model of Risk Factors

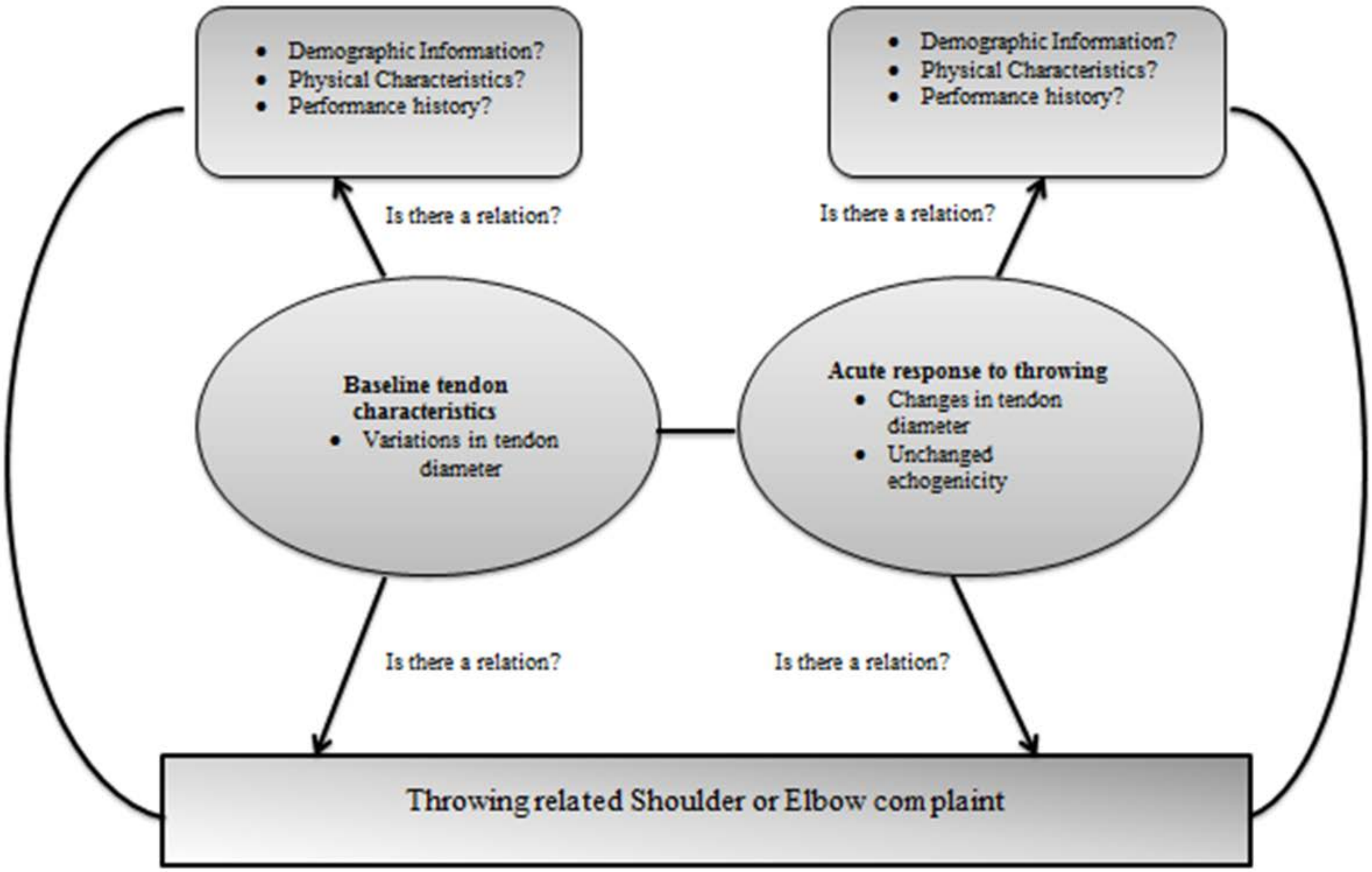

Figure 16: Conceptual Model of QUS's Relationship to Injury

5.2 METHODS

5.2.1 Participants

Participants were recruited from 2 separate baseball organizations located in 2 counties in west-central Pennsylvania, one Amateur Athletic Union (AAU) league with teams ranging in age from 8 through 17 years and one Pony League baseball team consisting of 13 – 14 year old players. Subjects were eligible to participate in this study if they were a youth or adolescent baseball player, 9 – 14 years of age and were currently playing baseball in an organized league. Subjects were excluded if they had a history of a shoulder or elbow injury that resulted in surgery, an injury to the throwing arm that resulted in a loss of playing time within the last year, or if they had shoulder or elbow pain at the time of initial testing. Female gender was not excluded if present on a team or in a league that was recruited. Subjects who participated in this study were the volunteers used in the study described in Chapter 4.

5.2.2 Testing Procedures

Pre-season QUS measurements of the LHB and INF tendons, along with demographic and physical examination information were collected for each of the eligible participants. Subjects then entered into their normal seasonal play and were contacted for an end of season interview between the end of the summer season and the start of the fall baseball season.

5.2.3 Demographic and Physical Examination

All collection of demographic information as well as physical examination procedures and methods are previously described in Chapter 3, section 3.2.2.1. Please refer to Chapter 3, section 3.2.2.1for a complete description of these methods.

5.2.4 Ultrasound Testing Set Up

Ultrasound testing set up was performed with the same procedures described in Chapter 4, section 4.2.3. Please refer to 4.2.3 for a full description of the ultrasound testing set up.

5.2.4.1 Quantitative Ultrasound System

Please refer to Chapter 4, section 4.2.1 for a detailed description of the QUS system used in this study.

5.2.4.2 Quantitative Ultrasound Reliability

Please refer to Chapter 2, sections 2.3.1 & 2.3.2 for information related to the reliability of the primary examiner in this study. The discussion of Chapter 2, section 2.4, provides additional information regarding QUS reliability.

5.2.4.3 QUS Image of the Infraspinatus Tendon

Complete methodology of the procedures performed for QUS imaging of the Infraspinatus tendon can be found in Chapter 2, section 2.2.3.2.

Examiners were trained in a specifically developed QUS protocol, had at least 1 year of experience, and followed the established protocol described in Chapter 2, section 2.2.3.2. In all situations, only one examiner performed the QUS testing on a subject.

5.2.4.4 QUS Image of the Long Head of the Biceps

Please refer to Chapter 2, section 2.2.3.3 for detailed information regarding QUS imaging of the LHB.

All general information regarding testing set up for LHB imaging was similar to that of the INF tendon. As with the INF, both examiners were trained in a specifically developed QUS protocol for the LHB tendon, had at least 1 year of experience, and followed the established protocol described in Chapter 2, section 2.2.3.3. All images were saved for later analysis and were presented to the investigator randomly.

Images before (baseline), during (at 20-25 pitches), and after (50-55 pitches) throwing were collected while ensuring that the reference marker was visible in the left hand aspect of the image to enhance the reliability of the serial image collection.

5.2.4.5 Analysis of Tendon Images

Please see Chapter 2, section 2.2.4 for a detailed description of the image analysis utilized in this study.

5.2.4.6 Quantitative Ultrasound Image Data Processing

Please refer to Appendix D for a detailed description of the data processing of the QUS images.

5.2.5 Serial Quantitative Ultrasound and Pitching Protocol

All participants were asked to refrain from any throwing activities prior to coming to the testing session, and were instructed to perform their typical pre-game / pre-practice activities and routines. Subjects were tested according to their usually scheduled meeting times for their team practices or as part of individualized pitching activities with their coaches. Baseline images were collected prior to the participant warming up for their throwing activity.

Please see Chapter 4, section 4.2.4.4 for detailed description of the pitching protocol followed in this study.

5.2.6 Follow-up Questionnaires and Pitch Count Booklets

Follow-up procedures were conducted to collect injury information and data on games pitched and pitch counts throughout the season. The primary measures derived from the follow-up procedures (site visits and telephone interviews) and pitch count logs included: the frequency of pain episodes, frequency of pitching while fatigued, frequency of experiencing a stiff shoulder, and the average pitch count, maximum game pitch count, and season pitch count for each participant. Secondary measures included the position(s) most often played and their level of satisfaction with their performance. The site visit or interview concluded with open-ended questions that provided the respondents the opportunity to discuss additional problems or issues experienced throughout the season.

Before the start of the season, participants were given a pitch count booklet (Appendix E). Instructions for its use were provided by a study investigator at the time the booklet was issued and instructions were also provided in the booklet. Each participant received at least two phone calls throughout the summer months to assess compliance and to remind them of the importance of filling in the information. When possible, coaches were also contacted to remind the players to complete the information in the booklet. Once the summer baseball season ended, a follow-up meeting was conducted at a team gathering for the Pony League baseball team where the booklets were collected and the follow-up interview / questionnaire was completed. Meetings were unable to be arranged for teams from the AAU league, therefore individual follow-up telephone interviews were conducted with the participants. End of season follow-up interviews looked to identify the presence of any arm pain or injury that was experienced at any point through-out the season.

5.2.6.1 Compliance with Pitch Count Booklets and Completion of F/U Interviews

A follow-up interview was completed on 33 of 37 participants (89.2%) who completed QUS testing prior to the onset of the season discussed in the original study (Chapter 4). Four participants (10.8%) were unable to be reached and were lost to follow-up. The four participants lost to follow up did not have any significant demographic differences from those who completed follow up. The approximately 11% lost to follow-up rate falls within reasonable rates of retention and likely does not present a significant threat to the validity of the study.[191] Participants were markedly less compliant with completing and returning the pitch count booklets. Only 16 out of 37 (43.2%) booklets were completed and returned at the end of the season.

5.2.7 Data Analysis

Strength values were averaged across three recordings for each test position for each subject and their recorded demographics and ROM were utilized. QUS data was processed according to the outlined procedure listed in section Appendix D. The average tendon width for the LHB and the INF were determined for all baseline values. Acute thickness change in the tendons was also determined by subtracting the width value from the baseline recording (pre-throwing) from the third QUS recording (post 50 pitches). Acute change in tendon width was then averaged across all participants. All participants who completed the follow-up interview were classified as either experiencing no pain throughout the season (0) or experiencing pain at some point during the season (1).

5.2.8 Statistical Analysis

Participant characteristics, including age, height, weight, and BMI were summarized using means and standard deviations. Medians and range of values were determined for demographic variables of the number of leagues that subjects played in and the number of years that they pitched. Frequencies were calculated to determine the percent of participants who were right hand dominant, primarily a pitcher, or who had a secondary position of a pitcher. Measures of central tendency (means and medians when the assumption of normality was violated) and dispersion (standard deviation) were calculated for physical examination data of ROM and body weight normalized strength of the dominant and non-dominant arms for the enrolled participants.

To examine the ability of demographic and physical examination information to predict the changes in tendon diameter with pitching, correlations and linear regressions were performed. All predictors for the linear regression were continuous, with a general linear relationship determined through scatter plots. The presence of outliers was assessed through P-P and scatter plots at 3.3 standard deviations[192]. Assumptions of independence of observations were assessed through the Durbin-Watson statistic, homoscedasticity through the residual plots, and the approximate normal distribution of the residuals was assessed through P-P plots and histograms. The linear regression assumption check was carried out for all significant and trending predictors. These analyses were performed using the sample described in Chapter 4 and allowed investigation into acute tendon changes along with demographic, ROM, and strength data for the entire sample.

Further analyses were performed on the subset of participants who participated in end of season follow-up to determine the predictive ability of each QUS variable and tendon change scores on the presence of shoulder or arm pain throughout the baseball season using a binary logistic regression. A combination of QUS variables was also used as independent variables in a binary logistic regression to predict the presence of upper extremity pain in youth and adolescent baseball players.

To relate the most informative and predictive QUS variables to demographic and or physical examination data, correlations, simple logistic regression, and multiple logistic regression were used to determine the most beneficial, easily identifiable information to determine risk of upper extremity pain in the subset of participants who were eligible for follow-up. All continuous predictors were assessed for the assumption of linearity and all predictors when combined in models were checked for multi-collinearity through the analysis of the variance inflation factor (VIF) and the tolerance statistic. The presence of outliers was assessed through P-P and scatter plots at 3.3 standard deviations. The logistic regression assumption check was carried out for the QUS variables that were utilized in the models to identify odds of having pain and for the demographic and physical examination predictors in this subset of participants.

5.3 RESULTS

5.3.1 Demographic, Physical Examination, and Complaint of Pain Information

Fifty youth and adolescent baseball players (age = 11.60 ± 1.53 years, height = 156.67 ± 13.29cm, weight = 49.38 ± 14.94kg, BMI = 19.71 ± 3.44, played in a median of 2 leagues and pitched for 3 years. Thirty-nine out of 50 (78%) were right arm dominant throwers. Twenty-two out of 50 (44.0%) participants reported their primary position as pitcher, with the remaining 28 (56.0%) participants listing pitcher as their secondary position. Information from these 50 subjects was used to determine correlations and linear regression predictors. Thirty-seven youth and adolescent baseball players were then eligible for follow up (age = 11.68±1.53 years, height = 157.07±14.78cm, weight = 51.05±16.42kg, BMI = 20.21±3.76, played in a median of 2 leagues, range 1 – 4, and pitched for 3 years, range 1 – 8). Nineteen out of 37 (51.4%) participants reported their primary position as pitcher, with the remaining 18 participants listing pitcher as their secondary position. Twenty-eight out of 37 (75.7%) were right arm dominant for throwing. No differences were seen when comparing the demographics of the two groups (table 35). The information from these 37 subjects was utilized to determine relationships to the presence of pain during the season.

Table 35: Baseline Demographic Information

	Total sample, n = 50		Follow-up sample, n = 37	
Variables	**Mean ± SD or Median* (range)**	**Frequency, (Percent)**	**Mean ± SD or Median* (range)**	**Frequency, (Percent)**
Age	11.60 ± 1.39	-	11.68 ± 1.53	-
Height	156.67 ± 13.29	-	157.07 ± 14.78	-
Weight	49.38 ± 14.94	-	51.05 ± 16.42	-
BMI	19.71 ± 3.44	-	20.21 ± 3.76	-
Number of leagues	2.0* (1 – 4)	-	2.0* (1 – 4)	-
Years Pitched	3.0* (1 – 8)	-	3.0* (1 – 8)	-

Table 35 continued

Throwing Arm Right	-	39/50, (78.0%)	-	28/37, (75.7%)
Primary Position Pitcher	-	22/50, (44.0%	-	19/37, (51.4%)
Secondary Position Pitcher	-	28/50, (56.0%)	-	18/37, (48.6%)

* Median

A repeat of the procedures for ROM and strength performed in Chapter 3 was completed with the modified sample sizes, n = 50 and n = 37 that correspond with those participated in QUS and follow-up testing. Physical examination of the participants revealed a typical thrower's profile with increased dominant arm external rotation at 90° and decreased internal rotation at 90° (see Table 36). Values for both the dominant and non-dominant arm for the ROM of external rotation at 0°, internal rotation at 90°, and external rotation at 90° can be found in Table 36 below.

Table 36: Physical Examination Data - Range of Motion (ROM)

	Total sample, n = 50		**Follow-up sample, n = 37**	
	Dominant Arm	**Non-Dominant Arm**	**Dominant Arm**	**Non-Dominant Arm**
Motion	**mean ± SD**	**mean ± SD**	**mean ± SD**	**mean ± SD**
External Rotation at 0°	89.07 ± 13.97	87.91 ± 11.44	89.05 ± 13.75	87.35 ±11.60
Internal Rotation at 90°	45.00* ± 11.35	52.00 ± 10.03	45.00* ±11.81	52.27 ± 9.85
External Rotation at 90°	115.75 ± 12.13	110.05 ± 9.28	113.89 ± 12.53	107.95 ± 8.75
* median value				

Strength of motions of the dominant and non-dominant arm are normalized to body weight to account for differences in strength secondary to growth and maturation in this age group. On average, the dominant throwing arm had an ER/IR ratio of 0.73 ± 0.23 (n = 50) and 0.78 ± 0.20 (n = 37). Other strength values as well as the maximum recorded pitch velocity achieved during testing are included in Table 37 below.

Table 37: Physical Examination Data - Strength and Pitch Velocity

Strength or Performance variable	Total sample, n = 50 Dominant Arm	Non-Dominant Arm	Follow-up sample, n = 37 Dominant Arm	Non-Dominant Arm
Body weight normalized	**mean ± SD**	**mean ± SD**	**mean ± SD**	**mean ± SD**
Elevation at 90°	.13 ± .03	.12 ± .03	.13 ± .04	.12 ±.03
External Rotation at 0°	.14 ± .03	.14 ± .04	.14 ±.03	.13 ± .04
External Rotation at 90°	.13 ± .04	.13 ± .04	.13 ± .04	.13 ± .04
Internal Rotation behind back	.14 ± .07	.14 ± .06	.12 ± .05	.12 ±.04
Elbow flexion	.25 ± .06	.25 ± .07	.25 ± .07	.25 ± .08
Internal Rotation at 90°	.18 ± .06	.17 ± .06	.17 ±.06	.17 ±.06
ER at 90° : IR at 90° ratio	.73 ± .23	.74 ±.20	.78 ±.20	.78 ± .19
Maximum velocity (mph)	57.12 ± 9.76		55.23 ± 10.22	

Complaint of pain in either the shoulder or elbow was tabulated by frequency and percent as well as the frequency and percent of having had either shoulder or elbow pain only throughout the season. Four out of 37 (10.8%) participants were unable to be reached and did not contribute to the follow up pain data. Therefore, 33 participants were included in the frequency tables of pain. A complaint of shoulder pain at any point in the season occurred in 12 / 33 (36.4%) (Table 38) of participants, and a complaint of elbow pain occurred in 6 / 33 (18.2%) of participants (Table 38). Total complaint of upper extremity pain, either in the shoulder or elbow therefore was reported in 15 / 33 (45.5%) participants (Table 38). Sub-analyses of the 4 subjects lost to follow-up revealed no significant differences in demographic, ROM, strength, or performance variables ($p > 0.05$), but did show INF baseline tendon width to be significantly smaller ($p = 0.007$), the INF tendon underwent a larger amount of change ($p = 0.00$), and the LHB underwent change less than the mean ($p = 0.00$).

Table 38: Complaints Throughout Season

Complaint of Pain in Dominant Shoulder at any Point Throughout Season		
	Frequency	**Percent**
No Pain	21 / 33	63.6
Pain	12 / 33	36.4
Missing follow-up	4 / 37	10.8

Table 38 continued

Complaint of Pain in Dominant Elbow at any Point Throughout Season		
	Frequency	**Percent**
No Pain	27 / 33	81.8
Pain	6 / 33	18.2
Missing follow-up	4 / 37	10.8

Complaint of Pain in Dominant Upper Extremity at any Point throughout Season		
	Frequency	**Percent**
No Pain	18 / 33	54.5
Pain	15 / 33	45.5
Missing follow-up	4 / 37	10.8

Pain that was reported in either the shoulder or elbow, i.e. the upper extremity, was used in the diagnostic utility analyses as well as the logistic regressions.

5.3.2 Predicting Change in Tendon Diameter with Pitching

All predictors met the assumptions for linear regression discussed in the data analysis section. Change in LHB tendon diameter from baseline to 50 pitches was not significantly correlated with any demographic or physical examination variable, (all $p > 0.05$). The only significant correlation found with the LHB change score was the negative correlation with baseline LHB width (rho = -0.47, $p = 0.00$). The INF change score from baseline to 50 pitches was significantly correlated with 1 performance variable; maximum pitch velocity (r = 0.31, $r^2 = 0.10$, $p = 0.047$) and with the baseline INF width (r = -0.42. $r^2 = 0.18$, $p = 0.00$). There was a trend toward statistical significance for dominant arm IR @ 90° strength (r = .30, $r^2 = 0.09$, $p = 0.05$) and elbow flexion strength (r = 0.29, $r^2 = 0.08$, $p = 0.06$) (Table 39)

Table 39: Correlations with QUS change scores, n = 50

QUS variable	Baseline variable	r or rho*	r^2	*p*-value
LHB change post - pre	LHB width (QUS)	*-0.47		0.001
INF change post - pre	Maximum pitch velocity	0.31	0.096	0.047
INF change post - pre	INF width (QUS)	-0.42	0.176	0.003
	Trends			
INF change post - pre	Dom. IR @ 90° strength	0.30	0.090	0.052
INF change post - pre	Dom. elbow flexion strength	0.29	0.084	0.062

A simple linear regression was calculated to predict the LHB change score from pre to post throwing based on the baseline LHB width. A significant regression equation was found ($F(1,46) = 10.60$, $p = 0.002$), with an $R^2 = 0.187$. INF change score from pre to post throwing was predicted by the baseline INF width, $F(1,46) = 9.80$, $p = 0.003$, with an $R^2 = 0.176$, and by maximum velocity, $F(1, 40) = 4.201$, $p = 0.047$, with an $R^2 = 0.095$, One predictor verged on significance, dominant arm IR @ 90° $F(1,40) = 4.024$, $p = 0.052$, with an $R^2 = 0.091$. All regression equations can be found in Table 40 below.

The ability to predict baseline tendon widths was accomplished by more predictors. The baseline LHB width was significantly predicted by age, $F(1, 48) = 4.186$, $p = 0.046$, $R^2 = 0.080$, and height, $F(1, 48) = 4.075$, $p = 0.049$, $R^2 = 0.078$. Regression equations for both can be found in Table 40 below. Baseline INF tendon width was significantly predicted by five variables, three of which were related to physical maturation (Age, height, and weight) and two related to pitching and exertion, please see Table 40 below.

Table 40: Linear regression results for Change Scores and Baseline Diameters

LHB change post - pre					
Predictor	**n**	**F-value**	***p*-value**	**R^2**	**LHB Change Score Equation**
Baseline LHB Diameter	48	10.60	0.002	0.19	= 1.234 + (-0.259*baseline tendon width)
INF change post - pre					
Predictor	**n**	**F-value**	***p*-value**	**R^2**	**INF Change Score Equation**
Baseline INF Diameter	48	9.80	0.003	0.18	= 1.811 + (-0.364*baseline tendon width)
Maximum pitch velocity	42	4.20	0.047	0.10	= -0.827 + (0.018*maximum pitch velocity)
IR @ 90° strength	42	4.02	0.052	0.09	= -0.292 + (2.960*IR @ 90° strength)
Elbow flexion strength	42	3.70	0.062	0.09	= -0.449 + (2.777*elbow flexion strength)
LHB baseline Diameter					
Predictor	**n**	**F-value**	***p*-value**	**R^2**	**LHB Baseline Diameter Equation**
Age	50	4.19	0.046	0.08	= 2.246 + (0.158*age)
Height	50	4.08	0.049	0.08	= 1.528 + (0.016*height)
RPE	48	3.06	0.087	0.06	= 3.484 + (0.088*RPE)
INF baseline Diameter					
Predictor	**n**	**F-value**	***p*-value**	**R^2**	**INF Baseline Diameter Equation**
Age	50	14.28	<0.001	0.23	= 1.869 + (0.218*age)
Height	50	27.63	<0.001	0.37	= -0.095 + (0.029*height)
Weight	50	14.89	<0.001	0.24	= 3.384 + (0.021*weight)
Maximum pitch velocity	42	10.24	0.003	0.20	= 2.615 + (0.031*maximum pitch velocity)
RPE	48	8.80	0.005	0.16	= 3.634 + (0.116*RPE)

5.3.3 Predicting Injury Based on QUS Findings

Binary logistic regressions were conducted with the QUS variables with the baseline and change in width values as the single predictor variable and the presence of upper extremity pain experienced at any point during the season as the dependent variable. Logistic regression models were then established with a combination of 2 QUS predictors. Due to the low sample size, multiple predictor regression models consisted of no more than two predictor variables. All continuous predictors met the assumption of linearity and all combined models met the assumption of multi-collinearity. Additionally, all cases of data had independence of errors and no significant outliers.

5.3.3.1 Baseline Findings and the Prevalence of Upper Extremity Pain During the Season

Baseline QUS variables for the LHB and INF tendon widths included one continuous measure for each tendon (width) and one nominal (larger than the mean), (present = yes, not present = no) predictor for each tendon. None of the baseline QUS variables entered individually into the regression reached statistical significance. However, one variable, LHB width greater than the mean value, model $\chi^2 = 3.428$, p –value = 0.064, AIC[193] = 42.81, R^2 =0.136, Wald = 3.207, coefficient p = 0.073, Odds Ratio = 3.929 (.879 – 17.563), converted effect size d[194] = 0.76 neared statistical significance. Increases in INF tendon width at baseline reduced the odds of experiencing upper extremity pain during the season. Though the variable failed to reach statistical significance, an INF tendon width greater than the mean, model $\chi^2 = 1.47$, p-value = 0.225, AIC = 46.00, $R^2 = 0.058$, Wald = 1.437, coefficient p = 0.231, Odds Ratio = 0.424 (.104 – 1.724), converted effect size d = 0.47 suggested a small to medium protective effect in regards to the prevalence of upper extremity pain during the season. Single baseline QUS predictor logistic regression output for all QUS variables can be found in Table 41.

Combining baseline QUS predictors for the logistic regression did not provide a statistically significant model. The first model, LHB greater than the mean & INF greater than the mean, model $\chi^2 = 5.384$, $p = 0.068$, AIC = 42.85, $R^2 = 0.207$, neared significance, explained nearly 21% of the variance in the model, and revealed odds ratios in the same direction as individual predictors. The second model, the continuous values of the LHB and INF width was not nearly as strong of a predictor, model $\chi^2 = 3.604$, p-value = 0.165, AIC = 44.63, $R^2 = 0.142$, explained only approximately 14% of the variance in the model and also had Odds Ratios in similar directions as individual predictors. .Complete logistic regression output can be found in Table 42 below.

Table 41: Logistic Regression Predictors, Baseline QUS Variables

Single Baseline Predictors of Pain	n	Model χ^2	*p*- value	Nagelkerke R^2	Wald	*p*-value	Odds Ratio	95% CI for OR	Effect Size[194]
LHB tendon width	32	1.541	0.215	0.063	1.337	0.248	1.835	.656 - 5.135	0.34
LHB width > mean*	32	3.428	0.064	0.136	3.207	0.073	3.929	.879 - 17.563	0.76
INF tendon width	33	0.954	0.329	0.038	0.919	0.338	0.557	.169 - 1.841	0.32
INF width > mean**	33	1.47	0.225	0.058	1.437	0.231	0.424	.104 - 1.724	0.47

*LHB mean width = 4.14mm **INF mean width = 4.36mm

Table 42: Logistic Regression Predictors, Baseline QUS Variables

Multiple Predictors of Pain	n	Model χ^2	*p*-value	Nagelkerke R^2	Wald	*p*-value	Odds Ratio	95% CI for OR
LHB > mean **&** INF > mean	32	5.384	0.068	0.207	LHB: 3.778 INF: 1.828	LHB: 0.052 INF: 0.176	LHB: 5.00 INF: 0.333	LHB: .987 - 25.341 INF: .068 - 1.639
LHB width & INF width	32	3.604	0.165	0.142	LHB: 2.151 INF: 1.863	LHB: 0.142 INF: 0.172	LHB: 2.357 INF: 0.384	LHB: 0.750 – 7.408 INF: 0.097 – 1.517

5.3.3.2 Change in QUS Findings and Prevalence of Upper Extremity Pain During Season

Change in tendon widths for the LHB and the INF tendons during a pitching performance were determined and were utilized as predictors in a logistic regression. Predictors included two continuous variables (1. change value from baseline to post pitching and 2. from baseline to post represented as a percentage of the baseline tendon width) and two nominal (present = yes, not present = no) QUS variables (change greater than mean & change less than the mean). None of the acute change QUS variables entered individually into the regression reached statistical significance and overall appeared to have less of an effect than the baseline QUS predictors.

The individual predictor that had the greatest ability to suggest upper extremity pain during the season was: LHB change score less than the mean value of change, model $\chi^2 = 1.659$, p-value = 0.198, AIC = 43.03, $R^2 = 0.07$, Wald = 1.61, $p = 0.204$, Odds Ratio = 2.571 (.598 – 11.059) converted effect size $d = 0.52$. Table 43 shows the regression output for all acute change variables as they related to the prevalence of upper extremity pain during the season.

Combining acute change QUS predictors for the logistic regression also did not provide any significant predictors of pain and did not improve on the single predictor models.

Table 43: Logistic Regression Predictors of Pain and Output, Acute Change Values

Variables	n	Model χ^2	*p*- value	Nagelkerke R^2	Wald	*p*-value	Odds Ratio	95% CI for OR	Effect Size[194]
INF change score (baseline to post)	32	0.16	0.69	0.017	0.16	0.69	1.26	.40 - 3.98	0.13
INF change score > mean	32	0.63	0.82	0.002	0.05	0.82	1.18	.29 - 4.88	0.09
INF change score < mean	32	0.05	0.82	0.002	0.05	0.82	0.85	.21 - 3.51	0.09
INF % of baseline change	32	0.09	0.76	0.004	0.09	0.76	2.09	.02 - 256.90	0.41
INF % of baseline change > mean	32	0.051	0.821	0.002	0.051	0.821	1.179	.285 - 4.879	0.09
INF % of baseline change < mean	32	0.051	0.821	0.002	0.051	0.821	0.848	.205 - 3.513	0.09
LHB change score (baseline to post)	31	1.41	0.25	0.06	1.28	0.26	0.41	0.89 - 1.91	0.49
LHB change score > mean	31	0.79	0.38	0.03	0.78	0.38	0.53	0.13 - 2.20	0.36
LHB change score < mean	31	1.66	0.20	0.07	1.61	0.20	2.57	.60 - 11.06	0.52
LHB % of baseline change	31	1.67	0.20	0.07	1.25	0.26	0.04	.00 - 10.56	1.73
LHB % of baseline change > mean	31	1.12	0.30	0.05	1.09	0.30	0.45	.10 - 2.02	0.44
LHB % of baseline change < mean	31	1.12	0.29	0.05	1.09	0.30	2.22	.50 - 9.96	0.44

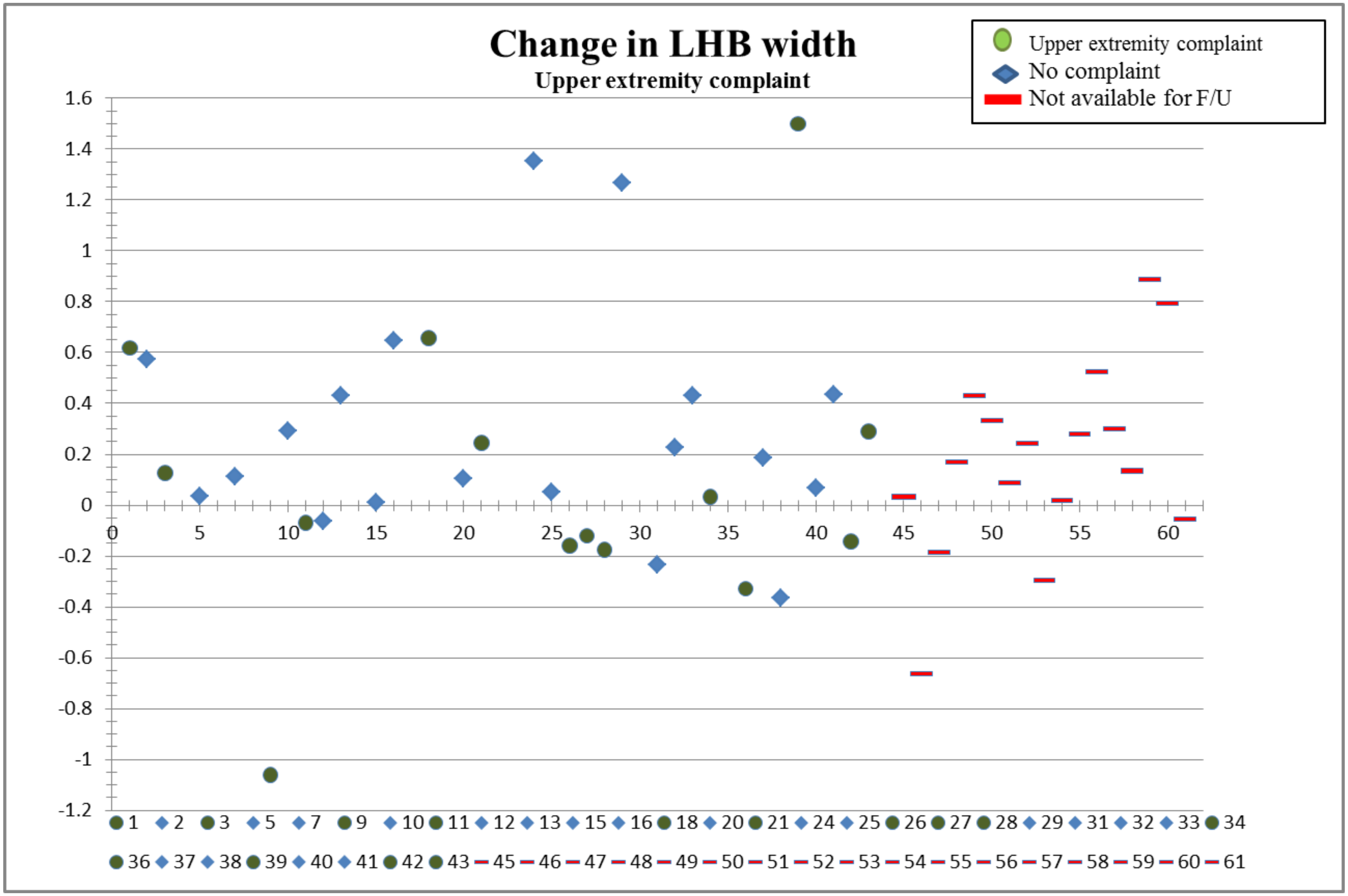

Figure 17: LHB Change in Each Subject

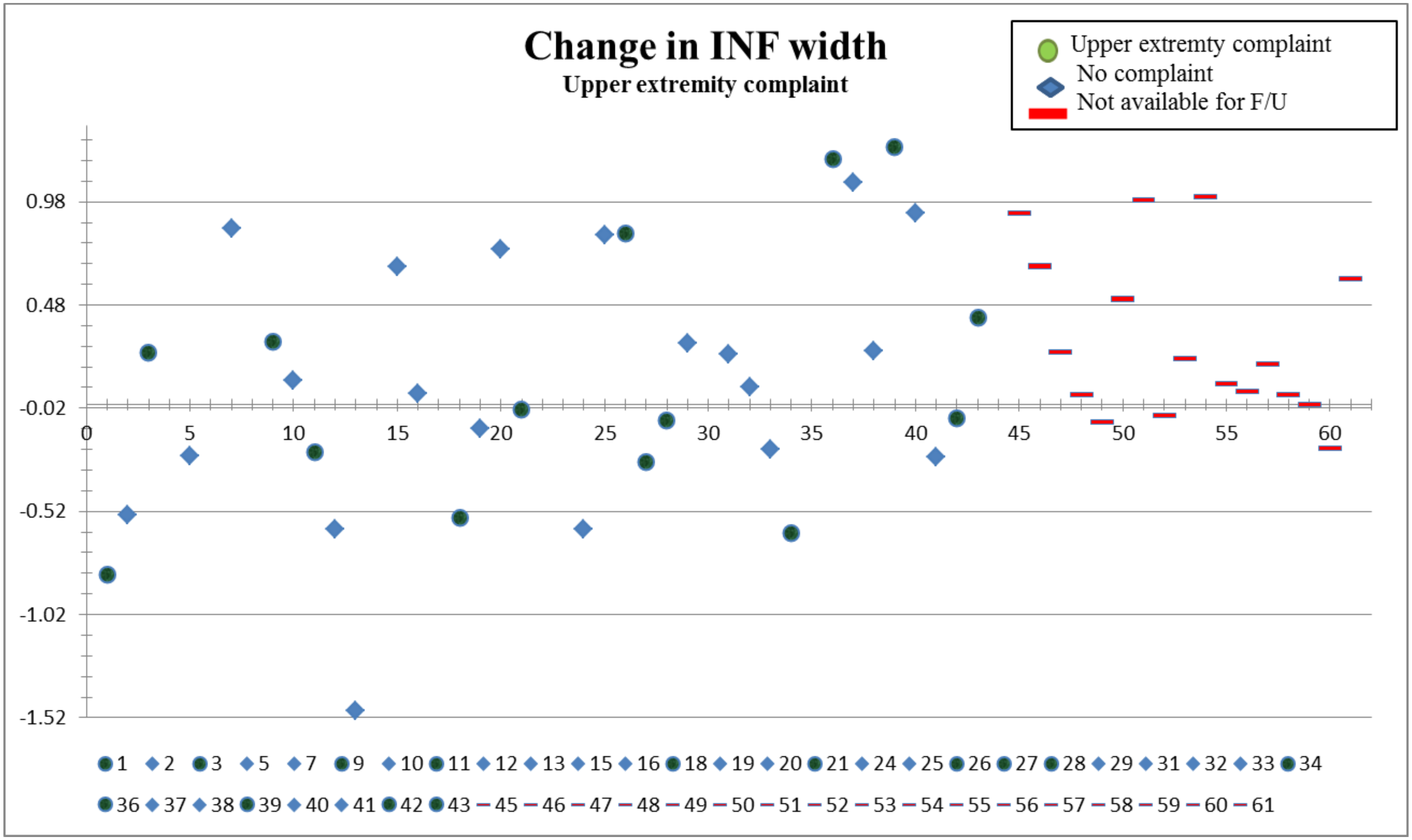

Figure 18: INF Change in Each Subject

5.3.3.3 Relating QUS Predictors of Pain to Demographic and Physical Exam Findings

In the subset of 37 youth and adolescent baseball players who were tested prior to the onset of the season and were able to participate in the follow-up, the QUS variables that provided both the largest and most stable (narrow confidence interval), though not statistically significant, odds ratio to predict those who experienced an upper extremity complaint was the baseline LHB width greater than the mean value. Variables that were significantly correlated to a LHB width greater than the mean value at baseline included: age ($r = 0.334$, $r^2 = .112$, $p = 0.046$), IR @ 90° strength ($r = .411$, $r^2 = .169$, $p = 0.013$), and the ER/IR ratio ($r = -.433$, $r^2 = .188$, $p = 0.008$). Significant and moderate correlations to the QUS variable can be found in Table 44.

Table 44: Correlation between LHB width > mean and Demo. & PE variables

Significant correlations		**r**	**r^2**	**p-value**
LHB width > mean	age	0.334	0.112	0.046
LHB width > mean	IR @ 90° strength	0.411	0.169	0.013
LHB width > mean	ER/IR strength ratio	-0.433	0.188	0.008
LHB width > mean	RPE	0.355	0.126	0.037
Moderate Correlation		**r**	**r^2**	***p*-value**
LHB width > mean	Height	0.32	0.102	0.057
LHB width > mean	Years Pitched	0.30	0.091	0.074

Simple logistic regression to determine significant predictors of a LHB width greater than the mean value identified two single physical examination findings, ER/IR strength ratio and IR @ 90° strength, both of the dominant arm. The ER/IR strength ratio, model $\chi^2 = 7.423$, $p = 0.006$, $R^2 = 0.249$, AIC[193] = 44.038, Wald = 5.33, coefficient $p = 0.021$, Odds Ratio = 0.005 indicated that as the ER/IR ratio decreased, the odds of having a LHB width greater than the mean increased. The variable IR @ 90° strength was transformed and the natural log (Ln) was utilized in the simple logistic regression, model $\chi^2 = 6.683$, $p = 0.01$, $R^2 = 0.227$, AIC = 44.778, Wald = 5.461, coefficient $p = 0.019$, Odds Ratio = 11.665. Results indicated that as IR @ 90° strength increased, so did the odds of having a LHB greater than the mean value. Results of the simple logistic regression for the LHB width greater than the mean can be found in Table 45. Multiple logistic regression resulted in several significant models for predicting LHB width greater than the mean value. The best model, as determined by the AIC[193] value, had three predictors: ER/IR strength ratio, IR @ 90° strength, and Age, model $\chi^2 = 17.279$, $p = 0.001$, $R^2 = 0.51$, and AIC = 34.182. Additional multiple logistic regression models can be found in Table 46.

Table 45: Predictors for LHB greater than the mean value, Simple L.R

Variables	n	Model χ^2	*p* - value	Nagelkerke R^2	AIC	Wald	*p*-value	Odds Ratio	95% CI for OR
Strength ER:IR ratio	36	7.42	0.006	0.249	44.04	5.33	0.021	0.005	.00 - .44
IR90 Ln transformed	36	6.68	0.01	0.227	44.78	5.46	0.019	11.665	1.49 - 91.55
Age	36	4.15	0.042	0.146	47.31	3.73	0.053	1.604	.99 - 2.59
Height	36	3.85	0.05	0.136	47.62	3.38	0.066	1.049	1.00 - 1.10
Weight	36	2.97	0.085	0.106	48.49	2.61	0.106	1.039	.99 - 1.09

Table 46: Predictors for LHB width greater than the mean value, Multiple L.R.

Variables	n	Model χ^2	*p*-value	Nagelkerke R^2	AIC	Wald	*p*-value	Odds Ratio	95% CI for OR
ER:IR strength ratio & IR @ 90° strength & Age	36	17.28	0.001	0.51	34.18	ER/IR: 4.91 IR 90: 2.17 Age: 5.00	ER/IR: .03 IR 90: .14 Age: .03	ER/IR: 0.00 IR 90: 5.77 Age: 5.00	ER/IR: .00 - .43 IR 90: .56 - 59.36 Age: 1.10 - 4.09
ER: IR ratio & Age	36	14.97	0.001	0.46	38.49	ER/IR: 6.32 Age: 5.85	ER/IR: 0.01 Age: 0.02	ER/IR: .00 Age: 2.16	ER/IR: .00 - .18 Age: 1.16 - 4.03
ER:IR strength ratio & IR @ 90° strength	36	10.92	0.004	0.45	40.54	ER/IR: 3.38 IR 90: 3.10	ER/IR: .07 IR 90: .08	ER/IR: .01 IR 90: 7.54	ER/IR: .00 - 1.36 IR 90: .80 - 71.31
Age & IR @ 90° strength	36	9.89	0.007	0.32	41.57	Age: 2.97 IR 90: 4.90	Age: 0.09 IR 90: 0.03	Age: 1.56 IR 90: 10.11	Age: .94 - 2.59 IR 90: 1.30 - 78.50

5.4 DISCUSSION

Clinicians are often interested in the utility of certain special tests or exam findings to identify pathology, increased risk, or to distinguish between those who may, in the future, present with a condition versus those do will not. We applied this concept to our data in two ways, 1. to assess if physical examination and performance variables were able to predict the amount of tendon diameter change seen in QUS with a pitching exposure, and 2. to see if QUS findings were related to the presence of an upper extremity complaint in the subsequent season. If a relationship between QUS findings and a season complaint could be identified, connections to easily determined variables could be established for greater generalizability.

In our small sample, no physical examination variable was able to significantly predict the amount of change in tendon diameter that each participant would incur with pitching. The variables that provided the most information regarding predicting tendon change with pitching were the baseline diameter of each tendon. For both tendons of interest, there was a negative correlation suggesting tendons with larger diameters at rest undergo less change in diameter with throwing and smaller diameter tendons undergo greater changes. This was also true when controlling for age. One performance variable, maximum pitch velocity was able to significantly predict the amount of diameter change seen in the INF tendon, while the strength of the dominant arm IR @ 90° verged on significance (p = 0.052). The ability to predict which individuals will undergo greater change in diameter could be beneficial if a link to pathology can be determined. Previous work has established that exercise or high intensity loading can stimulate adaptations in tendons that can be positive or negative.[175,176] Past investigations[178,179] examining acute effects have shown a trend towards increased tendon thickness with activity that is positively correlated with duration of exposure. Maximum pitch velocity and increases in IR @ 90° strength with pitching exposures could place greater demands on the posterior rotator cuff[24,29,55] resulting in an acute hypertrophy of the INF. Increased pitch velocity has been identified as an independent risk factor in adolescent[11], high school[5], collegiate[77], and professional[32] levels of pitching. Pitchers acquire greater ball velocity by increasing torque of glenohumeral rotation in the late cocking and acceleration phases of throwing.[159] Greater torque places higher stress on the entire kinetic chain,[78] including the throwing arm. Overuse injuries believed to occur from cumulative microtrauma are related to the high levels of stress placed on the weakest areas of the kinetic chain,[78] generally the shoulder or the elbow. It is possible that higher levels of stress associated with increased pitch velocity and strength of the acceleration motion, could overload the INF tendons resulting in a predictable amount of acute tendon change.

The prevalence of upper extremity pain in this sample of youth and adolescent baseball players accurately reflects that which has previously been reported.[2,3,154-156] Young throwers have been shown to have an incidence of shoulder or elbow pain as high as 47% - 51%.[2,3,156] Despite our small sample, a similar incidence was found in these highly competitive individuals. Results of this study showed no statistically significant individual predictors of having an upper extremity complaint throughout one baseball season in the logistic regression. However, this may be due in part to a small sample size and clinically important information may still be obtained from this study. Logistic regression related to baseline measurements identified increased odds of experiencing upper extremity pain, that neared statistical significance, when there was a larger LHB tendon width at baseline (LHB width greater than the mean value, $p = 0.07$, OR = 3.9, converted $d = 0.76$). Larger LHB tendon widths (larger than the mean) where then found to be positively correlated with IR @

90° strength (p = 0.01) and inversely associated with the ER/IR ratio (p = 0.01) in the dominant arm. Additional logistic regression with the presence of a LHB greater than mean value as the outcome variable showed both IR @ 90° strength (p = 0.02, OR = 11.67) and the unilateral ER/IR ratio (p = 0.02, OR = 0.01) to be significant to confirm this relationship. Biomechanically, early EMG studies of overhand pitching showed that biceps was most active during the deceleration phase of throwing and moderately active during the late cocking phase.[158] However, the acceleration phase, which corresponds to the muscle activity in IR @ 90° test position, showed the biceps to be relatively inactive.[158] Gowan et al[157] confirmed the findings reporting that the biceps was most active during late cocking and less so during acceleration, serving primarily to assist in positioning the shoulder and elbow for the delivery of the pitch. DiGiovine et al[195] reported biceps activity as a percentage of the maximum volitional isometric contraction (MVIC), showing the biceps reached its peak MVIC during deceleration (44%) compared to activity during late cocking (26%) and acceleration (20%). Conversely, Fleisig et al[29] reported large eccentric torques produced by the biceps, and other elbow flexors, during both the deceleration and acceleration phase. Studies agree the biceps plays a pivotal role in resisting humeral distraction immediately after ball release and also limits anterior translation of the humeral head as a restraint to external rotation during late cocking.[33] In fact, biceps activity has been shown to be increased in shoulders with anterior instability, providing assistance to the inferior glenohumeral ligament complex (IGHL) in resisting external rotation.[196,197] Additionally, compared to professional pitchers, amateurs have been shown to have a greater magnitude of biceps activity throughout the pitching motion, including the acceleration phase.[157] Given this information, it is possible that the correlation between IR @ 90° strength and increased LHB width may be secondary to adaptive changes in response to IR angular demands placed upon the tendon by activity induced strength gains in the acceleration phase. Additionally, if some amount of anterior laxity is present, secondary to either an underdeveloped posterior rotator cuff or lack of sufficient restraint from the IGHL complex, the LHB tendon width may increase in response to being an active restraint to external rotation. In either of these scenarios, the increased demands would predispose the LHB, and other structures in the shoulder, to possible injury with increased exposure to pitching. Furthermore, Hashimoto et al[104] noted that a vast majority of patients with fluid in the biceps tendon sheath have pathological conditions in the glenohumeral joint, suggesting a relationship between the LHB and other shoulder structures. The direct correlation between IR @ 90° and LHB width would also explain the inverse relationship the LHB has with the unilateral ER/IR ratio. Larger values of IR @ 90° will decrease the values of the unilateral ratio, causing the inverse relationship with the LHB width greater than the mean value.

Larger tendon width values of the INF at baseline, as identified by QUS, showed a protective effect of approximately medium size that may be clinically important though not statistically significant at this sample size. Logistic regression showed that when the INF tendon width was greater than the mean value that there was a reduction in the odds of experiencing seasonal complaints ($p = 0.23$, OR = 0.42, converted $d = 0.47$). The suggestion of a medium sized protective effect of a larger INF tendon corresponds with the protective effect of the decelerating function of the posterior rotator cuff.[24,29,55,198,199] as well as the concept of the INF and teres minor acting as the hamstrings of the glenohumeral joint to reduce strain on the anterior band of the IGHL complex.[200] Correlational analysis to identify those with a larger INF tendon width showed associations with mostly developmental variables (age, $r = 0.53$; height, $r = 0.62$; weight, $r = 0.56$; BMI, $r = 0.34$), but also with increased ball velocity ($r = 0.51$). Age was found to explain most of the variation in the INF tendon width, but its association with ball velocity further emphasizes the need to have proper muscular balance between the propulsive muscles and the protective posterior rotator cuff as young pitchers develop greater ball velocities.

The predictive ability of the amount of change in tendon width, identified by QUS, was limited in this study due to the 50 pitch limit encountered by coaches and parents and by a small sample size. However, an interesting, non-statistically significant, though approximately medium sized effect ($d = 0.44 – 0.52$) was noticed where increased odds were noted with change in the LHB tendon that was less than the mean change (converted $d = 0.52$) and the percentage of the baseline value change score that was less than the mean (converted $d = 0.44$). Further confirming this paradoxical trend, the change in LHB tendon width from pre to post (converted $d = 0.49$) and the percentage of baseline width change score in the LHB (converted $d = 1.73$) both indicated that as change in width increased, the odds of having seasonal complaints decreased. Again, these results did not reach statistical significance. However, the point estimate of the effect size would suggest an approximately medium effect was seen. Our initial hypothesis was that increased amount of change, whether raw amount or a percentage of the original width value, would be linked to increased likelihood of pathology. Though a very small effect was determined, a minimally increased risk of have upper extremity complaints at some point during the season in those who experienced the most change in the INF tendon adds some credence to this suspicion. However, the reverse behavior in the LHB defies this logical explanation. One conceivable explanation for this could be that those who experienced less change in the LHB width may have been the same athletes with a larger baseline tendon width, leaving little room for tendon width increase. Whereas those who had average or smaller than average LHB tendon widths at baseline, and therefore had a decreased odds of having seasonal complaints, were able to undergo acute tissue adaptations that may be normal when such short terms demands are placed on the tissue. While it is quite possible that QUS findings are no more predictive than strength values, this is not clear from this current study. Contributing to the lack of conclusiveness, sub-analyses of the subjects lost to follow-up revealed that the tendon characteristics found to be influential were present in this group of four participants. This could possibly suggest the four subjects lost to follow-up were at increased or decreased risk of experiencing pain, thus potentially presenting an underestimation of the true effect and a loss to follow-up bias. Further research will be needed to determine if similar tissue behavior is recognized in a larger sample size and with a greater pitch volume. Moreover, this study has confirmed the acute, short term tendon changes and baseline tendon characteristics can be identified with QUS.

5.4.1 Limitations

This study does have a number of limitations. First, the small sample size limited the ability to fit the regression models with more than 3 predictors as well as reduced the power of the individual predictor variables. The small sample size and reduced power could explain some of the larger confidence intervals associated with the odds ratios. Adding to the lower sample size were the 4 subjects lost to follow-up. Based on the trends in this study, their QUS findings would suggest that they were potentially at greater risk of a seasonal complaint. In theory, if the information that was lost to follow up was collected, the final results of this study may have been more conclusive. Non-normalized baseline tendon widths were utilized in the analyses conducted in this study. This is a potential limitation that body maturation and structure, and thus tendon size, may be related to another risk factor such as age, which may represent the real change in risk. Future studies examining tendon diameter should consider normalizing tendon width to age, BMI, or height to account for a possible mediator effect. In this investigation, there were significant correlations between baseline tendon widths of the LHB and INF tendons and age and height. We did not control for the potential effect secondary to a sample size that was already too small and limited. Another factor that was not accounted for at baseline was In regards to the tendon change scores and their relation to pain, pitchers were limited to 50 pitches by parents and coaches. Despite the pitch count guidelines that extend to 75 pitches for this population [2,3,12], parents and coaches were reluctant to allow pitchers to throw more than 50 pitches due to the timing of testing (pre-season) or to the stated reason that they do not have their pitchers throw this much in an actual game. Upon evaluating post-season pitching information on 16 pitchers who recorded and provided follow-up information on each pitching performance during the season, only 2 subjects (12.5%) reported average pitch counts per performance greater than 50 pitches. However, 14 subjects (87.5%) reported at least one pitching performance greater than 50 pitches. This information would suggest that many young athletes, knowingly or unknowingly, generally abide by the recommendations, with relatively few exceptions during the season. Though the response rate was low and the reference sample is extremely small, it is secondary to those exceptions as well as the possibility that the acute response may change as the season progresses, investigation at extended pitch counts is warranted. We believe that with continued pitching beyond this point would have resulted in greater acute changes in the tendons of interest, which could have possibly had more predictive ability. We recommend future testing on acute tendon changes with pitch count progressing to at least the 75 pitch amount to further demonstrate the changes that occur during extended pitching performances. Finally, the inability to completely recreate a game-like environment for all pitchers during testing may have also limited the results of this study. All pitchers pitched off the mound, however, not all pitched to a batter in a live situation, which could have limited the effort of the pitcher, and thus the intensity of the pitching performance.

5.5 CONCLUSION

Acute INF tendon change with overhead throwing of 50 pitches can be predicted by the maximum velocity with which a youth or adolescent pitcher throws. However, no single physical examination or performance variable was able to predict the amount of change the LHB experiences. One baseline QUS variable, having a LHB width greater than the mean value, showed a trend toward being predictive of those who will experience pain during a baseball season. No amount of tendon change with pitching was predictive of having pain in this limited sample, however the non-significant ($p > 0.05$) data may be able to be used in future power analyses to investigate this subject. The data would suggest that change in odds may be linked to having a larger LHB and INF tendon width at baseline. Logistic regression corroborated the potentially injurious effect of having a larger LHB tendon at baseline and the benefit of increased INF tendon width, however, a limited sample size prevents definitive conclusions. To most readily apply these findings to a clinical or sports performance environment, easily measured strength and demographic characteristics were identified that correlate with the QUS findings to provide the greatest generalizability. This study adds to the risk factor work already present in the youth and adolescent baseball literature, and corroborates the correlation between the long head of the biceps and pathology and the protective action of the posterior rotator cuff. To confirm these trends, we recommend further research, with larger sample sizes, that utilize methods to acutely identify tissue characteristics and behaviors during real-time activities that most closely replicate the competitive environment.

6.0 CONCLUSIONS

In order to provide information related to pitching and tissue changes through QUS, it is essential to have a reliable method of determining tissue changes, to document the average amount of change that occurs with pitching, to relate tissue characteristics and change amounts to pain, and finally to make the findings generalizable for public use. The goal of this study was to apply a reliable method of measuring tissue characteristics during a pitching performance, to relate the tissue characteristics to the incidence of upper extremity complaints experienced in the following baseball season, and to correlate those findings to easily identifiable personal and performance characteristics in the youth and adolescent population.

Determination of reliable QUS methods and testers resulted in fair to excellent (ICC = .40 - 0.96) intra-rater reliability for tendon width and echogenicity in both the LHB and the INF tendons. This was established through evaluation of 6 volunteers with no known history of shoulder injury or current involvement in aggressive upper extremity activity. Modification of an existing protocol for reliably scanning the LHB was developed and tested for the INF tendon. Although intra-rater reliability measures for the primary evaluator were slightly lower than hypothesized, QUS testing achieved no less than fair reliability for tendon width and echogenicity for both the LHB and the INF tendon, indicating the new method to scan the INF tendon was a reliable technique to use in future testing. Our reliability and MDC are comparable to other studies reporting reliability and SEM of QUS of the shoulder using the same or similar protocol. Future studies utilizing the protocol in this study should display the necessary reliability and consistency to identify acute changes in tendons. Repeating of the reliability study for the INF tendon may be needed to further establish reliability of the protocol when examining a larger, less homogenous group of subject in which pathology may or may not be present.

We evaluated strength and ROM characteristics to establish an upper extremity profile for our sample of 9 – 14 y/o overhead athletes, and showed that activity related adaptations begin to manifest as early as this age range, however not to the extent seen in teenage or adult baseball players. Our results that suggest the presence of the typical thrower's profile in this population are consistent with studies examining adolescent overhead athletes with a slightly older mean age. Likewise, we found that despite a loss of IR @ 90° ROM and an increase in ER @ 90° ROM, the total arc of motion was very similar between upper extremities, a finding that is consistent in studies examining throwers of older ages. No ROM variables were predictors for the presence of a seasonal complaint of pain. Body-weight normalized strength of the upper extremity, as measured by hand-held dynamometry, showed no differences between the age groups and provided values for strength of motions associated with the rotator cuff and throwing motion. Additionally, the unilateral ER/IR ratio was determined and was consistent in both the actual value and the side to side discrepancy found in the literature of older baseball athletes. Two strength findings, both in the dominant upper extremity, IR @ 90° and the ER/IR ratio both proved to be significant predictors of a seasonal compliant of pain. We believe this may be due to the connection with the tendon characteristics of the LHB and INF tendons that were identified as non-significant trends in Chapter 5. Larger LHB tendon diameters may reflect a chronic adaptation associated with repeatedly transmitting high forces. Increases in IR @ 90° strength, which will assist in increasing angular acceleration of the throwing arm, were found to be correlated with having a larger LHB tendon as well as experiencing an upper extremity complaint. Secondary to the relationship that the LHB has with pathology in the glenohumeral joint, it is possible that strength gains in acceleration may overload the musculoskeletal system to the point of tissue damage and pain. Likewise, the ER/IR ratio, when decreased, was significantly related to development of a seasonal complaint. Reductions in the ER/IR ratio would indicate a decrease in the posterior rotator cuff's ability to counter the anterior and distractive forces experienced during overhead throwing. Though not statistically significant, larger INF tendons, with greater cross-sectional area, suggested a reduction in risk and could indicate a posterior rotator cuff muscle's ability to generate greater force to counter IR. The data that is provided affords the clinician a comparison to healthy, uninjured youth and adolescent baseball players which they can assess their patients against. The importance of enhancing the strength and performance of the posterior rotator cuff is emphasized through the behavior of the unilateral ER/IR ratio and, when decreased, its relation to the presence of upper extremity complaints. In this population, future studies should evaluate the effectiveness of different strengthening programs, especially those that focus on the posterior rotator cuff, to decrease the incidence of pain experienced during the season.

The primary objectives of this study were to determine if changes occurred in tendons of the shoulder during a pitching performance and to evaluate whether these changes were related to the presence of upper extremity complaints. The results of this study suggest that throwing as few as 50 pitches results in approximately a 0.18mm (4.44%) increase in the LHB tendon and a 0.21mm (4.77%) increase in the INF tendon of the throwing arm. Direct comparison between the throwing and non-throwing shoulders revealed significantly different INF tendon width change with pitching. However, the change in tendon width in both the LHB and INF tendon were not correlated or determined to be predictive of those who experience upper extremity complaints as determined the findings in Chapter 5. While it is possible that the acute changes in the tendons may be part of a continuum leading to pain, it is also possible that the changes seen at the 50 pitch level are a normal response to a single pitching exposure. Unfortunately, the findings from Chapter 5 are limited by a few factors, including a small sample size, that restrict the decisiveness of the results. We believe the amount of change seen in this study was limited secondary to the restriction of pitches approximately 25 pitches before the current guidelines' upper limit for these ages (75 pitches).[14] The upward trajectory of the tendon width for both the LHB and the INF tendons suggest that continued pitching beyond the 50 pitch amount would result in greater acute changes in tendon diameter, which may have shown a more pronounced correlation to the presence of upper extremity complaints. Our results would also suggest that current recommendations expressing the importance of limiting potentially damaging cumulative overload to the tendon and allowing adequate recovery time between exposures could be related to the tissue changes shown to occur with pitching. Some degree of an acute response to throwing is expected. However, prevention of a potentially harmful amount, as well as an accumulation of overload throughout a season, would be of utmost importance. The presence of acute tendon changes confirms that a short term response occurs. What remains to be determined in future studies is whether tendon change is normal or pathological, if a threshold exists, and if individual variation can be pre-determined. Studies utilizing larger sample sizes and pitching that reaches or surpasses 75 pitches would assist in answering these questions.

Despite the inability to identify any single predictor of upper extremity complaints in this population that reached statistical significance, an approximately medium effect size was noted for baseline characteristics of the LHB tendon ($p = 0.07$, converted $d = 0.76$) and less so for the INF ($p = 0.23$, converted $d = 0.47$) tendon. In this study, LHB tendons that had baseline width values greater than the average in this population, had increased odds (OR = 3.9) of experiencing upper extremity complaints in the ensuing season. Interestingly, the presence of a LHB that was greater than the average width in this study was significantly correlated to have greater IR @ 90° strength and a lower ER/IR ratio, both of which were previously identified as significant predictors in Chapter 3. We concluded that the adaptive increase in unilateral IR @ 90° strength seen in trained, overhead athletes placed increased demands on the LHB tendon, mostly in deceleration phase of the throwing motion. The repetitive overload, mostly eccentric in nature, may either elicit hypertrophy or cause cumulative microtrauma to occur in the LHB tendon. The presence of increased IR @ 90° strength is directly linked to the unilateral ER/IR ratio, which was shown to have an inverse relationship with the LHB width. Increases in IR @ 90° force, without the concomitant increase in ER @ 90° strength, results in a muscular imbalance between the adaptively stronger internal rotators / accelerators and the often overloaded external rotators / decelerators.

Whereas the LHB tendon showed trends in identifying those with complaints, the INF tendon appeared to provide a small to medium protective effect for the upper extremity. INF tendon width values that were larger than the average value in this study were found to reduce the odds of experiencing upper extremity complaints from 45.5% (pre-test odds) to 35.13% (post-test odds). Intriguingly, the larger INF tendon width values were not correlated with ER @ 90° strength, but instead were related to one's age ($p = 0.00$), height ($p = 0.00$), weight ($p = 0.00$) and ball velocity ($p = 0.00$). The data would suggest that as young baseball players mature, the function of the posterior rotator cuff is enhanced and hypertrophy is experienced. Though not reaching statistical significance, the importance of the posterior rotator cuff and its ability to limit anterior translation of the humeral head and decelerate the arm after ball release are highlighted by the reduction in odds when the tendon is more developed.

Overall, these studies demonstrate that QUS is reliable method for measuring tendon characteristics in a youth and adolescent baseball athlete population and that this technology may be able to assist in detecting those who are increased risk of upper extremity issues with throwing. Furthermore, we were able to document the amount of change that occurred in two muscles of the throwing shoulder during a real-time pitching exposure.

The amount of change documented in this study may represent normal behavior as it was not strongly linked to the presence of symptoms in the season that preceded it. Conversely, the tendon changes may be the initiation of pathology. Noted limitations in the amount of pitching that each subject was exposed to, the nature of the environment, as well as a limited sample size may have constrained our results. The characteristics of the tendons at baseline appeared to show more relation to the presence of seasonal complaints. While our results suggest potentially injurious and protective behaviors of specific tendon characteristics, it is important to note that, likely secondary to low power, statistical significance was not achieved and definitive conclusions cannot be drawn.

Finally, we were able to determine a profile for both ROM and strength in a youth and adolescent baseball population. From this data, we were able to establish certain findings that were correlated to having upper extremity complaints. Not only were these findings individually significant predictors, but they were also connected to the QUS variables which had the strongest association with the same complaints. We believe this provides not only a possible explanation for upper extremity complaints at the tissue level, but also provides a general guideline for clinicians to direct their rehabilitation or sports performance training. Furthermore, we believe this information will allow more player specific guidance based off of risk factor assessments and linear regression modeling to predict the amount of change their tendons will undergo. These methods also have the potential to evaluate other tissues, such as the ulnar collateral ligament or other rotator cuff muscles.

Any number of applications of QUS along with an extended pitching performance may provide additional information regarding the tissue characteristics of the throwing arm and their relation to the prevalence of throwing-related injuries.

Future studies should include an investigation into tendon changes in width and other greyscale QUS variables in response to pitching utilizing a larger sample size and a laboratory environment to provide greater control over the experimental processes. Also, addition of post-season QUS imaging would allow investigators to assess for the influence that seasonal fatigue has on the acute response to pitching.

Application of similar research methods could be applied to explore the acute effect that pitching has on the ulnar collateral ligament as well. Repetitive loads that approach failure limits of the UCL are encountered with throwing,[201,202] and contribute to various pathology related to microtrauma and failure. Public and medical interest in UCL injuries in youth and professional overhead athletes has increased substantially over the years as pathologies associated with the UCL have reached widespread levels.[202] Despite the implementation of injury prevention guidelines and rules, UCL reconstructions continued to increase in the early 2000's, and no there has been no data to date showing injury rates are declining.[202] Amplifying the problem, there appears to be a public misconception of contributing factors for UCL injuries and the necessity and benefit of reconstruction.[203] To better manage and prevent UCL injuries, continued investigations are needed to further elucidate the effects that throwing has on the UCL and the use of QUS could prove to be a valuable asset in the future. Qualitative and quantitative ultrasound to evaluate ligament integrity with activity could be utilized, where damaged ligaments may appear thickened[204,205], with diffuse hypoechogenicity and surrounding fluid, and abnormal appearance overall.[205]

Studies further investigating procedures to reduce incidence rates should also be pursued. With the identification of upper extremity strength alterations, the protective effect of specifically designed strengthening programs and their effect on the incidence of pain should also be conducted. Finally, the effectiveness of the current pitch guidelines should be evaluated and comparisons of incidence of upper extremity complaints should be made between those leagues and teams that utilize the guidelines and those that do not. Results of such a study could provide further justification for methods aimed at limiting cumulative microtrauma in youth and adolescent baseball.

APPENDIX A

BACKGROUND AND SIGNFICANCE SUMMARY

A.1 EVIDENCE SUMMARY OF LITERATURE LINKING PITCHING AND INJURY

Author	Year	Pitch measure	Other risk factors	Age Range	Conclusions
Fleisig GS, et al[74]	1999	Pitching mechanics: kinematics, kinetics, and temporal parameters	None examined	Youth: age 10 – 15 years High School: 15 – 20 years College: age 17 -23 years Professionals: age 20 -29 years	Findings support the belief that a child should learn proper pitching mechanics at an early age. Increases in joint forces and torques seen in adult pitchers were most likely due to increased muscle strength and muscle mass. Natural progression of

					developing pitcher is to learn proper mechanics as early as possible and build strength as the body matures.
Lyman S, et al.[11]	2001	Pitch count (> 75 pitches per game) Pitching < 300 pitches during the season. Pitching > 600 pitches during the season. Pitch types	Decreased satisfaction with performance Arm fatigue during the game pitched in	8 – 12 years	To limit risk of upper extremity pain, young pitchers should not throw > 75 pitches in a game. Throwing > 600 pitches in a single season is a risk factor for elbow pain. Pitchers of all ages encouraged to learn the change-up instead of a breaking pitch to reduce the risk of injury. Remove pitchers from a game when arm fatigue is exhibited. Limit non-league pitching.
Lyman S, et al.[10]	2002	Pitch count Pitch types Pitching mechanics	None examined.	9 – 14 years	The risk of pain can be reduced with limitations on number of pitches thrown in game and in a season. (75 pitches per game and 600 pitches in a season recommended) Young pitchers should be cautioned about throwing

					curveballs and sliders.
Petty DH, et al.[38]	2004	Year-round throwing (< 2 full months of rest from throwing per year) Seasonal overuse: (frequent violation of recommendations of USA Baseball Medical & Safety Advisory Committee) Event overuse: (short episode of extreme overuse)	Pitch velocity > 80 mph Throwing breaking pitches before age 14 years Inadequate warm-ups	15 – 19 years	Coaches and parents of young baseball players should have knowledge of the recommendations of USA Baseball Medical & Safety Advisory Committee. Primary risk factor: overuse, be it yearly, seasonal, or event. Extra caution should be taken with those who pitch with higher velocity. Young throwers should take a 2 – 3 month break from all overhead throwing. Young pitchers are not recommended to throw curveball (breaking ball) before age 14.

Sabick MB, et al.[60]	2005	No specific pitch measure examined	Throwing kinetics	11 – 12 years	The weak proximal epiphyseal cartilage can be damaged by the external rotation torque encountered in the late cocking phase of throwing. The kinetics of throwing a fastball by youth pitchers is consistent with 2 clinical pathologies.
Olsen SJ, et al.[13]	2006	Pitching characteristics: Pitched more months per year, more innings per game, pitches per game, pitches per year	Starting pitcher vs. relief pitcher Higher pitch velocity Pitched with arm pain and fatigue more often Injured group taller and heavier	16 – 20 years	Pitching practices between those who had surgery and those who had no history of a significant pitching related injury are significantly different. Factors with the strongest association with injury were overuse and fatigue. High pitch velocity associated with increased risk for injury.
Dun S, et al.[82]	2008	Pitch type	None examined	10 – 14	Upper extremity kinetics are the greatest in the fastball and were the lowest in the change-up. Curveball is not a more dangerous pitch than a fastball in youth baseball pitchers.

Nissen CW, et al.[83]	2009	Pitch type	None examined	14 – 18	The curveball mechanics, as defined in this article, suggest that throwing a curveball may not increase the incidence of injury. Authors could not conclude that other pitching methods to throw a curveball or breaking pitch would have the same results. The number of pitches thrown and inadequate rest appears to be a greater risk factor injury.
Davis JT, et al.[76]	2009	Pitching mechanics	None examined	9 – 18 years	Youth pitchers with better pitching mechanics have more efficiency and lower torque and loads in the shoulder and elbow than do those with improper mechanics. Pitching with proper mechanics may help prevent shoulder and elbow injuries in youth pitchers.
Fleisig GS, et al.[12]	2011	Volume of pitching	Throwing curveballs (breaking pitch) at a young age. Playing catcher in addition to pitching.	9 -14 years	Youth baseball pitcher has a 5% risk of serious arm injury over a 10 year period. Pitching > 100 innings in a year were more likely to be injured. Playing catcher appears to increase the risk of a pitcher being injured.

					Study was unable to show that throwing curveballs (breaking pitch) before age 13 increased risk.

APPENDIX B

BASELINE DEMOGRAPHIC AND PHYSICAL EXAMINATION FORM

Age (years):	Height (inches) (self-reported)	Weight (pounds) (self-reported)
BMI:	Throwing Arm:	Years Pitched:
Primary Position:	Secondary Position:	Number of leagues:
*Hx Surgery:	*Hx shoulder pathology past year:	*Participate 3-9 months:

Range of Motion (degrees)		
ROM: ER @ 0°	R:	L:
ROM: IR @ 90°	R:	L:
ROM: ER @ 90°	R:	L:

Special Tests: (negative / positive)		
Neer’s Test	R:	L:
Hawkin’s Test	R:	L:
O’Brien’s Test	R:	L:
Speed’s Test	R:	L:
Posterior Impingement Sign	R:	L:
Relocation Test	R:	L:

Strength Measurement: (kg)	**Right:**	**Left:**

Supraspinatus: (Flexion at 90°)	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________
Infraspinatus: (ER at 0°)	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________
Teres Minor: (ER at 90°)	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________
Subscapularis: (Full IR)	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________
Internal Rotation @ 90°	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________
Biceps: (Elbow Flexion arm at side)	1.___________ 2.___________ 3.___________	1.___________ 2.___________ 3.___________

APPENDIX C

DATA COLLECTION SYSTEM AND ULTRASOUND IMAGE PROCESSING

C.1 RANDOM NUMBER GENERATION OF ULTRASOUND IMAGE

```
      %generate random number to select which image is displayed first
          random_nums = randperm(image_num);

          for filenumber=1:image_num
              file_count=num2str(filenumber);
              message=['Select image number ', file_count, ': '];
              disp(message);
              [filename,pathname]= uigetfile('*.*');
              new_filename = filename(1:size(filename,2)-4);
              file_list(filenumber,:)=new_filename;  %stores  filenames  of  all
images
          end


          for b = 1:image_num %count through number of images

              %define counter variable that loads images in a random order
              random = random_nums(b); %need to add one at the end of the loop

              filename_size = size(file_list(random,:));
              for j = 1:(filename_size(2))
                  shortname(random,j) = file_list(random,j);
                  j=j+1;
              end

              %define values from filename
              ID=[shortname(random,1:4)];
              investigator=[shortname(random,5)];
                  if investigator == '1' %Adam Popchak
                      invest_code=num2str(1);
                  elseif investigator == '2' %Nate Dogg
```

```
            invest_code=num2str(2);
        else
            invest_code=num2str(-99);
        end

    structure=[shortname(random,6)];
        if structure == 'b' %Biceps
            struct_code=num2str(1);
        elseif structure== 'i' %Infraspinatus
            struct_code=num2str(2);
        else
            struct_code=num2str(-99);
        end

    depth=[shortname(random,7)]; %already a number (3,4, or 5 cm)

    gain=[shortname(random,8:9)];
        if gain =='00'
            gain=['100']; %convert two digit code (00) to actual gain
(100)
        end

   image_time=[shortname(random,10)];  %usually  1,  unless  repeated
measurements were taken
   if image_time=='b'
       image_number = 1;
   elseif image_time=='1'
       image_number = 2;
       elseif image_time=='2'
       image_number = 3;
   else
       image_number = '-99';
   end

   image_number=num2str(image_number);
```

C.2 CONVERSION OF ULTRASOUND IMAGE TO READABLE IMAGE & MANUAL POINT SELECTION

```
      %reads image and stores as unsigned integer values from 0-255 in %matrix
'image'
    image=imread(shortname(random,:),'bmp');
    image=image(:,:,1);
    if depth == '3'
        header_pix=80;
    else %depth = 4 or 5
```

```
            header_pix=55; %default number of pixels to start of skin
        end

        [size_check_x size_check_y] = size(image);
        if size_check_x > 570 %see if borrowed machine was used
            image=image(37:600,:);  %resize  to  match  HERL  image  size
(564x800)
            if depth == '3'
                header_pix=60;
            else %depth= 4 or 5
                header_pix=35; %pixels to start of skin
            end
        end

        %calculates size of image matrix
        [size_x size_y] = size(image);

        %gets the conversion factor from pixels to area

[first_time,length,known_length,conversion,cm_convert,hconversion,hcm_convert] =
get_convert(first_time,image,length,known_length,loop_again,depth);

        %allows user to make polyline selections

[average_width,corners,distances,refleft,refright,skin_roi,muscle_roi]        =
get_lines(image,size_x,size_y,hcm_convert,header_pix);

        %converts the pixel lengths to mm
        actual_width = average_width/conversion;
        actual_dist = distances./conversion;

        %function allows user to encircle selection using series of mouse
clicks
        %hit enter after zooming appropriatly - (shift / double click to
end selection)
        %selects point right above tendon
        [cord_values,cords,out_y]                                        =
select_after_lines(size_x,size_y,image);

        %gets outermost point above tendon
        %[out_y] = get_point_shoulder;

        %creates reference block
        [reference]          =          create_reference_shoulder(out_y,
refleft,refright,image,average_width);

        %analyzes reference block, sorts into 10x10
        %[new,rows,cols] = analyze_shoulder(reference);

        %calls average calculation function
        %[reference_average,            selection_average]            =
calc_average_shoulder(cord_values,reference);

        %rotates image so that long axis of tendon is horizontal
        [rotated_cord_values]=rotate(cord_values,corners);
```

```
              %calculate imaging parameters for tendon ROI
              [t_counts, t_bins, t_meangrey, t_variance, t_std, t_skew, t_kurt,
t_entro, ...
                  t_contrast, t_correlation, t_energy, t_homogeneity, t_imagefft,
t_logfft,...
                  t_image_crop,t_imagefft100,     t_logfft100,     t_imagefftr,
t_logfftr] = imaging(rotated_cord_values);

              %calculate imaging parameters for reference ROI
              [r_counts, r_bins, r_meangrey, r_variance, r_std, r_skew, r_kurt,
r_entro, ...
                  r_contrast, r_correlation, r_energy, r_homogeneity, r_imagefft,
r_logfft,...
                  r_imagefft100,   r_logfft100,   r_imagefftr,   r_logfftr]   =
imaging_reference(reference);

              ratio = t_meangrey/r_meangrey;

              %calculate  first  order  statistics  for  rectangular  regions  of
interest
                  %skin (1 segment)
                  s_d=(size(skin_roi,1))/2; %distance to center of skin region
                  skin_roid=double(skin_roi); %convert to double class

                  %finds location and value of all non-zero entries in image
                  [row_skin,col_skin,val_skin] = find(skin_roid);

                  %find number of non-zero pixels in image
                  index_skin=size(row_skin,1);

                  %store non-zero pixels in a one-dimensional vector
                  for k=1:index_skin
                   skind(k,1)=skin_roid(row_skin(k),col_skin(k));      %double
precision
                  end

                  s_g_mean=mean(skind); %mean greyscale
                  s_g_var=var(skind); %greyscale variance
                  s_g_skew=skewness(skind); %greyscale skewness
                  s_g_kurt=kurtosis(skind); %greyscale kurtosis
                  s_g_entro=entropy(skin_roi); %greyscale entropy

                  %muscle (5 segments)

[m_region1,m_region2,m_region3,m_region4,m_region5,m_d,m_g_mean,m_g_var,m_g_skew,
m_g_kurt,m_g_entro] = roi_segment(muscle_roi);

                  %tendon (5 segments)

[t_region1,t_region2,t_region3,t_region4,t_region5,t_d,t_g_mean,t_g_var,t_g_skew,
t_g_kurt,t_g_entro] = roi_segment(t_image_crop);

                  %convert distances to mm
                  s_d=s_d/conversion;
```

```
            m_d=m_d./conversion;
            t_d=t_d./conversion;

        %store segmented region of interest variables for saving;
        segment_stats=[s_d s_g_mean s_g_var s_g_skew s_g_kurt s_g_entro ...
            m_d m_g_mean' m_g_var' m_g_skew' m_g_kurt' m_g_entro' ...
            t_d t_g_mean' t_g_var' t_g_skew' t_g_kurt' t_g_entro']; %66
columns

        %calculate power information from Log of 2-D fft
            [EnergyVarsLog] = fft_processing(t_logfft100);

        %calculate power information from Log of 2-D fft
            [EnergyVars] = fft_processing(t_imagefft100);

        %stores variables in 2x2 cell array
        store{1,b} = [t_meangrey,r_meangrey,ratio];
        store{2,b} = path;
    store{3,b} = [actual_width];
```

C.3 MATLAB OUTPUT OF PROCESSED IMAGE

```
%%%%%% begin output section of program %%%%%%

    %creates path to new directory on all matlab using computers
    %newdirectory = ['H:\Ultrasound\ShoulderImageAnalysis'];

    %changes directory of my file for saving
    %cd (newdirectory);

    %loops to remove .bmp file extension from path
    filename_size = size(file_list(random,:));
    for j = 1:(filename_size(2)-4)
        temp_id(j) = file_list(random,j);
        j=j+1;
    end

    %defines file label
    file_2_open = [temp_id];


    opening_name=['shoulder_tendon.txt'];

    j = b+2;
    k = b+1;
    %stores several global variables in single array for printing to file
```

```
shoulder_data=[actual_width,t_meangrey,r_meangrey,ratio,(actual_dist'),t_vari
ance,r_variance,t_std,r_std,...

t_skew,r_skew,t_kurt,r_kurt,t_entro,r_entro,t_contrast,r_contrast,...
            t_energy,r_energy,t_homogeneity];

        % prepares writing to a new file name using the original path,
appends data to end of file
        fid=fopen(opening_name,'a');

        if one_time == 0
            %writes headers to file
            fprintf(fid,'\n %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t  %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\n',...
                'Filename','ID', 'Investigator', 'Structure', 'Depth',
'Gain','Image_num',...
                'Tendon Width','T_Mean','R_Mean','T/R_ratio',...
                'Skin_dist','TenTop_dist','TenBot_dist','Bone_dist',...

'T_Var','R_Var','T_StD','R_StD','T_Skew','R_Skew','T_Kurt','R_Kurt','T_Entro'
,'R_Entro',...

'T_Con01','T_Con02','T_Con03','T_Con04','T_Con05','T_Con06','T_Con07','T_Con0
8','T_Con09','T_Con010',...
                'T_Con-11','T_Con-22','T_Con-33','T_Con-44','T_Con-
55','T_Con-66','T_Con-77','T_Con-88','T_Con-99','T_Con-1010',...
                'T_Con-10','T_Con-20','T_Con-30','T_Con-40','T_Con-
50','T_Con-60','T_Con-70','T_Con-80','T_Con-90','T_Con-100',...
                'T_Con-1-1','T_Con-2-2','T_Con-3-3','T_Con-4-4','T_Con-5-
5','T_Con-6-6','T_Con-7-7','T_Con-8-8','T_Con-9-9','T_Con-10-10',...

'R_Con01','R_Con02','R_Con03','R_Con04','R_Con05','R_Con06','R_Con07','R_Con0
8','R_Con09','R_Con010',...
                'R_Con-11','R_Con-22','R_Con-33','R_Con-44','R_Con-
55','R_Con-66','R_Con-77','R_Con-88','R_Con-99','R_Con-1010',...
                'R_Con-10','R_Con-20','R_Con-30','R_Con-40','R_Con-
50','R_Con-60','R_Con-70','R_Con-80','R_Con-90','R_Con-100',...
```

```
                'R_Con-1-1','R_Con-2-2','R_Con-3-3','R_Con-4-4','R_Con-5-
5','R_Con-6-6','R_Con-7-7','R_Con-8-8','R_Con-9-9','R_Con-10-10',...

'T_Energy01','T_Energy02','T_Energy03','T_Energy04','T_Energy05','T_Energy06'
,'T_Energy07','T_Energy08','T_Energy09','T_Energy010',...
                'T_Energy-11','T_Energy-22','T_Energy-33','T_Energy-
44','T_Energy-55','T_Energy-66','T_Energy-77','T_Energy-88','T_Energy-
99','T_Energy-1010',...
                'T_Energy-10','T_Energy-20','T_Energy-30','T_Energy-
40','T_Energy-50','T_Energy-60','T_Energy-70','T_Energy-80','T_Energy-
90','T_Energy-100',...
                'T_Energy-1-1','T_Energy-2-2','T_Energy-3-3','T_Energy-4-
4','T_Energy-5-5','T_Energy-6-6','T_Energy-7-7','T_Energy-8-8','T_Energy-9-
9','T_Energy-10-10',...

'R_Energy01','R_Energy02','R_Energy03','R_Energy04','R_Energy05','R_Energy06'
,'R_Energy07','R_Energy08','R_Energy09','R_Energy010',...
                'R_Energy-11','R_Energy-22','R_Energy-33','R_Energy-
44','R_Energy-55','R_Energy-66','R_Energy-77','R_Energy-88','R_Energy-
99','R_Energy-1010',...
                'R_Energy-10','R_Energy-20','R_Energy-30','R_Energy-
40','R_Energy-50','R_Energy-60','R_Energy-70','R_Energy-80','R_Energy-
90','R_Energy-100',...
                'R_Energy-1-1','R_Energy-2-2','R_Energy-3-3','R_Energy-4-
4','R_Energy-5-5','R_Energy-6-6','R_Energy-7-7','R_Energy-8-8','R_Energy-9-
9','R_Energy-10-10',...

'T_Homogen01','T_Homogen02','T_Homogen03','T_Homogen04','T_Homogen05','T_Homo
gen06','T_Homogen07','T_Homogen08','T_Homogen09','T_Homogen010',...
                'T_Homogen-11','T_Homogen-22','T_Homogen-33','T_Homogen-
44','T_Homogen-55','T_Homogen-66','T_Homogen-77','T_Homogen-88','T_Homogen-
99','T_Homogen-1010',...
                'T_Homogen-10','T_Homogen-20','T_Homogen-30','T_Homogen-
40','T_Homogen-50','T_Homogen-60','T_Homogen-70','T_Homogen-80','T_Homogen-
90','T_Homogen-100',...
                'T_Homogen-1-1','T_Homogen-2-2','T_Homogen-3-3','T_Homogen-4-
4','T_Homogen-5-5','T_Homogen-6-6','T_Homogen-7-7','T_Homogen-8-
8','T_Homogen-9-9','T_Homogen-10-10');
        end

        %reformats vectors to accommodate output
        [shoulder_data]=shoulder_data';

        %writes filename to file
        fprintf(fid,'\n %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t
',file_2_open,ID,invest_code,struct_code,depth,gain,image_number);

        %writes data to file
        fprintf(fid,'%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
```

```
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f', shoulder_data);


        % prepares writing to a new file name using the original path,
appends data to end of file
        fid2=fopen('FFT_information.txt','a');

        if one_time == 0
            %writes headers to file
            fprintf(fid2,'\n %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s',...
                'Filename', 'ID', 'Investigator', 'Structure', 'Depth',
'Gain','Image_num',...
                'E_05_045', 'E_05_4575', 'E_05_75105', 'E_05_105135',
'E_05_135180', 'E_05_875925', 'E_510_045',...
                'E_510_4575', 'E_510_75105', 'E_510_105135', 'E_510_135180',
'E_510_875925', 'E_1015_045',...
                'E_1015_4575', 'E_1015_75105', 'E_1015_105135',
'E_1015_135180', 'E_1015_875925', 'E_1520_045',...
                'E_1520_4575', 'E_1520_75105', 'E_1520_105135',
'E_1520_135180', 'E_1520_875925', 'E_2030_045',...
                'E_2030_4575', 'E_2030_75105', 'E_2030_105135',
'E_2030_135180', 'E_2030_875925', 'E_3040_045',...
                'E_3040_4575', 'E_3040_75105', 'E_3040_105135',
'E_3040_135180', 'E_3040_875925', 'E_4050_045',...
                'E_4050_4575', 'E_4050_75105', 'E_4050_105135',
'E_4050_135180', 'E_4050_875925', 'E_05_total',...
                'E_510_total', 'E_1015_total', 'E_1520_total',
'E_2030_total', 'E_3040_total', 'E_4050_total',...
                'E_total_045', 'E_total_4575', 'E_total_75105',
'E_total_105135', 'E_total_135180',...
                'E_total_875925', 'maxvalue', 'maxpercentage', 'meanpower',
'varpower', 'skewpower', 'kurtpower');
```

```
        end

        %reformats vectors to accommodate output
        [EnergyVars]=EnergyVars';

        %writes filename to file
        fprintf(fid2,'\n %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t
',file_2_open,ID,invest_code,struct_code,depth,gain,image_number);

        %writes data to file
        fprintf(fid2,'%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f', EnergyVars);

        % prepares writing to a new file name using the original path,
appends data to end of file
        fid3=fopen('FFT_information_Log.txt','a');

        if one_time == 0
            %writes headers to file
            fprintf(fid3,'\n %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s',...
                'Filename', 'ID', 'Investigator', 'Structure', 'Depth',
'Gain','Image_num',...
                'E_05_045', 'E_05_4575', 'E_05_75105', 'E_05_105135',
'E_05_135180', 'E_05_875925', 'E_510_045',...
                'E_510_4575', 'E_510_75105', 'E_510_105135', 'E_510_135180',
'E_510_875925', 'E_1015_045',...
                'E_1015_4575', 'E_1015_75105', 'E_1015_105135',
'E_1015_135180', 'E_1015_875925', 'E_1520_045',...
                'E_1520_4575', 'E_1520_75105', 'E_1520_105135',
'E_1520_135180', 'E_1520_875925', 'E_2030_045',...
                'E_2030_4575', 'E_2030_75105', 'E_2030_105135',
'E_2030_135180', 'E_2030_875925', 'E_3040_045',...
                'E_3040_4575', 'E_3040_75105', 'E_3040_105135',
'E_3040_135180', 'E_3040_875925', 'E_4050_045',...
                'E_4050_4575', 'E_4050_75105', 'E_4050_105135',
'E_4050_135180', 'E_4050_875925', 'E_05_total',...
                'E_510_total', 'E_1015_total', 'E_1520_total',
'E_2030_total', 'E_3040_total', 'E_4050_total',...
                'E_total_045', 'E_total_4575', 'E_total_75105',
'E_total_105135', 'E_total_135180',...
                'E_total_875925', 'maxvalue', 'maxpercentage', 'meanpower',
'varpower', 'skewpower', 'kurtpower');
        end

        %reformats vectors to accommodate output
```

```
        [EnergyVarsLog]=EnergyVarsLog';

        %writes filename to file
        fprintf(fid3,'\n %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t
',file_2_open,ID,invest_code,struct_code,depth,gain,image_number);

        %writes data to file
        fprintf(fid3,'%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f',
EnergyVarsLog);

     % prepares writing to a new file name using the original path, appends
data to end of file
        fid4=fopen('Depth_Correction_Vars.txt','a');

        if one_time == 0
            %writes headers to file
            fprintf(fid4,'\n %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t%8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t%8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t
%8s\t%8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t %8s\t%8s\t %8s\t %8s\t
%8s\t %8s\t %8s\t %8s\t %8s\t %8s',...
                'Filename', 'ID', 'Investigator', 'Structure', 'Depth',
'Gain','Image_num',...
                    'Skin_dist','TenTop_dist','TenBot_dist','Bone_dist',...

'Skin_mid','Skin_mean','Skin_var','Skin_skew','Skin_kurt','Skin_entro',...

'Musc1_mid','Musc2_mid','Musc3_mid','Musc4_mid','Musc5_mid',...

'Musc1_mean','Musc2_mean','Musc3_mean','Musc4_mean','Musc5_mean',...

'Musc1_var','Musc2_var','Musc3_var','Musc4_var','Musc5_var',...

'Musc1_skew','Musc2_skew','Musc3_skew','Musc4_skew','Musc5_skew',...

'Musc1_kurt','Musc2_kurt','Musc3_kurt','Musc4_kurt','Musc5_kurt',...

'Musc1_entro','Musc2_entro','Musc3_entro','Musc4_entro','Musc5_entro',...

'Ten1_mid','Ten2_mid','Ten3_mid','Ten4_mid','Ten5_mid',...

'Ten1_mean','Ten2_mean','Ten3_mean','Ten4_mean','Ten5_mean',...

'Ten1_var','Ten2_var','Ten3_var','Ten4_var','Ten5_var',...

'Ten1_skew','Ten2_skew','Ten3_skew','Ten4_skew','Ten5_skew',...
```

```
'Ten1_kurt','Ten2_kurt','Ten3_kurt','Ten4_kurt','Ten5_kurt',...

'Ten1_entro','Ten2_entro','Ten3_entro','Ten4_entro','Ten5_entro');
        end

        %reformats vectors to accommodate output
        Depth_Data=[(actual_dist') segment_stats];
        [Depth_Data]=Depth_Data';

        %writes filename to file
        fprintf(fid4,'\n %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t %10s\t
',file_2_open,ID,invest_code,struct_code,depth,gain,image_number);

        %writes data to file
        fprintf(fid4,'%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t
%10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f\t %10.4f',
Depth_Data);

%         %saves tendon ROI to file loadable by matlab
%         save_image_1 = ['tendon_',temp_id];
%         save(save_image_1,'cord_values',);
%
%         %saves cropped area of tendon ROI to file loadable by matlab
%         save_image_2 = ['cropped_',temp_id];
%         save(save_image_2,'t_image_crop');
%
%         %saves reference ROI to hard disk as m-file loadable by matlab
%         save_image_3 = ['ref_',temp_id];
%         save(save_image_3,'ref');


        %save reference area, and roi regions as unsigned 8 bit so that it
can be displayed
        %using imshow
        ref=uint8(reference);

        %saves ROIs to file loadable by matlab
        save_image_1 = ['ROIs_',temp_id];

save(save_image_1,'rotated_cord_values','t_image_crop','ref','skin_roi','m_re
gion1',...

'm_region2','m_region3','m_region4','m_region5','t_region1','t_region2',...
            't_region3','t_region4','t_region5');

        %save histogram data
        save_hist = ['hist_',temp_id];
```

```
        save(save_hist,'r_bins','t_bins','r_counts','t_counts');

        %save fft data
        save_fft = ['fft_',temp_id];

save(save_fft,'r_imagefft','t_imagefft','r_logfft','t_logfft','r_imagefft100'
,'t_imagefft100',...

'r_logfft100','t_logfft100','r_imagefftr','t_imagefftr','r_logfftr','t_logfft
r');

        %-----------------------------------------------------------------
------

        %increments counter to only display header once
        one_time = one_time + 1;
    end

    %close output files
    fclose(fid);
    fclose(fid2);
    fclose(fid3);
    fclose(fid4);



    %displays results to screen
    shoulder_results(store,image_num);


    %prompts user to repeat program
    repeat=menu('Would you like to analyze a new set of images?','Yes','No');

    %if analyzing new image, close all current figures
    if repeat == 1
        close all
    end

end %end external while loop

fclose('all');
```

APPENDIX D

QUS DATA PROCESSING MANUAL POINT SELECTION

Ultrasound image files were exported from the ultrasound machine and were renamed to fit a specific format that could be read by Matlab. The images were then read into Matlab and written to individual image files (Appendix C.1). Within each image, a manual point selection protocol was carried out (Appendix C.2).

D.1 MULTISTEP PROTOCOL

The initial step in the manual point selection protocol was to select the center of the left and right interference patterns. Once the center of the left and right interference patterns were selected, the protocol creates a grid that defines the region you will be working in (Figure 19).

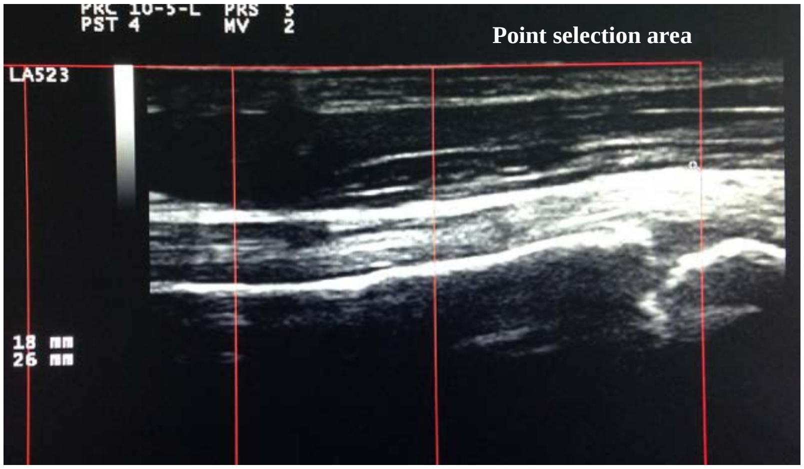

Figure 19: Defined regions of manual point selection

In this screen you are prompted to click two points at the bottom of the skin surface. After detection of the bottom of the skin surface, selection of the largest rectangle within the skin region (Figure 20), followed by the muscle region (Figure 21) was completed.

Figure 20: Manual point selection of largest area in skin region

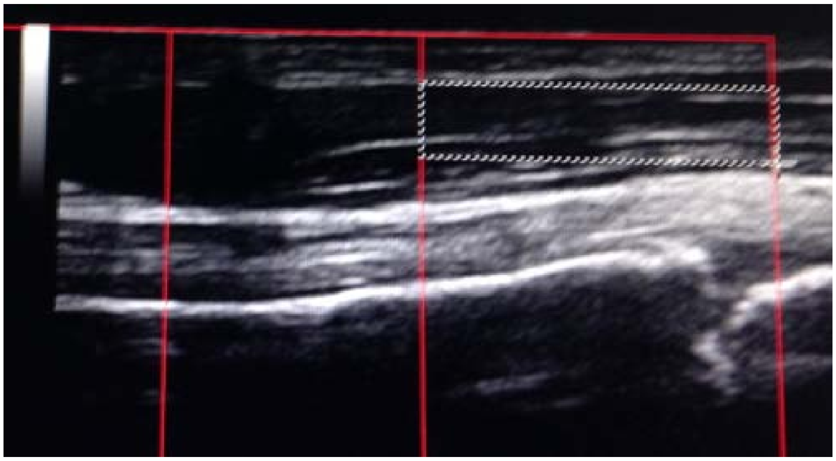

Figure 21: Manual point selection of largest area in muscle region

The Matlab program then cued the operator to select two points on the bone underneath the tendon (Figure 22). Next selection of two lines, first above, then below the tendon (Figure 23) is completed followed by selection of the area inside the lines (Figure 24). At this stage, Matlab produces an image of the ROI only, where the operator must select the largest rectangle that is entirely in the tendon border (Figure 25).

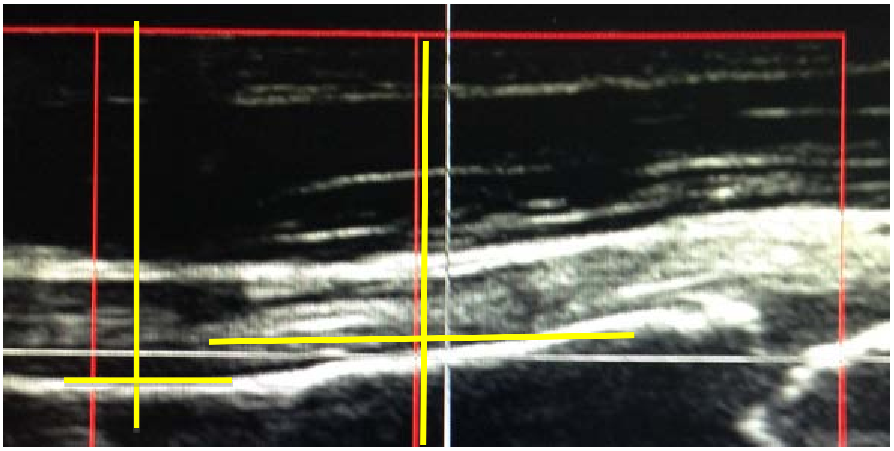

Figure 22: Manual point selection of two locations on bone

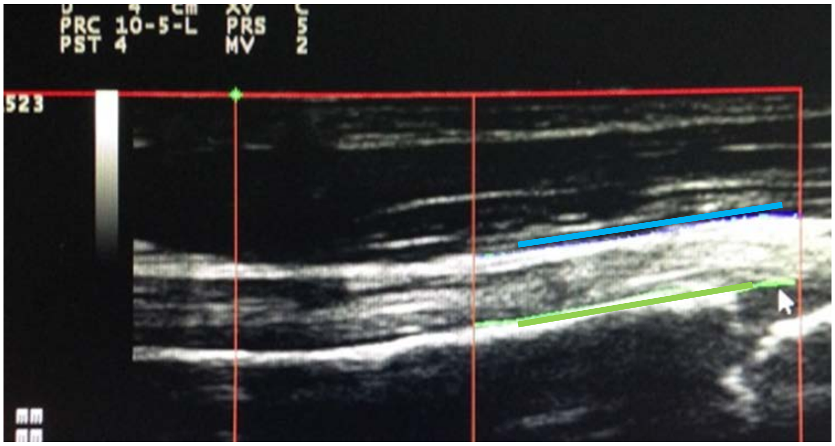

Figure 23: Manual point selection of lines at top and bottom of tendon

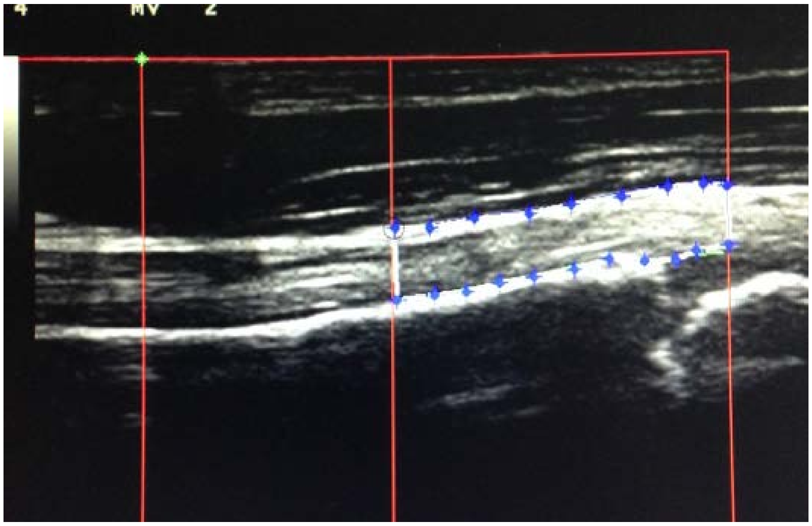

Figure 24: Manual point selection of click points inside lines

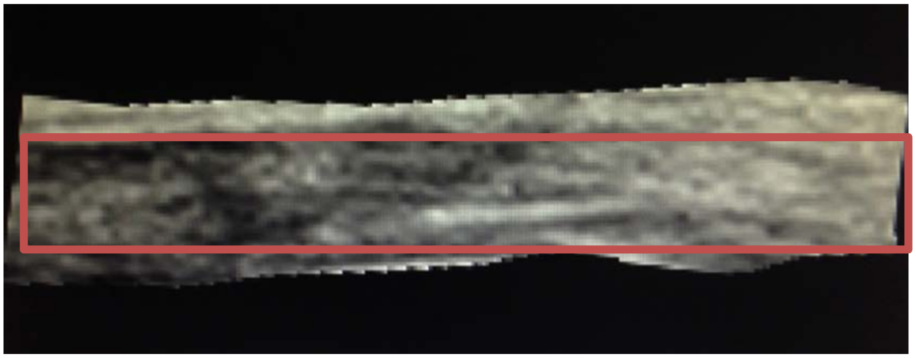

Figure 25: Manual point selection of largest rectangle in ROI

The specific outlined Matlab process was carried out on for all images of the LHB and INF (or 95 shoulders for LHB and 98 shoulders for INF) at 3 time points.

Output from the Matlab program (Appendix C.3) included the variables of primary interest, tendon diameter and echogenicity (T_mean) as well as additional grayscale variables. Output was copied and pasted into an excel file for aggregation of the data for processing.

APPENDIX E

PITCH COUNT BOOKLET

Soft Tissue Changes Associated with Repetitive Overhead Throwing
in an Adolescent Population

Participant Pitch Count Log

Adam Popchak, PT, DPT, MS, SCS
University of Pittsburgh
School of Health and Rehabilitation Sciences

Instructions:

For each game played during your season, please record the following information:

1. **Date:** Please record the date of the game played
2. **Team:** Please record the name of the team that you played for that day
3. **Position:** Please record the position(s) played during that game
4. **Pitch Count:** If you pitched in that game, please record the number of pitches you threw
5. **Pitch While Fatigued:** If you pitched while fatigued, please mark "YES." If you did not pitch while fatigue, please mark "NO." If you did not pitch that game, please mark "NA."
6. **Arm stiffness or tightness after game:** If you experienced stiffness or tightness in your arm after the game, please mark "YES." If you did not experience those symptoms, please mark "NO."
7. **Pain in shoulder from throwing:** If you experienced pain in your shoulder from throwing in the game, please mark "YES." If you did not experience pain from throwing in the game, please mark "NO."
8. **Self-Satisfaction:** If you were satisfied with your performance that game, please mark "YES." If you were not satisfied with your performance, please mark "NO."

A member of the research team will contact you regarding the data you are collecting. Please remember that your comments and input will be kept confidential. If you have any questions, please contact Adam Popchak @814-659-8844 or by email at ajp64@pitt.edu. Thank you very much for your participation in this research.

Date	Team	Position	Pitch Count	Pitch while fatigued	Arm stiffness or tightness	Pain in shoulder	Self-satisfaction

Thank you very much for your participation in this research project. Your contribution has been valuable and very much appreciated.

If at any point during the study period you have questions regarding the use of this pitch count log or other aspects of the study, please contact Adam Popchak by email at ajp64@pitt.edu or by phone at 814-659-8844.

If you would need additional pitch count logs, please contact Adam Popchak at the above given information and more will be provided.

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