RECOVERY OF INFRASPINATUS CROSS-SECTIONAL AREA, ECHO INTENSITY, AND GLENOHUMERAL RANGE OF MOTION FOLLOWING OVERHAND PITCHING

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ABSTRACT

Brett Steven Pexa: Recovery of Infraspinatus Cross Sectional Area, Echo Intensity, and Glenohumeral Range of Motion Following Bouts of Overhand Pitching
(Under the direction of Joseph Myers)

Previous work demonstrates that eccentric load associated with baseball pitching results in swelling of the infraspinatus, with accompanying change in glenohumeral flexibility. Infraspinatus swelling and flexibility measurements provide markers for both trauma that results from pitching and a means to monitor recovery following pitching. The purpose of this study was to longitudinally track changes in measures of infraspinatus swelling (cross-sectional area and echo intensity) and humeral rotation flexibility daily, up to 7 days following a bout of pitching. Ten Division 1 baseball pitchers volunteered as participants. One general linear models was run to analyze change in scores per dependent variable per limb (twelve in total). Infraspinatus cross-sectional area increased one day following pitching and internal rotation decreased for three days after pitching. Baseball pitchers cause damage that can last up to 3 days. Recovery must occur to pitch on subsequent days so arms may return to baseline before reapplying stress.

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CHAPTER I

Introduction

Baseball is a popular sport in America, with over 4.5 million participants every year[1] and over 17,000 participants at the collegiate level.[2] The overhead throwing motion involved with baseball predisposes the upper extremity to acute and chronic injuries.[3] These injuries primarily occur in pitchers and over 25 percent result in extended time loss from sport (10 days or more).[4-7] In collegiate baseball, shoulder and elbow pain attributed for 36% of all injury complaints.[6] As level of play increased from minor to major leagues, this number rises to nearly 50%.[4,7]

Pitch count is associated with increased injury rate in baseball pitchers.[8] Research shows that as pitch counts increase, there is an increased injury rate in the elbow and shoulder at all levels of play.[9] Additionally, injured participants tend to exhibit higher pitches per season, innings per season, pitches per game, and warm-up pitches prior to participation.[10,11] This may indicate that injuries may come from the cumulative effect of pitching, rather than just one bout with a high pitch count. These studies have led to the development of pitch count regulations and limits on the maximum amount of innings pitched in the Little League Baseball.[12] The pitch count regulations also suggest how many days of rest are needed between pitching bouts, but do not present strong evidence regarding the recommendations.

Upper extremity injuries during baseball can be attributed to the forces created at the shoulder and elbow during overhead throwing.[13] During overhead throwing, the humerus is pulled anteriorly for nearly the entire throwing motion prior to ball release.[13] Additionally, a large increase in humeral head compression is present in the deceleration phase and peaks just after ball release.[13] The infraspinatus plays a large role in mitigating the forces placed on the shoulder during the overhead throwing motion. The infraspinatus increases shoulder stability by increasing joint compression and eliminating anterior shear forces through a posterior line of pull.[14] It is also highly active during the deceleration phase of pitching, suggesting an eccentric function to slow the arm following ball release.[15] This eccentric activity compounded with high pitch counts is hypothesized to have an effect on the physical characteristics of the posterior musculature.

Eccentric muscle activity has been shown to cause muscle damage, specifically to the sarcomere itself.[16] Studies indicate that an increase in muscle volume occurs following eccentric exercise,[17,18] and recent evidence suggests that cross-sectional area when obtained by ultrasound can assess muscle volume of the infraspinatus.[19,20] Ultrasound has been proven as an accurate method to measure cross-sectional area in muscle.[21] A unique characteristic in ultrasound is the ability to assess echo intensity, which is a reliable measurement of muscle damage. Echo intensity is directly related to the amount of interstitial fluid,[22] adipose tissue, and intramuscular fibrous tissue in the muscle belly. [23] Increases in cross-sectional area and echo intensity may indicate fatigue in a muscle and can act as indicators of muscle damage. Following eccentric activity, range of motion deficits are linked to shortened connective tissue and passive muscle stiffness.[18,24] A recent study showed a deficit in passive shoulder internal rotation and total arc of motion that lasted 24 hours following a bout of overhead throwing.[25]

While pitch counts have been shown to have a relationship with injury rates,[9] a neglected part of this equation is how the physical characteristics of the shoulder recover following extended bouts of overhand pitching. Inadequate rest time prevents the scapular stabilizing muscles from adequately mitigating forces in the shoulder due to fatigue and cumulative damage. Recovery is a return to normal state, in this case measured by cross-sectional area, echo intensity, and humeral internal rotation. Current studies focus on sports performance to assess required recovery time.[26] The current standard for rest is a five-day period in Major League Baseball and a six-day period in collegiate baseball, but there is no evidence to support this. Full recovery must happen so the muscle has time to return to a baseline before reapplying stress to the tissue. Cumulative damage may occur if this stress continues build on top of an already damaged muscle.

Pitch count may be a injury risk factor due to the cumulative effect of eccentric muscle activity that damages the posterior shoulder, but there is a substantial lack of evidence regarding recovery following overhand pitching. There are changes in the physical characteristics of the posterior shoulder musculature that indicate muscle damage and inflammation. Returning a pitcher to the mound while the effects from a pitcher's last overhand bout are still present may predispose the athlete to injury because the shoulder musculature may not function optimally to stabilize the humeral head. Recovery is critical to the rotator cuff and arm decelerators. Muscles must have time to regain their strength and range of motion to dissipate forces and allow full range of motion. Identifying time frames regarding recovery of a muscle will help establish better standards for days of rest between starts. Using ultrasound to assess muscle recovery is unconventional outside of a lab, but there may be changes present associated with muscle recovery and range of motion assessment.

Purpose

The primary purpose of this study is to identify changes in infraspinatus cross-sectional area, echo intensity, and humeral rotation range of motion following extended bouts of overhand pitching and track the recovery of these variables immediately post-exposure and every 24 hours for 6 days following exposure to identify the curve of recovery of these variables over time.

Research Questions and Hypothesis

Reasearch Question 1: How does infraspinatus cross-sectional area change from baseline immediately and every 24 hours for 6 days following pitching in collegiate baseball pitchers?

- Hypothesis 1: The cross-sectional area will increase following a pitching bout. Cross-sectional area will then decrease back to baseline as days following exposure increase.

Research Question 2: How does echo intensity change from baseline immediately and every 24 hours for 6 days following pitching in collegiate baseball pitchers?

- Hypothesis 2: The echo intensity will increase in intensity following a pitching bout. Echo Intensity will decrease back to baseline in intensity as days following exposure increase.

Research Question 3: How does glenohumeral rotation range of motion change from baseline immediately and every 24 hours for 6 days following pitching in collegiate baseball pitchers?

- Hypothesis 3: A decrease in glenohumeral rotation will be noted within 24 hours following exposure. Internal rotation will increase back to baseline as days following exposure increase.

Research Question 4: How does horizontal adduction range of motion change from baseline immediately and ever 24 hours for 6 days following pitching in collegiate pitchers?

- Hypothesis 4: A decrease in horizontal adduction will be noted within 24 hours following a pitching bout. Horizontal adduction will increase back to baseline as days following the pitching bout increase.

CHAPTER II

Participation and Injury

Baseball is a popular sport played from youth levels up to professional leagues. There are over 4.5 million members annually[1] with 17,000-27,000 collegiate baseball players.[2,5] Baseball players often develop upper extremity injuries that include impingement, rotator cuff injury, shoulder instability, labral tears, and elbow ulnar collateral ligaments injuries.[4-7,27] Regarding collegiate baseball, 58 percent of all injuries were upper extremity related and 75 percent of all time-lost due to injuries were related to the upper extremity.[6] As the level of play increased in baseball, participants showed a higher rate of injury.[27] Pitchers are especially at risk for upper extremity injury and have a higher incidence ratio than their fielding counterparts.[5-7] Fifty-six to seventy-five percent of pitching injuries require time lost from sport.[4,5,7] Of these pitching-related injuries, 25 percent are considered severe and require 10 or more days lost from sport.[5] Despite considerable improvements in diagnostic measures, conditioning, and surgical procedures, Major League baseball still shows an increasing trend in injuries to pitchers.[4]

Baseball Pitching Motion

The pitching motion can test the glenohumeral joint to its maximum capacity in regards to strength and to range of motion.[14] The pitching motion utilizes static and dynamic soft tissue structures of the shoulder,[14] and can be broken down into 5 phases: windup phase, stride phase, arm cocking phase, arm acceleration phase, and arm deceleration phase.[13,15,28] Windup and stride phases are used to generate force in large muscle groups of the lower extremities and place the body in a position where it can transmit maximal force on the ball.[15] In the throwing motion, the lower body acts to generate force, the shoulder acts to funnel that force into the upper extremity, and the upper extremity then imparts the force on the ball.[29]

The arm cocking phase is from lead foot strike to maximal glenohumeral external rotation.[13] Posterior shoulder musculature activates in this stage to horizontally adduct and externally rotate the humerus.[15] This posterior force also causes the humeral head to migrate posteriorly. This posterior migration activates the rotator cuff, which is considered highly active in this stage, to provide compression and maintain stability throughout the full arm cocking.[13] The infraspinatus acts to reduce the anterior directed force on the anterior joint capsule and the anterior shear force on the labrum.[13] To combat an internal rotation torque of 65-70 N-m, the internal rotators (pectoralis major, subscapularis, anterior deltoid, latissimus dorsi) show very high activity to eccentrically slow the internal rotation.[15] Scapular muscles should not be ignored here, and greater scapular muscle imbalances will place the shoulder in a compromised position.[15]

The arm acceleration phase is from maximal external rotation to ball release. This phase is characterized by maximal EMG output from glenohumeral internal rotators to accelerate the arm in the anterior direction, resulting in a force of 6500 degrees per second of internal rotation velocity.[15] Following ball release, the pitching motion enters arm deceleration phase. Arm deceleration phase acts to dissipate the forces that were not imparted on the ball.[28] During arm deceleration, posterior musculature must act to slow the arm, reduce anterior shear force, and reduce anterior directed acceleration.[15]

Scapular stabilizing muscles and the rotator cuff show high EMG activity in this phase,[15] as shown by a glenohumeral compression force of 1090 N.[13] The biceps brachii also shows high EMG output and acts to increase glenohumeral stabilization.[15]

Baseball Specific Injury Mechanisms

The unique motion of overhand pitching uses strong lower extremity segments to transmit power to the upper extremity. With large muscle groups of the lower extremity acting so quickly, the upper extremity is tested to maximal capacity at the scapulothoracic and glenohumeral joints.[28] These forces create large torques at the elbow and shoulder that stress tissues to their thresholds.[13] This combination of stresses combined with a typical starting pitching outing of over 60 pitches can create changes in the dominant arm of the pitcher. When these stresses are performed on a consistent basis over a typical season, the stresses become magnified and injury risk factors will begin to affect the participant.

Increased Pitch Count

Pitch volume has long been seen as a risk factor for injury.[8,9,11,30] In 2001, Lyman et al.[30] found when pitch count exceeded 75 in youth pitchers, the risk for elbow pain increased by 50% and pitchers were 3.2 times more likely to experience shoulder pain. Lyman et al.[9] expanded upon this study and found a significant correlation of in-game pitch count and complaint of shoulder pain. Additionally, there was an increase in the complaints of shoulder and elbow pain as pitches thrown in a season increased.[9] In 2006, Olsen et al.[10] then found that there is a significant increase in upper extremity throwing injury when a player threw more games per year, more months out of the year, more pitches per game, more innings per game, more pitches per year, and more warm-up pitches before a game.

An increase in pitch count will have a direct effect on injury to the pitcher. As pitch count increases, muscles are taxed more. Fatigue of the rotator cuff causes superior humeral head migration, thus limiting the amount of space in the subacromial space and increasing subacromial impingement symptoms.[28,31] An increase in pitch count and poor mechanics will predispose pitchers to SLAP tears by increasing the amount of stress at the biceps labral complex.[28]

Studies have recommended that there be a limit to the amount of pitches thrown in a game, innings thrown in a season, and pitches that should be thrown in a year.[9,10,30] Baseball organizations have taken these studies and used them to help develop guidelines for youth pitchers. Little League Baseball now has rules in place that limit the number of pitches that can be thrown by a pitcher each day. They also have rules in place that require rest for pitchers arms in an attempt to fully recover before another throwing bout,[8] although there is no evidence to support full recovery. After they leave these leagues however, pitch counts are no longer enforced and the pitching frequency and volume is often in the hands of uneducated coaches. The current trend in Major League Baseball is using a 5-man rotation of starting pitchers with an approximate maximum pitch count nearing 110 pitches. College baseball teams typically have 4 starters that throw once per week 6 days apart with maximum pitch counts reaching 100 pitches.

Glenohumeral Internal Rotation Deficit (GIRD) and Total Range of Motion (TRM) deficit

Pathologic glenohumeral internal rotation deficit (GIRD) is defined as the loss in degrees of glenohumeral internal rotation of the throwing shoulder compared with the non-throwing shoulder without a subsequent gain of external rotation range of motion.[32] During pitching, the posterior shoulder musculature must absorb and reduce the distractive forces that occur during the deceleration phase.[13,15] If these muscles are unable to do so, they transmit the force to the posterior joint capsule, primarily the inferior glenohumeral ligament, which will inherently thicken to deal with the increased loads that are being placed upon it.[32-34] Osseous adaptations have also been identified that contribute to GIRD. Humeral retroversion has been identified in throwers when compared to their non-throwing side.[36]

Burkhart et al. (2003) hypothesize that a loss of internal rotation without a subsequent gain of external rotation is the most important pathological process that can happen in a thrower's shoulder.[32] The external range of motion increase creates a decrease in the internal range of motion to maintain a full arc of motion, or total rotational range of motion (TRM).[37,38] GIRD is a very common problem in throwers and has been widely studied and documented.[32,36,39,40] Patients with GIRD are more likely to suffer from the effects of subacromial impingement.[31,41] GIRD will cause the scapula to tilt anteriorly, causing the amount of space under the coracoacromial arch to be decreased and impingement symptoms to be increased.[28,41] GIRD has been identified as a pathomechanic motion for SLAP tears.[32,42] Tight posterior cuff musculature creates a change in the positioning of the humeral head in the glenoid.[42] This change alters the mechanics of the shoulder predisposing a pitcher to a SLAP tear.[32]

The tightened posterior capsule also causes the humeral head to migrate in a posterior and superior position, causing increased contact between the humeral head and the labrum. This shift in the axis of rotation predisposes the shoulder to a labrum related injury during throwing.[42] Pathologic GIRD and a decrease in Total Range of Motion (TRM) increases the risk of sustaining a UCL tear.[33,39,43] Pitchers with a UCL deficiency had lost almost 30 degrees of internal rotation.[39] GIRD will cause several pathological mechanisms regarding the rotator cuff as well. First, the change in the axes will change the lever arms and line of pull for the rotator cuff muscles, causing them to activate at wrong times and creating improper vectors.[32,42] Second, posterior cuff tightness causes the humeral head to migrate to a superior and posterior position, increasing contact between the humeral head and rotator cuff.[42] GIRD has been linked to patterns of internal impingement as well. A tight posterior cuff allows the posterior rotator cuff to become pinched between the greater tuberosity and posterior glenoid.[44] GIRD has a direct effect on scapular kinematics and plays a role in scapular dyskinesis.[34,45]

Horizontal Adduction

Horizontal adduction range of motion is an important measurement when assessing the range of motion of the posterior shoulder, and decreased horizontal adduction measurements have been noted in professional baseball players.[35,46] Eccentric motion of the posterior shoulder during deceleration creates contractures in the tissue and eventual thickening of the inferior glenohumeral ligament.[32,33,35] Tyler et al.[35] describes a reliable and valid technique in measuring posterior shoulder tightness. Supine measurement of horizontal adduction while stabilizing the scapula has strong correlation with posterior shoulder tightness.[35,42] Posterior shoulder tightness has been linked to internal impingement and subacromial impingement due to the superior migration of the humeral head.[44,47]

Scapular Dyskinesis and the SICK Scapula

Pitchers with GIRD may present with associated scapular dyskinesis. GIRD affects the way the glenohumeral and scapulothroacic joints move.[34] Burkhart et al.[29] define scapular dyskinesis through a combination of multiple physical signs. Scapular malposition, inferior medial border prominence, coracoid pain and malposition, and dyskinesis of scapular movement (SICK) define this syndrome. Throwers often times have altered scapular position at rest[48] and during humeral elevation[49] but the SICK scapula will present itself as a depressed shoulder and scapula.[29] This scapular position is depression, extreme protraction and anterior tilting, usually caused by tight pectoralis minor, which is why the coracoid pain begins.[29] Specifically in throwers, scapular dyskinesis may present itself in a decrease in velocity or accuracy.[48]

This scapular malposition has been linked to impingement syndrome. Muscle tightness, specifically in pectoralis minor, teres minor, and infraspinatus, or any combination of these, has been associated with an increase in subacromial impingement.[50] Muscle tightness will also alter the timing of other scapular muscles. If a weakness or timing issue arises, improper upward rotation of the scapula may occur, thus limiting room for humeral head elevation.[31,41] Poor timing of muscle activation may decrease shoulder stability. Labral pathologies may develop during late cocking and acceleration phases when the humeral head translates back and forth, causing further contact between the humeral head and the labrum.[51] Subjects with internal impingement showed to have significantly more sternoclavicular elevation and posterior tilting of the scapula, indicating scapular dyskinesis.[48]

Eccentric Muscle Activity

Eccentric muscle activity has been found in the literature to create delayed onset muscle soreness, muscle swelling noted by girth measures and cross-sectional area, deficits in range of motion, and overall muscle damage.[16,18,24] Eccentric motion plays a large role in the pitching motion,[15] and Fleisig et al.[13] called the deceleration phase a critical point in the pitching motion due to the activation of the posterior musculature, primarily the infraspinatus, to decelerate the arm following ball release. Muscle damage occurs for all posterior deceleration muscles, but the infraspinatus is large, thick muscle that can be easily assessed through diagnostic ultrasound.

Muscle volume increases following eccentric activity.[17,20,52] Following eccentric exercise, Chen et al.[17] found that there was a significant increase in the volume of the muscle bellies when measuring arm circumference. Chapman et al.[52] compared the effects that contraction speed had on the muscle belly's arm circumference and found that there was a significant increase in arm circumference for a fast velocity contraction group compared to a slow velocity contraction group. Multiple studies have used diagnostic modalities to document changes in muscle volume.[20,53,54] Chleboun et al.[53] found that eccentric exercise caused changes in muscle volume that were visual on diagnostic ultrasound. Oyama et al.[20] used diagnostic ultrasound to find that there was an increase in cross-sectional area of the infraspinatus following high speed eccentric exercise of the infraspinatus, which was to simulate the deceleration phase of pitching.

Muscle shortening has been documented following eccentric activity.[17,18,20,52] ROM deficits have been found immediately following eccentric exercise, and may stay with the affected muscle for as long as 10 days.[18] Additionally, the amount of muscle shortening was affected by the rate of contraction. As the velocity of the eccentric muscle activity increased, there was also an increase in the amount of muscle shortening.[52] In regards to the posterior shoulder, Oyama et. al.[20] noted a decrease in the muscle length of the infraspinatus following high speed eccentric contractions when measured by the supine internal rotation and horizontal abduction range of motion assessment. Reinold et al.[25] and Kibler et al.[55] also noted a decrease in range of motion following baseball pitching.

Eccentric motion has been noted to cause muscle damage.[16,22,24] An increase in the creatine kinase levels indicate that a breakdown of tissue may be present in the myofibrils and z-disks.[16] Tissue breakdown allows interstitial fluid and edema to buildup in the muscle, thereby increasing cross sectional area and showing an increase in echo intensity.[20,22] Gonzalez-Izal et al.[56] showed an increase in echo intensity 48 hours following maximal eccentric exercise, but there was not a significant difference in maximal concentric exercise. This indicates that there is more damage to the muscle following eccentric activity. Echo intensity, which has been shown to measure muscle quality through a gray-scale analysis,[57] has been shown to be elevated for at least 72 hours following exercise.[22] An increase in muscle edema, paired with a decrease in muscle quality has been hypothesized as the reason for decreased strength in muscles following exercise,[18] which may cause an increase in injury risk factors.

Some studies have shown that eccentric exercise decreases the amount of force that someone may be able to produce.[17,18,22,52] These are the same studies that also identify changes in muscle volume,[17,52] echo intensity,[22] and range of motion changes.[52] With so many different studies that have both decreased force production combined with increased muscle volume, echo intensity, and decreases in range of motion, one may be able to group these variables together and see they are related. Since assessing muscular strength with a biodex is not feasible in the clinical setting, finding a clinically applicable test, such as range of motion testing or diagnostic ultrasound assessment, is critical to assessing the state of muscle recovery.

Infraspinatus Activity during Throwing

The rotator cuff muscles are most active when the forces at the shoulder are the highest. These times have been identified as the late cocking phase, acceleration phase, and the deceleration phase.[13,15] During the late cocking phase, the arm is abducted to near 90 degrees and maximally externally rotated. A glenohumeral internal rotation torque is generated close to 65 N-m and a varus force at the elbow close to 65 N-m.[13,15] The entire rotator cuff is active to keep the humeral head in the glenoid fossa, and the infraspinatus specifically must keep the humeral head in a posterior position to limit the amount of contact with the anterior joint capsule and the anterior labrum.[14,15] The acceleration phase creates near maximum stresses at the shoulder and the elbow. The shoulder creates 6500 degrees of internal rotation velocity at the shoulder.[15] This high force generation culminates at ball release, but the shoulder must quickly then move from force generating concentric movements to force dissipating eccentric movements. After ball release, the arm creates 1090 N of compressive force to decrease any movement or shear force that is created at the shoulder joint.[13,15]

The infraspinatus has been shown to have a significant contribution to compressive forces at the glenohumeral joint.[14] The infraspinatus has a good line of pull to decrease anterior shear force at the shoulder.[58] This line of pull allows for the infraspinatus to act as the primary decelerator of the rotator cuff.[15] Infraspinatus EMG values have indicated that the infraspinatus is highly active starting at ball release and throughout all of the follow-through phase.[15] When the shoulder is close to the end range of stability, the infraspinatus is highly active and keeps the shoulder in the glenoid cavity.[58] Labriola et al. (2005) studied cadaveric models and found that when the infraspinatus tendon was cut, the compressive force at the shoulder decreased by 50 N and anterior directed forces increased by 1180 percent.[14]

While the infraspinatus is subjected to high eccentric loads for a large volume of repetitions, physical characteristics and physiologic processes indicate that the infraspinatus is stressed. Oyama et al.[20] found that repeated eccentric exercise that simulates baseball throwing will create a decrease of glenohumeral internal rotation. Reinold et al.[25] and Kibler et al.[55] found that there is a decrease in the internal range of motion of the shoulder following bouts of overhand baseball pitching. Muscle tightness of the infraspinatus may alter scapular kinematics as well as disrupt the normal motion of the glenohumeral joint.[20,34,41] Infraspinatus muscle damage has been identified through diagnostic ultrasound via increased cross-sectional area following extended eccentric exercise.[20] Muscle damage to the infraspinatus may cause a decrease in the ability of the infraspinatus to create force. This lack of control for deceleration will predispose the anterior labrum, anterior joint capsule, and biceps labral complex for injury due to the occurrence of anterior translation of the humeral head.[13-15,28,33,59]

Recovery and Treatment

Pitching imparts excess stress on the shoulder complex and surrounding tissues. The need for recovery is important for a pitcher to reach peak levels every outing, while still minimizing injury risk. In collegiate pitchers, electrical stimulation has shown to improve recovery when compared to active and passive techniques.[60] Following pitching, it is commonplace to see pitchers ice their arms, and Yanagisawa et. al.[19] found that ice accompanied with light shoulder exercise improved internal rotation range of motion scores and decreased muscle volume of the rotator cuff.

Arm care is also commonplace for many baseball teams at the collegiate level. Arm care is centered around scapular stabilization, rotator cuff strengthening and glenohumeral range of motion.[61] These exercises prepare the pitchers arm for the stresses that are going to be imparted on it. The thrower's ten is a popular set of exercises that encompasses these needs and addresses them through resisted exercise using therabands and free weights. Exercises can be performed on a stability ball such as internal and external rotation, full can exercises, lateral raise, prone T raise, prone Y raise, prone W, bicep curls and tricep extensions.[62] Posterior musculature is strengthened through the lower trapezius 5 series. Side-lying external rotation and wrist strengthening are important as well to prevent arm injury.[62] While arm care is important at preventing injury, there are very common techniques that health care professionals and pitchers themselves use to aid in recovery, such as soft-tissue massage, icing after pitching, heating prior to pitching, and NSAID use.

Instrumentation

Cross-Sectional Area

Cross-sectional area can be found through several different methods, but the most cost effective and widely available technique is with brightness mode (B-mode) diagnostic ultrasound.[63] Diagnostic ultrasound has been shown to be highly repeatable, effective, and reliable in capturing cross sectional area with sufficient contrast and clarity.[21,63] Additionally, panoramic ultrasound is capable of producing highly repeatable and accurate cross sectional areas of larger locomotive muscles.[21,63] Cross-sectional area and echo intensity can be taken with the same diagnostic ultrasound machine and be assessed with the same panoramic ultrasound picture.[57] The techniques in Oyama et al.[20] showed ICC scores of 0.984 and standard errors of 0.26 square centimeters during pilot testing.

Echo intensity

Echo intensity is the measure of muscle quality when using grayscale analysis on a diagnostic ultrasound machine.[57] Pillen et al.[23] found that echo intensity strongly correlated with muscle quality and structural changes. Echo intensity has been related to the correlation of interstitial fluid within the muscle at the time of its imaging.[22] Eccentric muscle activity causes an increase in muscle edema that can be detected by echo intensity. Radaelli et al.[22] tracked the biceps brachii muscle following eccentric exercise. The authors found it possible to track echo intensity increase after exercise and every 24 hours following for 72 hours with high reliability and sensitivity (ICC [2,1] for EI was 0.91, and the coefficient of variation was 2.2%).[22] Rosenberg et al.[57] provided further reliability and sensitivity scores, but this study incorporated panoramic ultrasound rather than static B-mode ultrasound (ICC [2,1] = 0.72, SEM = 3.68)

Internal Rotation

Internal rotation range of motion assessment is a clinical tool that is used to assess posterior shoulder tightness in baseball pitchers.[20,25,35,40] Wilk et al.[38] used a standard goniometer in a supine position and showed to have good correlation with intratester reliability (ICC [2,1] = 0.81). Internal rotation range of motion can be measured with a digital inclinometer and has been shown to have reliable readings when the patient is supine with the arm supported and the scapula stabilized.[40,48] Myers et. al.[40] showed sufficient reliability when performing pilot testing for internal range of motion measurements with a digital inclinometer (ICC [3,1] = 0.985, SEM = 1.51°). Higher reliability scores indicate that the digital inclinometer assessment should be employed when assessing internal rotation range of motion.

Horizontal Adduction

Horizontal adduction range of motion assessments measure posterior shoulder tightness. Tyler et al.[35] also provided evidence that there is a strong correlation between posterior shoulder tightnes and a decrease in glenohumeral internal rotation range of motion. This study also introduced a new way to assess horizontal adduction: with the patient lying supine (gold standard), and with the patient side lying.[35] Myers et al.[40] provided a reliability and validity study and indicated that the supine assessment of horizontal adduction shows higher intersession ICC scores when compared to it's side-lying counterpart (ICC [3,k] = 0.75, SEM=1.8 cm; ICC [3,k] = 0.49, SEM=1.7 cm, respectively).[40] Outside of the laboratory, clinicians have found even higher scores of intratester reliability when performed on professional baseball players by experienced clinicians (ICC [2,k] = 0.93, SEM=1.64°).[46]

Clinical Significance

To date, very little research has studied the recovery of baseball pitchers in regards to injury mechanisms. Literature has suggested that following pitching there is a decrease in range of motion, increase in muscle volume, and a mechanism available to create muscle damage. The literature fails to recognize how long these effects last on the muscle. Therefore, the purpose of this study is to identify changes in infraspinatus cross-sectional area, echo intensity, and glenohumeral range of motion following pitching in collegiate baseball players and track the recovery of these variables immediate post-exposure and every 24 hours following exposure to identify the curve of recovery of these variables over time.

CHAPTER III

Methods

Participants were active pitchers on the University of North Carolina at Chapel Hill varsity baseball team that competed in the fall season. Participants were between 18-22 years old at the time of data collection. The fall season lasts for 6 weeks. Each pitcher pitched once per week. Each start was considered an individual event that was not affected by previous pitching bouts.

Participants were considered eligible if they were uninjured during the time of data collection, competed in the fall season, and threw more than 25 pitches in one outing. Previous pitching experience and injury history was not part of exclusion criteria. If a pitcher was hurt during game participation, all data collected up to that time was included in the present study. An injury was defined as a complaint or diagnosis that caused the subject to stop throwing and miss a scheduled start. If another pitcher replaced them and met the inclusion criteria, they were included for data sampling. Excluded subjects could be readmitted into the study if they returned healthy and met the minimum pitch count.

Pitch count was collected by team managers and used in the study. The fall season schedule monitored pitcher's pitch count. Starting pitchers threw at least 20, 40, 60, 80, and 100 pitches per start in an increasing fashion. The pitcher's innings and effectiveness were not a part of the inclusion or exclusion criteria. Pitch count was used as a covariate for the statistical analysis.

Instrumentation

A portable B-mode diagnostic ultrasound machine (LOGIQe, General Electric, Milwaukee, WI, USA) with a 4cm multi-linear array probe was used to obtain bilateral limb cross-sectional area and echo intensity of the infraspinatus muscle for each participant, during each testing session. All images were taken at 12.0 MHz with gain set at 58. Depth was set at 5 cm for each pitcher. If the depth was set too shallow and the entire muscle belly did not fit in the image, the depth was set to 6 cm. A digital inclinometer (Saunders Group, Chaska, MN, USA) was used to assess glenohumeral range of motion.

Design

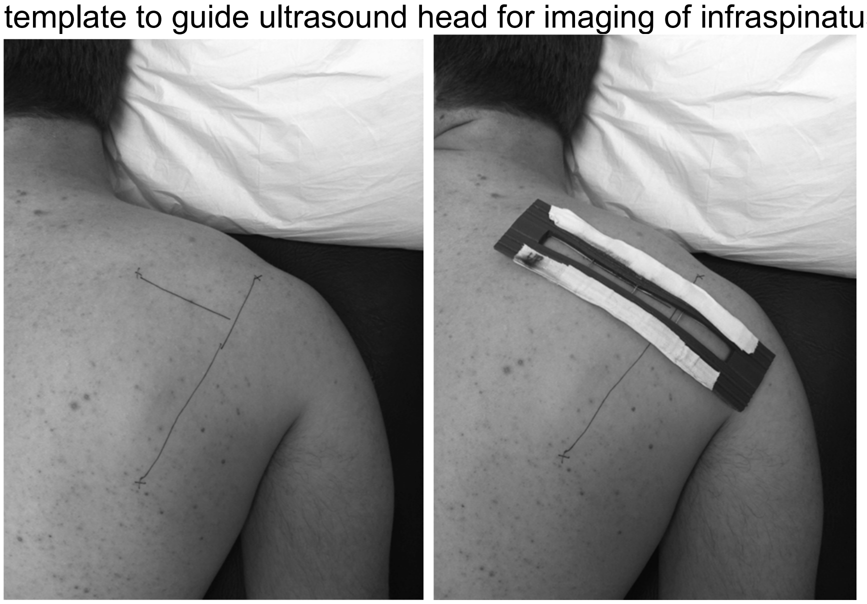
The design of this study was cross-sectional repeated measures. Pitchers were measured within two hours prior to pitching (Baseline), within 30 minutes post exposure (ImPost), and then every 24 ± 2 hours following until they made their next start, which was 6 days later. All measurements were taken prior to throwing activity and arm care for the day. Data collected throughout the study included cross-sectional area, echo intensity, glenohumeral internal rotation range of motion, external rotation range of motion, and horizontal adduction.

Procedure

All possible fall season pitchers provided consent approved by the University of North Carolina’s Institutional Review Board. The coaching staff chose the fall season starters. Height, mass, handedness and age was a part of general demographic information. Measurements were taken on site in a university satellite athletic training room. Measurements occurred prior to pitching (Baseline), immediately post pitching (ImPost), and every 24 hours following until next exposure. Pitchers were excluded if they became injured in a game.

Infraspinatus cross-sectional area and echo intensity was measured with the subject lying prone with their arms at their sides. The researcher palpated the scapula and marked the trigonum spinae (intersection of the medial border and the spine of the scapula), acromial angle, and inferior angle with a permanent marker. First, a line was drawn that connected the acromial angle and the inferior angle of the scapula. A second line that bisected the trigonum spinae was drawn perpendicular to the first line. The second line represented the standardized location of measurement of the infraspinatus. A template was put over the site to guide the ultrasound head over the designated area. A researcher then placed the ultrasound head in the template and produced a panoramic picture of the infraspinatus muscle belly. (**Figure 1**)

Figure 1. Left: Anatomical landmarks for infraspinatus muscle. Right: Custom foam template to guide ultrasound head for imaging of infraspinatus muscle.



Glenohumeral rotation range of motion was assessed with the subject lying supine with the arm abducted to 90 degrees and elbow flexed 90 degrees. One researcher placed a digital inclinometer on the dorsal surface of the forearm. One researcher stabilized the scapula by placing a posteriorly directed force on the coracoid process, and then rotated the shoulder until terminal internal rotation was reached as indicated by no further motion (**Figure 2**). The researcher then read the digital inclinometer and recorded the score. External rotation was taken the same way, but passive external rotation was measured. Three measurements of range of motion were taken.

Figure 2. Assessment of glenohumeral rotational range of motion

Glenohumeral horizontal adduction range of motion was assessed with the subject lying supine on the table. The subject was asked to raise their shoulder so the researcher was able to place their hand on the lateral border of the scapula to stabilize it while performing the assessment. The researcher used their thenar eminence to apply a downward (towards the table) and inward (towards the spine) force to stabilize the scapula. The researcher then passively horizontally adducted the shoulder until terminal horizontal adduction was reached (**Figure 3**). Once reached, the second researcher used an inclinometer to assess the angle that was created between the humerus and the horizontal plane from the superior aspect of the shoulder. Three measurements were taken.

Figure 3. Assessment of horizontal adduction range of motion

Pitch counts were kept by the team manager of the North Carolina Tar Heel baseball team and were given to the researcher for record keeping.

Data Reduction

Panoramic images were opened in NIH Image J software (National Institutes of Health, Bethesda, MD, USA) to create cross-sectional area readings (**Figure 4**). The measurement was scaled and then a tracing was made inside of the epimysium of the infraspinatus with NIH Image J software using the polygon function (**Figure 5**). The measurement function delivered the area inside the tracing. This technique has been shown to be reliable and valid for data reduction in previous literature to measure cross-sectional area.[64] Echo intensity was the mean of the computer aided grayscale analysis. The muscle belly image that was used for cross sectional area was same image that was used for echo intensity analysis. The range of scores are from 0 to 255 arbitrary units, with lower scores indicating decreased muscle damage and a darker more consistent image.[57] Muscle damage was shown as an image that is lighter and had more white pixels when compared to a normal muscle image.

Figure 4. Panoramic image obtained of the infraspinatus

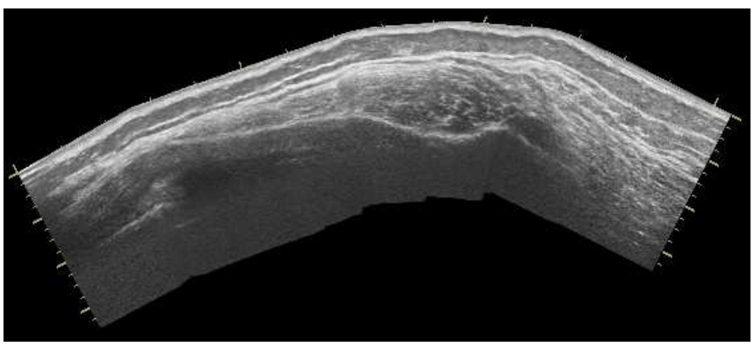
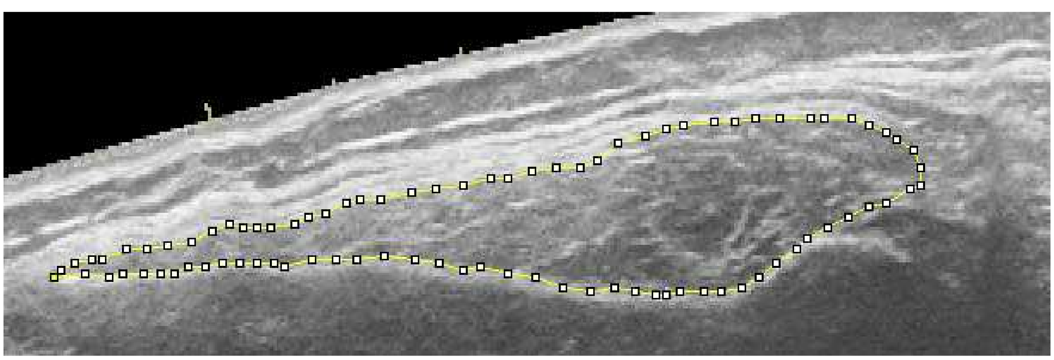


Figure 5. Epimysium tracing of the infraspinatus muscle



Three measurements were taken of internal rotation, external rotation, and horizontal adduction, and the average of the three measurements were used.

Statistical Analysis

A separate random-intercept general linear models was run for each dependent variable on the dependent and independent limbs using SAS 9.3 (SAS Institute Inc., Cary, North Carolina). Random-intercept general linear models were run due to the repeated measures of only 10 subjects. Post-hoc testing was performed with planned comparisons between the Baseline measurement and the following days with a bonferroni adjustment. There were 7 total comparisons, so with alpha level set at 0.05, variables were deemed significant at <0.0071 Cross-sectional area, echo intensity, internal rotation, external rotation, glenohumeral total arc of motion, and glenohumeral horizontal adduction are the dependent variables and pitch count will act as a covariate. Research questions, along with all outcome measures used in the study, are listed in **Table 1**.

Table 1. Statistical analysis to assess recovery of cross sectional area, echo intensity, and range of motion variables following bouts of pitching in starting pitchers.

Question	**Description**	**Data Source**	**Statistical Analysis**	**Method**
1	How does cross-sectional area change from baseline immediately and every 24 hours for 6 days following game pitching in collegiate baseball pitchers?	Diagnostic ultrasound measurements pre-exposure, post-exposure and every 24 hours following exposure	Measurements of cross sectional size at pre, post, and scores 24 hours apart	General linear model IV: Time DV: Cross sectional area Covariate: Pitch Count
2	How does echo intensity change from baseline immediately and every 24 hours for 6 days following game pitching in collegiate baseball pitchers?	Diagnostic ultrasound measurements pre-exposure, post-exposure and every 24 hours following exposure	Measurements of echo intensity at pre, post, and scores 24 hours apart	General linear model IV: Time DV: Echo Intensity Covariate: Pitch Count
3	How does glenohumeral rotation range of motion change from baseline and every 24 hours following game pitching in collegiate baseball pitchers?	Range of motion assessment via inclinometer pre-exposure, post-exposure, and every 24 hours following exposure	Measurements of glenohumeral rotation range of motion at pre, post, and scores 24 hours apart	General linear model IV: Time DV: Glenohumeral rotation range of motion Covariate: Pitch Count
4	How does glenohumeral horizontal adduction range of motion change from baseline and every 24 hours following game pitching in collegiate baseball pitchers?	Range of motion assessment via inclinometer pre-exposure, post-exposure, and every 24 hours following exposure	Measurements of glenohumeral horizontal adduction range of motion at pre, post, and scores 24 hours apart	General linear model IV: Time DV: Glenohumeral horizontal adduction range of motion Covariate: Pitch Count

CHAPTER IV

Results

Ten collegiate starting pitchers participated in the current study including 3 left-handed pitchers and 7 right-handed pitchers. The 10 pitchers combined for 41 separate pitching bouts. Participant demographics are presented in **Table 2**.

Table 2. Participant demographics

Demographic Information		
Age (years)	*Height (cm)*	*Mass (kg)*
18.8 ± 1.2	189.23 ± 7.3	93.1 ± 15.3

For each dependent variable, random-intercept general linear models were conducted to determine significance and where appropriate post-hoc analyses should be conducted. The complete results of those general linear model analyses is presented in **Table 3**.

Table 3. General linear model main effects

Type 3 Tests of Fixed Effects

		Effect	F Value	Pr > F
Dominant	CSA	Time	10.44	<.0001
		Pitch Count	1.15	0.2848
	EI	Time	15.4	<.0001
		Pitch Count	0.26	0.6093
	TRM	Time	23.57	<.0001
		Pitch Count	3.95	0.0481
	ER	Time	9.97	<.0001
		Pitch Count	1.25	0.2639
	IR	Time	13.13	<.0001
		Pitch Count	5.8	0.0168
	HA	Time	5.36	<.0001
		Pitch Count	3.86	0.0508
Non-Dominant	CSA	Time	3.7	0.0021
		Pitch Count	8.06	0.0049
	EI	Time	10.15	<.0001
		Pitch Count	0.12	0.7307
	TRM	Time	4	0.0012
		Pitch Count	29.11	<.0001
	ER	Time	3.72	0.0021
		Pitch Count	24.59	<.0001
	IR	Time	5.59	<.0001
		Pitch Count	28.86	<.0001
	HA	Time	62.57	<.0001
		Pitch Count	42.94	<.0001

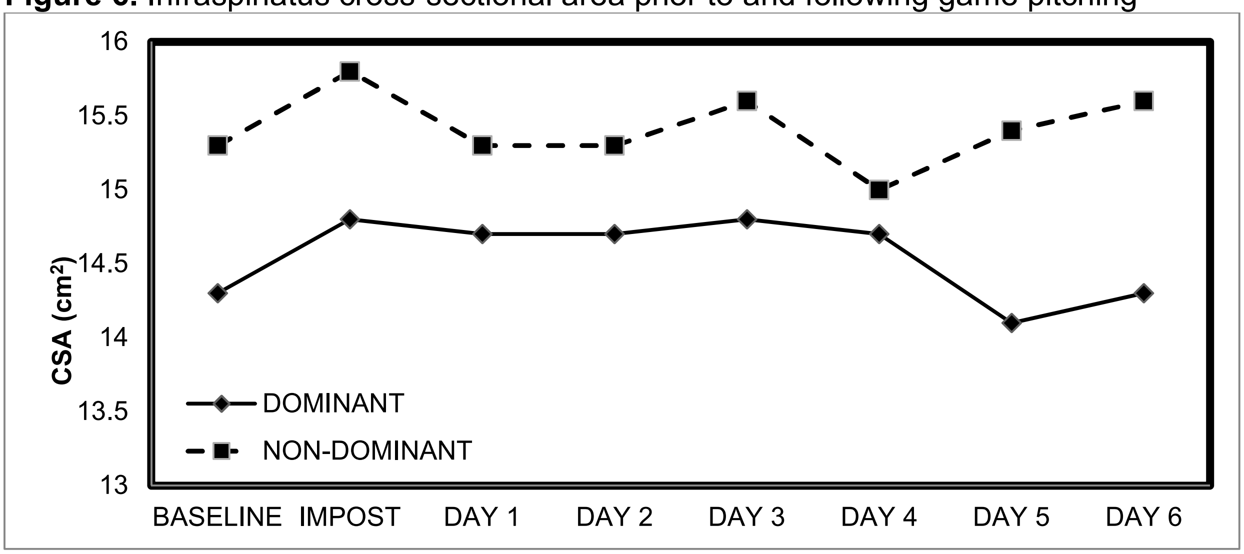
Time had a significant effect on the infraspinatus cross-sectional area (CSA) of the dominant arm ($F_{7,62}$ = 10.44, p=<0.0001) and the non dominant arm ($F_{7,62}$ = 3.70, p=0.0021) (**Table 3**). Specifically, CSA was significantly larger 1 day following exposure when compared to baseline (t_{62} = 3.51, p=0.0008) (**Table 4**). While significant time effects were present for the non-dominant limb cross-sectional area, no significant differences were present between the baseline and other testing times during post hoc analysis. Pitch count was not a significant covariate of the dominant arm. Infraspinatus cross-sectional area prior to and following game pitching is presented in **Figure 6**.

Table 4. Infraspinatus cross-sectional area descriptive data

	Cross-Sectional Area (cm^2)	
Time after Exposure	*Dom*	*NDom*
Baseline	14.3 ± 2.4	15.3 ± 2.3
ImPost	14.8 ± 2.5	15.8 ± 2.6
Day 1	14.7 ± 2.3*	15.3 ± 2.6
Day 2	14.7 ± 2.1	15.3 ± 2.3
Day 3	14.8 ± 2.1	15.6 ± 2.7
Day 4	14.7 ± 2.3	15.0 ± 2.6
Day 5	14.1 ± 2.1	15.4 ± 2.6
Day 6	14.3 ± 2.3	15.6 ± 2.3

** Denotes significant change with respect to baseline*

Figure 6. Infraspinatus cross-sectional area prior to and following game pitching



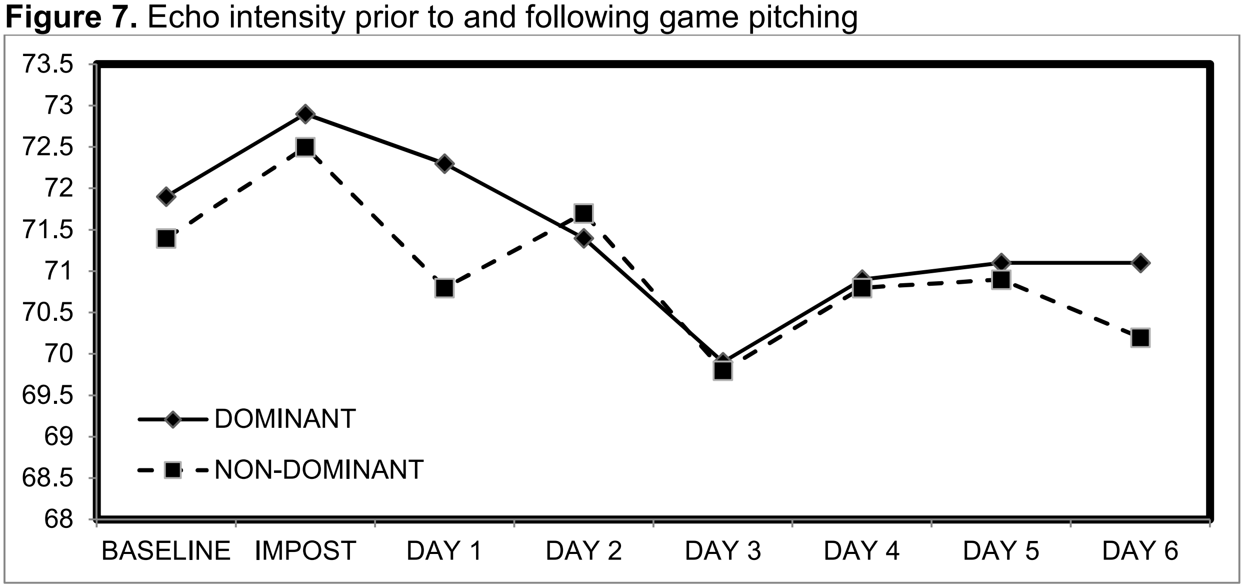
Time also had a significant main effect on echo intensity. Time was significant on the dominant ($F_{7, 62}$ = 15.4, p=<0.001) and non-dominant arm ($F_{7,62}$ = 10.15, p=<0.0001) (**Table 3**), while pitch count had no effects on either limb. In the dominant limb, post-hoc testing revealed that echo intensity was significantly lower 3 days following exposure when compared to the baseline scores (t_{62} = -6.64, p=<0.0001) (**Table 5**). Non-dominant limb post-hoc testing showed echo intensity was significantly lower 3 days following exposure when compared to baseline (t_{62} = -4.79, p=<0.0001) (**Table 5**). Echo intensity values prior to and following game pitching are presented in **Figure 7.**

Table 5. Echo intensity descriptive data

	Echo Intensity	
Time after Exposure	*Dom*	*NDom*
Baseline	71.9 ± 5.3	71.4 ± 4.7
ImPost	72.9 ± 6.8	72.5 ± 5.3
Day 1	72.3 ± 6.8	70.8 ± 6.3
Day 2	71.4 ± 6.6	71.7 ± 5.8
Day 3	69.9 ± 5.5*	69.8 ± 4.6*
Day 4	70.9 ± 5.0	70.8 ± 4.9
Day 5	71.1 ± 6.7	70.9 ± 4.6
Day 6	71.1 ± 5.9	70.2 ± 5.2

** Denotes significant change with respect to baseline*

Figure 7. Echo intensity prior to and following game pitching



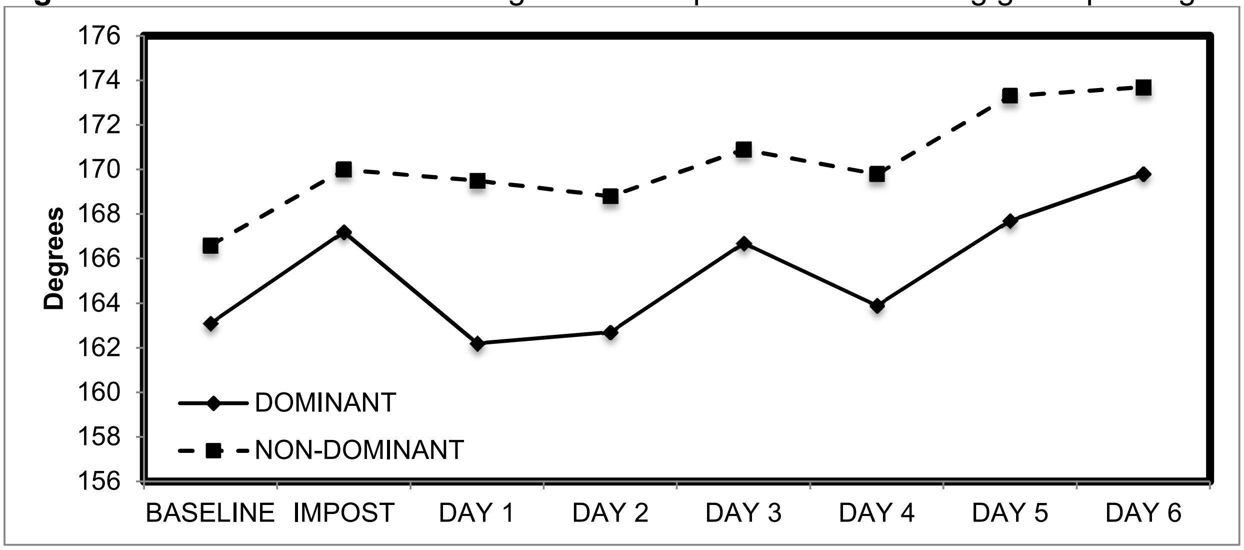
Total range of motion showed significant main effects of time in both the dominant ($F_{7,59}$ = 23.57, p=<0.0001) and the non-dominant arms ($F_{7,59}$ = 4.00, p=0.0012) (**Table 3**). On the dominant side, post-hoc testing showed that the baseline scores were significantly lower than 5 days (t_{59} = -5.25, p=0.0061) and 6 days (t_{59} = 4.15, p=0.0001) following exposure (**Table 6**). On the non-dominant arm, post-hoc testing showed that baseline scores were significantly lower than 3 days (t_{59} = 3.17, p=0.0024), 5 days (t_{59} = 3.62, p=0.0006), and 6 days (t_{59} = 3.84, p=0.0003) following exposure (**Table 6**). Pitch count showed to be a significant covariate in the non-dominant shoulder ($F_{1,231}$ = 29.11, p=<0.0001), but there was no effect in the dominant shoulder. Total range of motion prior to and following game pitching is presented in **Figure 8.**

Table 6. Humeral total rotation range of motion descriptive data

Total Rotation Range of Motion (degrees)		
Time after Exposure	*Dom*	*Ndom*
Baseline	163.1 ± 15.0	166.6 ± 13.5
ImPost	167.1 ± 15.5	170 ± 14.5
Day 1	162.2 ± 15.2	169.5 ± 13.2
Day 2	162.7 ± 12.1	168.8 ± 11.1
Day 3	166.7 ± 10.6	170.9 ± 11.8*
Day 4	163.9 ± 13.6	169.8 ± 13.6
Day 5	167.7 ± 10.8*	173.7 ± 13.2*
Day 6	169.8 ± 11.9*	173.7 ± 10.3*

*Denotes significant change with respect to baseline

Figure 8. Humeral total rotation range of motion prior to and following game pitching



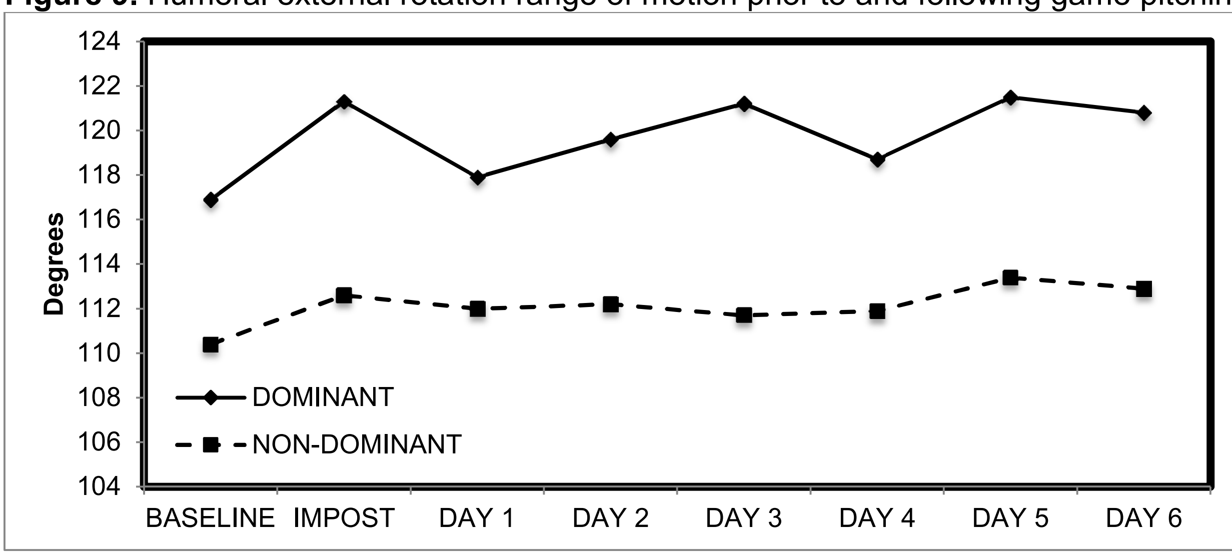
Time was shown to have a significant main effect on external rotation range of motion on the dominant limb ($F_{7,59}$ = 9.97, p=<0.0001) and the non-dominant limb ($F_{7,59}$ = 3.72, p=0.0021) (**Table 3**). Post-hoc testing was performed on the dominant limb, and baseline scores were significantly lower than scores immediately following exposure (t_{59} = 3.44, p=0.0011) and 5 days following exposure (t_{59} =3.30, p=0.0017) (**Table 7**). There was no significant finding on any days between the immediately post exposure and day 5 post exposure. On the non-dominant limb, post-hoc testing only showed that baseline scores were significantly lower than scores 6 days following exposure (t_{59} = 2.85, p=0.0061). Pitch count was a significant covariate on the non-dominant arm ($F_{1,231}$ = 24.59, p=<0.0001) but not on the dominant arm. External rotation ranges of motion prior to and following game pitching is presented in **Figure 9.**

Table 7. Humeral external rotation range of motion descriptive data

External Rotation Range of Motion (degrees)		
Time after Exposure	*Dom*	*NDom*
Baseline	116.9 ± 11.7	110.4 ± 10.5
ImPost	121.3 ± 10.3*	112.6 ± 10.1
Day 1	117.9 ± 11.1	112.0 ± 9.2
Day 2	119.6 ± 9.1	112.2 ± 8.6
Day 3	121.2 ± 8.6	111.7 ± 8.6
Day 4	118.7 ± 9.2	111.9 ± 9.8
Day 5	121.5 ± 8.1*	113.4 ± 9.6
Day 6	120.8 ± 6.9	112.9 ± 7.1*

*Denotes significant change with respect to baseline

Figure 9. Humeral external rotation range of motion prior to and following game pitching



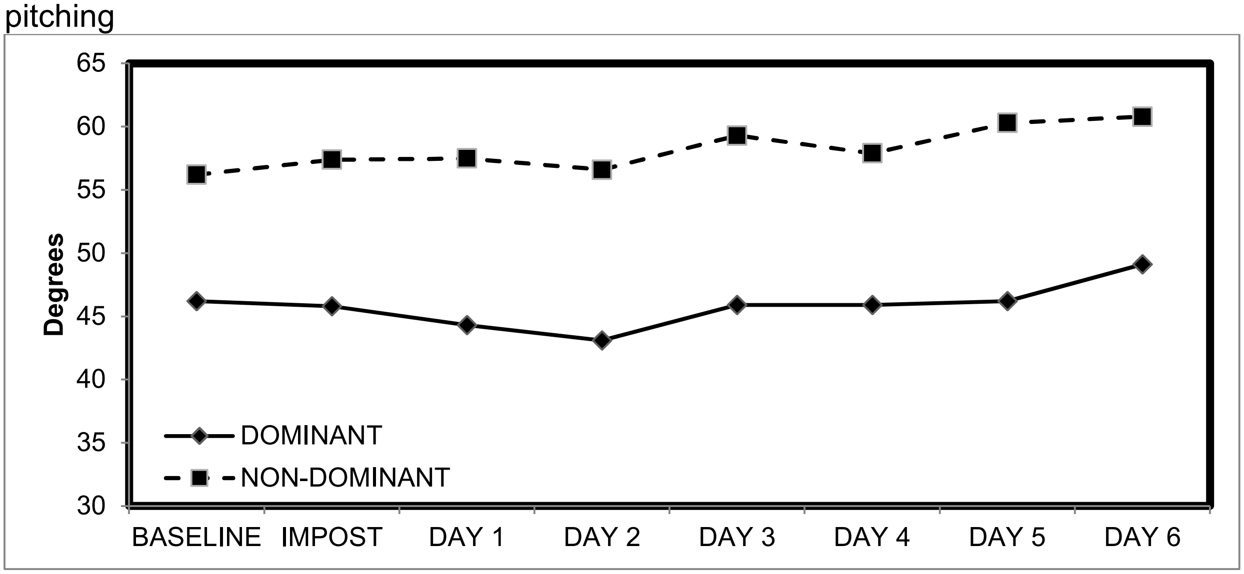
Internal rotation range of motion was significantly affected by time on both the dominant ($F_{7,59}$ = 13.13, p<0.0001) and non-dominant arms ($F_{7,59}$ = 5.59, p<0.0001) (**Table 3**). Post-hoc testing showed baseline scores were significantly lower when compared to scores 1 day after exposure (t_{59} = -3.92, p=0.0039), 2 days after exposure (t_{59} = -2.94, p=0.0047), and 3 days after exposure (t_{59} = -2.88, p=0.0055) (**Table 8**). On the non-dominant arm, post-hoc testing found significant findings between baseline scores and 5 days following exposure. Baseline scores were significantly lower than day 5 following exposure (t_{59} = 3.30, p=0.0016) (**Table 8**). Pitch count was not a significant covariate on the dominant arm, but was a significant contributor to non-dominant scores ($F_{1,231}$ = 28.86, p=<0.0001). Internal rotation ranges of motion prior to and following game pitching is presented in **Figure 10.**

Table 8. Humeral internal rotation descriptive data

Internal Rotation Range of Motion (degrees)		
Time after Exposure	*Dom*	*Ndom*
Baseline	46.2 ± 7.8	56.2 ± 5.6
ImPost	45.8 ± 9.9	57.4 ± 6.6
Day 1	44.3 ± 9.2*	57.5 ± 6.3
Day 2	43.1 ± 7.6*	56.6 ± 4.5
Day 3	45.9 ± 8.3*	59.3 ± 6.5
Day 4	45.9 ± 7.7	57.9 ± 5.7
Day 5	46.2 ± 7.2	60.3 ± 5.8*
Day 6	49.1 ± 8.6	60.8 ± 6.2

*Denotes significant change with respect to baseline

Figure 10. Humeral internal rotation range of motion prior to and following game pitching



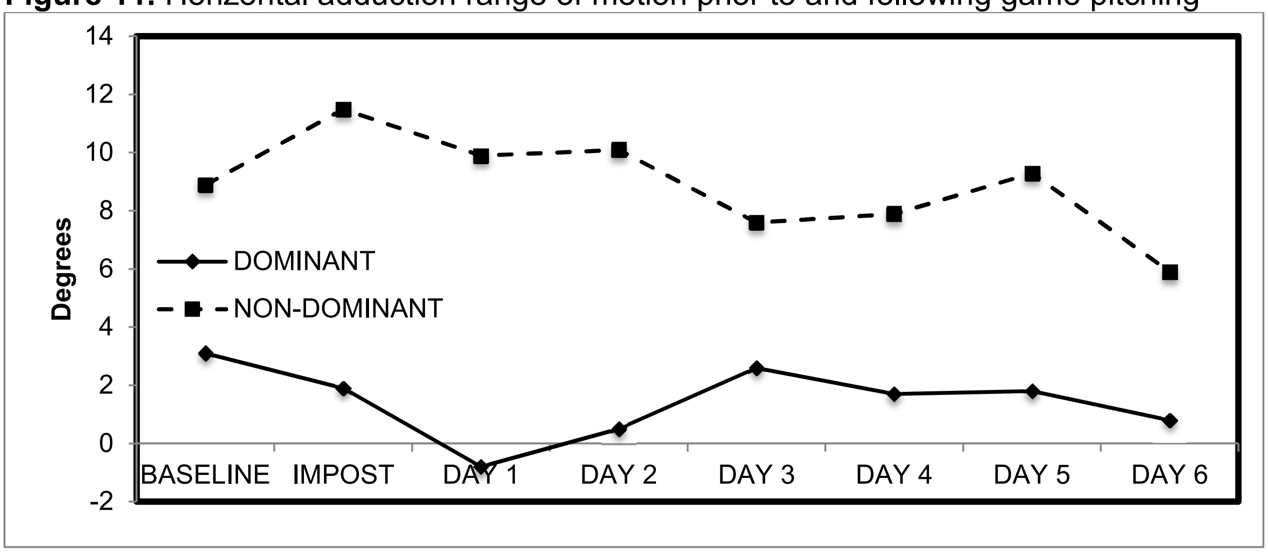
Horizontal adduction range of motion was not significantly impacted by time for the dominant limb($F_{7,59}$ = 2.36, p=.0339), but was significantly impacted on the non-dominant limb($F_{7,59}$ = 62.57, p=<0.0001) (**Table 3**). Post-hoc testing of non-dominant limb horizontal adduction revealed baseline scores were significantly lower than immediately after exposure (t_{59} = 3.38, p=0.0013) and significantly higher than 3 days following exposure (t_{59} = -4.35, p=0.0022) (**Table 9**). Horizontal adduction ranges of motion prior to and following game pitching are presented in **Figure 11.**

Table 9. Horizontal adduction range of motion descriptive data

Horizontal Adduction Range of Motion (degrees)		
Time after Exposure	*Dom*	*Ndom*
Baseline	3.1 ± 10.8	8.9 ± 5.8
ImPost	1.9 ± 5.2	11.5 ± 6.0*
Day 1	-0.8 ± 5.8	9.9 ± 7.1
Day 2	0.5 ± 5.7	10.1 ± 6.2
Day 3	2.6 ± 11.2	7.6 ± 5.1*
Day 4	1.7 ± 3.8	7.9 ± 3.8
Day 5	1.8 ± 11.3	9.3 ± 4.3
Day 6	0.8 ± 3.5	5.9 ± 3.9

*Denotes significant change with respect to baseline

Figure 11. Horizontal adduction range of motion prior to and following game pitching



CHAPTER V

Discussion

Cross-sectional area on the dominant arm increased one day following pitching and then returned statistically returned to baseline by day 2. The non-dominant arm did not have any significant change from baseline. These findings support our hypothesis, indicating that time would have a significant effect on cross-sectional area. Previous literature has demonstrated that eccentric activity has caused changes to muscle volume.[16,17,20,52-54] These changes may be attributed to the increase in muscle edema due to increased creatine kinase, which has shown to be present in the muscle for up 5 days post exercise.[18] Lauritzen et al.[16] hypothesized that considerable damage to the z-disks of the sarcomere may also produce acute inflammation following eccentric exercise. Damage to the infraspinatus muscle fibers would warrant an inflammatory response, indicating the creatine kinase increase and subsequent muscle volume increase.

Eccentric exercise protocols may have played a role in changes to muscle volume. Chapman et al.[52] used high velocity exercise to simulate dynamic performance. The high velocity (210 degrees per second) that they used was similar to an athletic movement and showed significant changes in muscle volume up to 10 days after the exercise. Despite an internal rotation velocity of approximately 6500 degrees per second,[13,15] the infraspinatus CSA was only elevated significantly for 24 hours following pitching and returned to baseline by day 2 statistically. The current study also uses a very specific group of participants that may have attenuated to the physical demands placed on them. The amount of swelling may be limited due to their unique skill set and ability to recover. The exercise protocol presented by Oyama et al.[20] was most like baseball throwing with respect to the fast eccentric activity to the specific body area that is present in the deceleration phase of throwing. The exercise protocol was based on 225 repetitions, far more than most baseball pitch counts, not including warm-up or pitching in between innings. The current study showed that pitch count did not have an influence on infraspinatus CSA, indicating that the eccentric activity was to blame for the increase in muscle volume. The current study was unique with respect to the exercise protocol. The intervention was a true athletic movement with no added resistance other than the subject's own limb weight.

Echo intensity did not change significantly from baseline. In fact, the only significant changes did not occur until the third day following exposure, where it was declining rather than increasing. This does not support our hypothesis, which stated that echo intensity would increase in the dominant limb. Similar eccentric exercise studies show that echo intensity is a good indicator of muscle quality and muscle damage.[22,23,56,57] Radaelli et al.[22] demonstrated that women who performed a resistance exercise bout had an elevated echo intensity one day following exposure continuing through day 3. The present study contradicts these results, showing no significant findings in regards to echo intensity. Though insignificant, the high echo intensity values immediately after throwing could be indicative of higher blood flow due to activity. The discrepancies between Radaelli et al.[22] and the current study may be population sensitive as well. Radaelli et al.[22] used untrained females in their study while our population utilized baseball pitchers with years of experience. The current population pool has also brought in treatment that was not affected by the authors. The baseball pitchers that were partaking in this study were receiving arm care, taking NSAIDs, and performing arm care as well to help recovery.

When external rotation is combined with internal rotation scores to create total range of motion, we see that there are no major changes within the first few days. This is contradictory to our hypothesis, were we had anticipated a decrease in TRM. TRM has been previously studied and is considered clinically important when identifying range of motion restrictions that could lead to injurious effects.[37,38] Despite external rotation staying consistent over the course of the testing period, external rotation should not be deemed unimportant. One could theorize that if external rotation is unaffected, internal rotation changes can be used to identify pathologic range of motion changes. This is not the case, as pathologic GRID becomes a injury risk factor when internal rotation loss exceeds external rotation gain. TRM on the dominant arm was consistently lower than the non-dominant arm, and Day 5 and Day 6 were the only significantly higher values when compared to baseline. Perhaps, the significance of day 5 and day 6 time points being significantly higher than baseline indicates that the TRM will continue to increase as the season continues.

Internal rotation range of motion on the dominant arm was significantly decreased for three days following exposure to game pitching. There was no effect on the non-dominant arm. This was in agreement with our hypothesis and with other literature regarding eccentric exercise, including those studying baseball players and internal rotation. Literature has shown that eccentric exercise causes muscle shortening.[17,18,20,52] Clarkson et al.[18] and Chen et al.[17] show range of motion decreases that peak around 3 days and then slowly return to baseline. The current study shows range of motion scores are lowest around day 2 and return to baseline on day 4. While this largely agrees with previous literature, the slight changes in our range of recovery may be due to the participant population. The previous studies used participants that are not accustomed to the forces that were placed upon them. The current study's participant pool consisted of elite-level Division 1 pitchers with long histories of pitching exposures. Additionally, because the participant pool was in the middle of a competitive season, pitchers received rehabilitation and treatment to maintain range of motion for competitive performance.

Many studies have documented the internal rotation deficits among dominant arms in baseball players, often times called glenohumeral internal rotation deficit, or GIRD.[29,37-39,44,45,49] Many studies identify pathologic GIRD,[28,29,31,41,42,44] while other studies identify times at which GIRD may come about.[20,25,55] The current study agrees with Reinold et al.[25] and Kibler et al.[55] with respect to lower internal rotation scores over time. Both studies showed a decrease in internal rotation at least 24 hours after the pitching exposure, with Kibler et al.[55] showing lower internal rotation ranges of motion up to 3 days following pitching. The participant pool in both of these studies also closely resembles the participants in the current study. Both Kibler et al.[55] and Reinold et al.[25] used experienced elite level pitchers to participate in the study. Kibler et al.[55] restricted the subjects from stretching, use of soft tissue therapy, and ice following throwing. The current study had no such limitations, and therefore may have been a more suitable view into the recovery of elite pitchers who will be receiving treatment from health care professionals at their own organization. While more clinically applicable, this may be considered a limitation in this study, as it adds variables that contribute to the range of motion recovery that were not visible to the authors and not documented.

Horizontal adduction in the dominant arm did not show any statistically significant findings in this study, despite previous research indicating that horizontal adduction range of motion losses will occur with pitching due to a shortened infraspintatus.[35,46] Despite a loss in internal rotation possibly indicating a shortened infraspinatus, horizontal adduction did not change significantly over the testing period. While there were no statistically significant findings for horizontal adduction in the dominant arm in response to exposure, statistically significant findings between the dominant and non-dominant arms were found. More specifically, the dominant arm had consistnently lower . This data agrees with Laudner et al.[46] and Tyler et al.[35] with respect to dominant and non-dominant comparison. Despite the low scores of the dominant arms, there was no reported internal impingement of the dominant arm. Myers et al.[44] studied how low horizontal adduction scores in participants that have already been diagnosed. The effects of acute pitching may not have an effect on our study, but pitching may have a cumulative effect to create low horizontal adduction scores. Despite insignificant findings of horizontal adduction, this variable should continued to be studied, as it has been correlated with injurious mechanisms.[47,59]

The infraspinatus and all posterior musculature are highly active in the deceleration phase of throwing.[13,15] It is important to continue to study this muscle group, as it contributes to posterior shoulder tightness,[34,44,46] internal rotation deficits,[34,37,45] and other injury risk factors such as scapular dyskinesis.[29,45,50] Few studies have researched the rotator cuff following baseball pitching. A study by

Yanagisawa et al.[54] researched the entire rotator cuff and found an increase in T2 relaxation times among the external rotator group—infraspinatus and teres minor—indicating a larger amount of water and interstitial fluid in these areas. In regards to baseball and range of motion, Reinold et al.[25] and Kibler et al.[55] both noted a decrease in ranges of motion following overhand pitching. Pitch counts have been shown to play a role in injury rates of baseball pitchers,[9,11,12,30] but this study contradicted those claims as there was no significant pitch count main effect on cross sectional area or internal rotation changes. This indicates that acute pitch counts will not have an effect on any dependent variable presented in this study. Future studies should still consider high pitch counts to contribute to injury rates, but should study them in long-term longitudinal studies with range of motion or ultrasonography variables as well. Biomarkers drawn through blood or saliva could also give us more information about the recovery of the body as well.

In regards to recovery, all variables did return to baseline before the next pitching bout. In other eccentric exercise studies, Oyama et al.[20] showed that range of motion scores diminished after eccentric exercise, but the study neglected to identify how long these changes last. Reinold et al.[25] identified that internal rotation and cross-sectional area was significantly lower immediately after and 1 day after throwing, but the study also neglected to identify how long these variables were diminished. Kibler et al.[59] identified internal rotation lags following overhand pitching that last up to 3 days, but this study did not see a recovery back to baseline. Chen et al.[17] showed that ROM scores were lowest at day 1 post exposure and then returned to baseline. In the same study, muscle volume peaked at day 4 and then began to show signs of recovery.[17] Chapman et al.[52] showed increases in muscle volume that peaked at 3 days following exposure and ROM scores that were lowest immediately after exercise but then returned to baseline 7 days following exercise exposure. Compared to Chapman et al.[52] and Chen et al.[17] our research showed quicker muscle volume recovery but a slower range of motion recovery. In the present study, internal rotation scores were significantly decreased up to 3 days following pitching exposure and then returned to baseline, which agreed with Kibler et al.[55]

The present study also has unforeseen variables that may have contributed to the recovery of range of motion scores and muscle volume. The study did not limit its subject's choice to receive treatment, ice or rehabilitation exercises. Yanagisawa et al.[19] used various therapeutic measures to assist the subject return to normal range of motion values and cross sectional area values. Yanagisawa et al.[19] found that ice treatment with light shoulder exercise helped the variables reach baseline quickest following baseball pitching. Warren et al.[60] used electric stimulation to help pitchers between innings and found that there were significant less reports of soreness following electrical stimulation use. Recovery is an important part of baseball pitching. If a pitcher's arm is unable to recover, then the cumulative effect of pitching may create injuries due to inadequate ability to deal with forces and make a participant stop throwing. The effects of these variables may be more prominent in relief pitchers, as they throw without much rest and very little warning of when they will throw.

Limitations

As with all research, the current study is not without limitations. One limitation was the availability and access to sufficient participants. There were only 10 participating varsity pitchers that volunteered to be a part of the study. We were able to get 41 separate exposures, but they were just the same pitchers repeated over the 6 week fall season. We chose to use only elite level pitchers that pitch on a consistent basis, with a very specific schedule. Our low numbers also played a roll on the statistics that we ran, due to the repeated testing that occurred. The current study also was unable to account for treatment, arm care, rehabilitation, soft tissue work, stretching, weight lifting and other care that may have affected recovery rates in the dominant arm. Data collections occurred in the fall season thus we had no control over the participants. The coaches created the schedule for the fall season, therefore the testing schedule was at their disposal. All pitches were treated the same, and we were unable to control the number of warm-up pitches that the pitcher threw. Future studies can still be done to help us build from this base of knowledge. This study should be done again, but in a younger population with a larger sample size. The adolescent population has higher number of participants and is more easily accessible, as well as an inability to access rehabilitative recovery aids.

Conclusions

Infraspinatus CSA showed an increase in volume one day following exposure, but then return to baseline after the increase. Internal rotation was elevated immediately after throwing and lasted for 3 days following pitching exposure. Internal rotation returned to baseline in subsequent days prior to the next pitching bout. Changes in infraspinatus CSA and internal rotation ROM were present in the dominant arm, but not in the non-dominant arm. The use of the non-dominant arm as a inter-personal control helped confirm that the results of this study. Echo intensity, external rotation, horizontal adduction, and total range of motion did not show any significant findings that changed from baseline following throwing in the dominant arm. Internal rotation could be tracked as a clinical measure to determine if the throwing arm has returned to a normalized state before a subsequent pitching bout. The results from this study indicate a need for further research into pitching recovery and attempts should be made to identify the development of injury risk factors through recovery research.

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