

RELATIONSHIP BETWEEN PITCH COUNT AND INFRASPINATUS CROSS-  
SECTIONAL AREA AND SHOULDER RANGE OF MOTION

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## ABSTRACT

BRENTON MICHAEL NEUHARTH: Relationship Between Pitch Count and Infraspinatus Cross-Sectional Area and Shoulder Range of Motion  
(Under the direction of Joseph B. Myers)

*Objective:* Higher pitch counts increases injury risk, but the physical changes that occur with increased pitch count are not understood. Therefore, the purpose of this study is to examine the relationship between pitch count and changes in infraspinatus cross-sectional area (ICSA) and shoulder range of motion (ROM) after pitching.

*Methods:* Pitchers on a collegiate baseball team were measured in ICSA, shoulder internal rotation ROM, and horizontal adduction ROM before and after pitching. Pitch counts were correlated with percent changes in ICSA, internal rotation ROM, and horizontal adduction ROM.

*Results:* There was a significant relationship between percent change in ICSA and pitch count ( $r_{36}=0.467$ ,  $p=0.004$ ).

*Conclusions:* The correlation between ICSA and pitch count indicates that as the pitch count increases, ICSA, increases. This finding, along with future research on the role of pitch type, mechanics, and velocity on ICSA, can be used to make pitching recommendations and track recovery.

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## CHAPTER I

### Introduction

Baseball is one of the most popular sports in the United States with over 4.5 million participants annually and about 27,000-31,000 of those participants are collegiate baseball players (Dick et al., 2007; Seefeldt V, 1992; *Student-Athlete Participation: 1981-1982 - 2010-11*, 2011; "USA Baseball Final Report," 2009). With baseball, a large number of injuries and lost time are attributed to throwing-related upper extremity injuries, and are found more among pitchers. These time lost injuries include impingement, rotator cuff injuries, shoulder instability, labral tears, and elbow ulnar collateral ligament injuries (Chambless et al., 2000; Conte et al., 2001; Dick et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McFarland & Wasik, 1998; Posner et al., 2011). In collegiate baseball, 36% of all complaints and missed days are attributed to shoulder and elbow pain (McFarland & Wasik, 1998) and that number only increases in minor leagues and major leagues (Chambless et al., 2000; Conte et al., 2001; Posner et al., 2011). Several studies have correlated pitch count with injury and have made recommendations for the numbers of pitches to be thrown per game and per week at various levels of baseball, yet there is little evidence connecting pitch count to the acute effects of pitching that lead to injury (Limpisvasti et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McNeil, 2006; *USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006*, 2006).

There are large forces at the shoulder during the act of pitching (Fleisig et al., 1995). The late cocking phase occurs when the arm is maximally externally rotated and horizontally

abducted and creates a large anterior shear force and compressive force. This compressive force more than doubles during the deceleration phase of pitching (Fleisig et al., 1995). The infraspinatus muscle helps decrease these forces by providing joint compression and minimizing anterior shear force and superior migration of the humeral head (Labriola et al., 2005; Lee et al., 2000). The largest percentage of maximum voluntary isometric contraction of the infraspinatus occurs during the cocking phase and that percentage remains high through the deceleration phase (Escamilla & Andrews, 2009).

In order to help decelerate the arm, the infraspinatus contracts eccentrically following ball release (Laudner et al., 2006; Myers et al., 2007). The effects of repetitive eccentric contractions are well documented and include sarcomere damage (Lauritzen et al., 2009), shortened connective tissue, passive muscle stiffness, and decreased range of motion (Clarkson et al., 1992; Newham, 1988). Edema has been shown by increased cross-sectional area seen on both diagnostic ultrasound and magnetic resonance imaging and the damaged sarcomeres were also viewed on magnetic resonance imaging (Chleboun et al., 1998; Yanagisawa, Niitsu, et al., 2003). Deficits in maximum voluntary isometric contractions have also been seen immediately after repetitive eccentric exercises at the elbow and remain for a significant period time after (Lauritzen et al., 2009).

Effects of repetitive eccentric exercise are important because sarcomere damage, passive muscle stiffness, and decreased range of motion in the infraspinatus could lead to risk factors previously identified in the literature (Burkhart et al., 2003a; Clarkson et al., 1992; Dines et al., 2009; Grossman et al., 2005; Lauritzen et al., 2009; Myers et al., 2006; Newham, 1988). Decreased shoulder internal rotation, horizontal adduction, total arc of motion, and posterior capsule tightness have been linked to pathologic conditions and

injuries to the shoulder and elbow (Burkhart et al., 2003a; Dines et al., 2009; Grossman et al., 2005; Myers et al., 2006).

Currently we know that pitch count is related to injury, but we do not clearly understand what physical changes occur with increased pitch count that predisposes the athlete to injury. Because of the role of the infraspinatus in pitching, and the cascade of events that may occur due to high pitch volume, it is important to understand how pitch count is related to changes in the infraspinatus cross-sectional area, as well as other physical attributes that may be altered due to edema in the infraspinatus. Future research needs to be done to show the effects of the functional movement of pitching in an athletic population and to see if there is a dose-response to the number of pitches thrown and these acute effects of pitching. Understanding the relationship between pitch count and the acute effects of pitching may be able to validate or suggest recommendations to change current pitching methodology and lead to further research studies looking into the proper treatment and recovery time following a bout of game pitching.

### **Purpose**

Posterior shoulder tightness, as measured by decreased shoulder internal rotation and horizontal adduction range of motion, has been well documented as a risk factor for various shoulder and elbow injuries. Decreased range of motion could result from the acute effects of pitching due to the eccentric activity damaging the sarcomere and shortening the connective tissue of the infraspinatus muscle. To date, no previous study has identified a dose-response relationship between number of pitches thrown and acute changes in physical characteristics such as infraspinatus cross-sectional area, internal rotation range of motion, and horizontal adduction range of motion. Therefore, the purpose of this study is to examine the relationship

between pitch count and the change in infraspinatus cross-sectional area and shoulder range of motion following a single bout of game pitching by collegiate pitchers. Understanding this relationship will either validate or recommend changes in typical pitch count guidelines. Also, knowing this relationship can lead to future research into the appropriate treatment and recovery time post-pitching in order to prevent the development of several injury risk factors.

### **Research Questions**

RQ1: What is the relationship between pitch count during a single bout of game pitching and percent change in infraspinatus cross-sectional area?

RQ2: What is the relationship between pitch count during a single bout of game pitching and percent change in shoulder internal rotation range of motion?

RQ3: What is the relationship between pitch count during a single bout of game pitching and percent change in shoulder horizontal adduction range of motion?

### **Variables**

1. Pitch count during a single bout of game pitching
2. Percent change in infraspinatus cross-sectional area
3. Percent change in shoulder internal rotation range of motion
4. Percent change in shoulder horizontal adduction range of motion

### **Hypotheses**

*H1*: Infraspinatus cross-sectional area will be positively correlated with pitch count.

Infraspinatus cross-sectional area will increase as pitch count increases.

- $H_0: r = 0$
- $H_A: 0 \leq r \leq 1.0$

*H2*: Shoulder internal rotation range of motion will be negatively correlated with pitch count.

Shoulder internal rotation range of motion will decrease as pitch count increases.

- $H_0: r = 0$
- $H_A: -1.0 \leq r \leq 0$

*H3*: Shoulder horizontal adduction range of motion will be negatively correlated with pitch count.

Shoulder horizontal adduction range of motion will decrease as pitch count increases

- $H_0: r = 0$
- $H_A: -1.0 \leq r \leq 0$

### **Operational Definitions**

1. **Single game pitch count** equals number of pitches thrown during a competitive baseball game. Does not include number of pitches thrown during warm-ups or between-inning practice pitches.

### **Delimitations**

1. Age: Collegiate baseball pitchers (age 18-22)
2. Gender: Male

### **Limitations**

1. Time between pre-game measurement and pitching bout may include other warm-up activities such as arm strengthening exercises, upper body ergometer, or throws not from a mound
2. Will include all pitchers on the team regardless of previous history of injury
3. Will include all pitchers on the team regardless of previous baseball and/or pitching experience

4. Will be analyzing all pitchers the same regardless of role (starter, middle reliever, closer)
5. Will be treating all types of pitches the same

**Assumptions**

1. Sample accurately represents the population of collegiate baseball players
2. Diagnostic ultrasound accurately measures infraspinatus cross-sectional area

## CHAPTER II

### **Participation and Injury Data**

Baseball is one of the most popular sports in the United States with over 4.5 million participants annually and about 27,000-45,000 collegiate baseball players (Dick et al., 2007; Seefeldt V, 1992; *Student-Athlete Participation: 1981-1982 - 2010-11*, 2011; "USA Baseball Final Report," 2009). With baseball, especially pitching, a large number of injuries and lost time is attributed to upper extremity injuries such as impingement, rotator cuff injury, shoulder instability, labral tears, and elbow ulnar collateral ligament injury (Chambless et al., 2000; Conte et al., 2001; Dick et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McFarland & Wasik, 1998; Oberlander et al., 2000; Posner et al., 2011). Upper extremity injuries account for 67% of all injuries to pitchers in the Major Leagues (Posner et al., 2011) and pitchers account for almost half of all disabled list reports, with shoulder and elbow injury accounting for almost half of the days on the disabled list (Conte et al., 2001). In the Minor Leagues, there is a higher incidence of injury and longer time missed for the lower levels when compared to the higher levels (Chambless et al., 2000). In collegiate baseball, shoulder and elbow pain account for 36% of complaints and missed days (McFarland & Wasik, 1998).

### **Pitching Biomechanics and Functional Anatomy**

#### *The Pitching Motion*

The act of pitching is built on the speed principle which states that the transfer of momentum through the larger, more proximal segments must be summated (Putnam, 1993).



This means that the distal segment initiates movement once the proximal segment reaches maximum angular velocity. Several studies have looked at this, showing that the pelvis rotates ahead of the torso, which then initiates the shoulder musculature and finally the elbow musculature (Hirashima et al., 2002; Oliver & Keeley, 2010).

The motion of pitching is broken down into six phases: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. The stride phase begins when the knee is lifted to its maximum height, arm cocking begins when the lead foot makes contact with the ground, arm acceleration begins when the shoulder reaches maximum external rotation, arm deceleration starts once the ball is released, and follow-through occurs when the shoulder reaches maximum internal rotation (Figure 1) (Braun et al., 2009; Fleisig et al., 1995; Fleisig et al., 1996; Limpisvasti et al., 2007; Parks & Ray, 2009).

The late cocking phase is the point in time when the shoulder is in maximal external rotation and the torso is beginning to rotate away from the pitching shoulder. This puts the shoulder in 90 degrees of abduction and at least 90 degrees of external rotation, which has been identified as the position at risk for internal impingement, which will be described later (Grossman et al., 2005).

### *Muscle Activity*

During the wind-up phase, the greatest amount of muscle activity is seen in the upper trapezius, serratus anterior, and anterior deltoid muscles. These muscles must concentrically contract to upwardly rotate and elevate the scapula while abducting the arm, then eccentrically contract to control downward rotation of the scapula and adduction of the shoulder while the arm is being lowered. The rotator cuff muscles act primarily to compress the glenohumeral joint with some shoulder rotation activity during this wind-up phase (Escamilla & Andrews,

2009).

During the stride phase, the shoulder must abduct, externally rotate, and horizontally abduct while the scapula upwardly rotates, elevates, and retracts. The deltoid, supraspinatus, infraspinatus, serratus anterior, and upper trapezius all concentrically contract to perform this motion. During this phase, the supraspinatus is most active, with the upper trapezius and serratus anterior acting primarily to stabilize and properly position the scapula (Escamilla & Andrews, 2009).

There is a large amount of muscle activity at the shoulder during the arm cocking phase. The deltoid acts to maintain about 90 degrees of shoulder abduction. The pectoralis major and anterior deltoid act to horizontally adduct the shoulder. There is high activity in all of the rotator cuff muscles in order to counteract glenohumeral distraction and maintain stability. The infraspinatus, teres minor, and latissimus dorsi also assist in maintaining glenohumeral stability by resisting anterior humeral head translation. Finally, the infraspinatus and teres minor contract concentrically to attain maximal external rotation while the pectoralis major, latissimus dorsi, and subscapularis contract eccentrically to control the rate of external rotation. There are multiple functions of various muscles taking place during this phase to both initiate motion, control the rate of motion, support scapular positioning, and maintain glenohumeral stability (Escamilla & Andrews, 2009).

Arm acceleration has the highest activity of the internal rotators, the subscapularis, pectoralis major, and latissimus dorsi. The deltoids also stay active to maintain a constant level of shoulder abduction (Escamilla & Andrews, 2009).

During the arm deceleration phase, the kinetic energy not transferred to the ball is dissipated in order to minimize injury. The infraspinatus, teres minor, teres major, posterior

deltoid, and latissimus dorsi all contract eccentrically to decelerate horizontal adduction and internal rotation while also minimizing glenohumeral distraction and anterior translation (Escamilla & Andrews, 2009).

### *Forces During Pitching*

There are a number of forces acting at the shoulder during pitching. It has been shown that during the late cocking phase the shoulder endures a large amount of anterior shear force due to the extreme apprehension position it is put in with about 90 degrees of abduction, at least 90 degrees of external rotation, and extreme horizontal abduction (Fleisig et al., 1995; Werner et al., 2010). The late cocking phase also creates a large superior shear force and a substantial compressive force at the shoulder. However, the deceleration phase creates the largest compressive force at the shoulder (Fleisig et al., 1995), while chronic distractive forces are experienced at the shoulder during follow-through and may lead to posterior capsule tightness, a risk factor for shoulder and elbow injuries (Parks & Ray, 2009).

### **Injury Risk Factors**

Baseball is often considered to be a relatively safe sport with low injury rates at various levels (Andrews & Fleisig, 1998). It has been reported that the minor leagues has approximately 1.79 injuries per 10 games (Chambless et al., 2000), with an injury risk ratio of 1.09 per 1000 athlete-exposures for pitching (Posner et al., 2011). Collegiate baseball has reported 5.78 injuries per 1000 athlete-exposures (Dick et al., 2007). In Little League, seven percent of all pitching appearances result in shoulder pain, while fifteen percent of appearances result in elbow pain. Almost half of all pitchers report elbow or shoulder pain at some point throughout a Little League baseball season (Lyman et al., 2002; Lyman et al., 2001).

### *Pitch Count*

Higher pitch counts have been associated with increased risk for shoulder and elbow pain, and each level of baseball has implemented typical practices and guidelines for numbers of pitches to be thrown in a game and over various periods of time (Lyman et al., 2002; Lyman et al., 2001; McNeil, 2006; Olsen et al., 2006; *USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006*, 2006). For Little Leaguers ages 13-14, the USA Baseball Medical and Safety Advisory Committee recommends limiting them to 75 pitches per outing and 125 pitches per week (*USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006*, 2006). Recommendations for days of rest are based on pitch counts per pitching outing; one day of rest with 30 pitches thrown, two days with 40 pitches, three days with 60 pitches, and four days with 90 pitches thrown for ages 17-18 (Limpisvasti et al., 2007). With Major Leaguers, there has been a trend toward lower pitch counts and five-man pitching rotations in recent years. It is common practice to limit a starting pitcher to 100 pitches per outing and to pitch every five or six days (McNeil, 2006).

Pitch count has been identified as a risk factor in previous studies. Olsen, et al. saw that higher number of warm-up pitches, more innings pitched per game, more pitches thrown per game, and pitching eight or more months out of the year were associated with a higher risk of shoulder and elbow injuries (Olsen et al., 2006). In Little League, pitchers are 3.2 times more likely to have shoulder pain when throwing greater than 75 pitches when compared to less than 25 pitches. The risk of elbow pain increases 6% for every 10 pitches thrown and increases 50% when greater than 75 pitches are thrown (Lyman et al., 2001).

### *GIRD*

There have been other risk factors associated with shoulder and elbow injuries,

mainly excessive posterior capsule tightness as shown by decreased internal rotation (GIRD) and horizontal adduction range of motion, and the SICK scapula (Burkhart et al., 2003a, 2003b; Dines et al., 2009; Grossman et al., 2005; Myers et al., 2006). Glenohumeral internal rotation deficit (GIRD) is defined as the loss of internal rotation of the throwing shoulder compared with the non-throwing shoulder (Burkhart et al., 2003a). The pitching shoulder must gain external rotation, which results in a decrease in internal rotation in order to maintain the full total arc of motion (Crockett et al., 2002; Dines et al., 2009; Dwelly et al., 2009; Wilk, Macrina, et al., 2011). The shift in range of motion can exacerbate the position during the late cocking phase of pitching and put the pitcher at more risk for internal impingement (Wilk et al., 2002). This shift in range of motion is caused by adaptations necessary to cope with the demands of pitching by either osseous structures and/or soft tissue structures (Crockett et al., 2002; Reinold et al., 2008). Studies have shown that the throwing shoulder has greater glenoid and humeral retroversion, more external rotation, and less internal rotation than both the subjects' non-dominant shoulder and a control group of dominant shoulders (Crockett et al., 2002; Reagan et al., 2002). This provides evidence that GIRD may be caused by osseous adaptations to pitching. Other causes of GIRD could be explained by soft tissue musculotendinous adaptations due to muscle damage (Reinold et al., 2008), especially following damage to the infraspinatus.

Problems arise when the number of degrees of internal rotation lost is not matched by the number of degrees of external rotation gained (Burkhart et al., 2003b; Wilk, Macrina, et al., 2011). During pitching, the posterior rotator cuff must absorb the energy required to decelerate the arm following ball release. If the rotator cuff is insufficient in doing so, the posterior joint capsule must absorb an increasing amount of that energy (Burkhart et al.,

2003a). If the posterior capsule absorbs a large amount of this energy, then undergoes repetitive microtrauma and tissue healing (Burkhart et al., 2003b; Thomas et al., 2010a; Thomas et al., 2010b). This can result in hypertrophied posterior capsule thickness and ultimately decreased shoulder internal rotation range of motion (Michener et al., 2003; Thomas et al., 2011). For every four degrees of shoulder internal rotation range of motion lost, posterior capsule thickness increases by one centimeter (Tyler et al., 1999).

### *Horizontal Adduction*

Horizontal adduction range of motion assessment has been developed and validated as a way to clinically quantify posterior shoulder tightness (Tyler et al., 1999). This may be a better way to represent posterior shoulder tightness as opposed to isolated capsular tightness due to the role of the posterior rotator cuff musculature in horizontal adduction range of motion restraint (Michener et al., 2003). Contracture of posterior soft tissue structures, including the infraspinatus, may be causing GIRD and loss of total arc of motion and eventually lead to pathologic conditions (Borsa et al., 2005). Tight posterior soft tissue structures is thought to cause anterior and superior migration of the humeral head, contributing to impingement (Tyler et al., 1999). Contracture of this posterior shoulder soft tissue structures may be caused by the eccentric contractions necessary to decelerate the shoulder during follow-through (Clarkson et al., 1992; Newham, 1988). Throwers have been shown to have more posterior shoulder tightness than non-throwers as seen by horizontal adduction range of motion assessment and has been linked to both subacromial and internal impingement (Myers et al., 2006; Tyler et al., 2000). Injured baseball players have been shown to have almost five degrees less horizontal adduction range of motion in their throwing shoulder when compared to non-injured baseball players (Shanley et al., 2011).

### *SICK Scapula*

The SICK scapula is defined as scapular malposition, inferior medial border prominence, coracoid pain and malposition, and dyskinesia of scapular movement (Burkhart et al., 2003b). Type III SICK scapula displays prominence of the superomedial border of the scapula and is associated with impingement and rotator cuff lesions. Due to this malpositioned scapula, the kinematics of the glenohumeral and acromioclavicular joints are altered and affect the length-tension relationships of the muscles that act on the scapula and proximal humerus (Burkhart et al., 2003b). Having medial border prominence of the scapula indicates an internally rotated scapula, which in turn increases the impingement zone and contact pressure leading to increased risk of internal impingement during the late cocking phase of pitching (Mihata et al., 2012).

### **Injuries and Pathomechanics**

#### *Internal Impingement*

There are a number of specific shoulder injuries that have been linked to GIRD, such as articular-sided rotator cuff tears, labral tears, and impingement (C. M. Jobe, 1995). Also, baseball players with ulnar collateral ligament insufficiency have been shown to have more than 15 degrees of GIRD (Dines et al., 2009). Superior labral tears, anterior-to-posterior, (SLAP lesions) have been identified in cadaver throwing shoulders that had decreased shoulder internal rotation and horizontal adduction (Grossman et al., 2005). The injury of particular importance, however, is internal impingement syndrome due to the effect that pitching mechanics have on developing this injury (Myers et al., 2006).

Internal impingement is due to the posterosuperior aspect of the glenoid contacting the intra-articular portion of the humeral neck at 90 degrees of abduction and at least 90

degrees of external rotation (C. M. Jobe, 1995; Walch et al., 1992). This position of impingement occurs during the late cocking phase of pitching and can result in damage to the rotator cuff muscles and/or the posterosuperior labrum (C. M. Jobe, 1995; Walch et al., 1992). The high internal rotation torque occurring during the late cocking and early acceleration phase along with a gain in external rotation can cause internal impingement of rotator cuff musculature during pitching (Dun et al., 2008).

Internal impingement can be caused by GIRD and also scapular orientation. During overhead activity such as pitching, the normal scapular motion includes upward rotation, external rotation, and posterior tilting (Borich et al., 2006). Healthy baseball players tend to have more scapular upward rotation and internal rotation in their throwing arm (Myers et al., 2005), while those with GIRD of more than 15 degrees have been shown to have less scapular upward rotation and even more scapular internal rotation (Thomas et al., 2010b). When comparing high school and collegiate pitchers, collegiate pitchers showed greater internal rotation and total arc motion deficits, while having more scapular internal rotation and less glenohumeral external rotation gain and scapular upward rotation. As level of competition increases, these glenohumeral and scapular alterations worsen and have been seen in athletes with diagnosed shoulder injuries (Thomas et al., 2010a).

### *Subacromial Impingement*

Subacromial impingement has been seen in subjects with posterior shoulder tightness (Tyler et al., 2000). Subacromial impingement is caused by various factors including shoulder instability, scapulothoracic weakness, and posterior capsule tightness (Bigliani & Levine, 1997; Schmitt & Snyder-Mackler, 1999; Warner et al., 1990). Tight capsular and muscular structures, often seen in pitchers, can lead to altered arthrokinematics (F. W. Jobe



& Pink, 1993; Terry et al., 1991). This asymmetrical muscular and joint capsule tightness, along with altered arthrokinematics, leads to upward translation of the humeral head, decreased subacromial space, and impingement (Harryman et al., 1990).

### *UCL Injury*

The anterior band of the elbow ulnar collateral ligament (UCL) provides the primary restraint against valgus stress and can withstand forces up to 261 Newtons (Fleisig et al., 1995). Each pitch approaches or even exceeds this threshold (Fleisig et al., 1995; Morrey & An, 1983). Therefore, other more proximal forces must counter the valgus torque placed on the elbow. Shoulder internal rotation is this counteracting force during the late cocking phase of pitching (Fleisig et al., 1995; Putnam, 1993). Decreased shoulder internal rotation and decreased total arc range of motion have been seen in subjects with elbow ulnar collateral ligament deficiency (Dines et al., 2009).

### **Effect of Eccentric Contractions on Muscle**

Repetitive eccentric contractions, like the role the infraspinatus has during pitching, have been shown to damage the muscle (Clarkson et al., 1992; Lauritzen et al., 2009; Newham, 1988). This mechanical damage to the muscle results in shortening of connective tissue, passive muscle stiffness, and decreased range of motion (Clarkson et al., 1992; Newham, 1988).

The evidence of muscle damage following eccentric exercise has been seen in some studies. Edema has been shown by an increase in muscular cross-sectional area on ultrasound imaging (Chleboun et al., 1998). Creatine kinase levels that signal muscular use and breakdown have also been shown to increase the greatest following eccentric exercises when compared to other forms of exercise (Clarkson et al., 1992). Edema is also evident by the

presence of mononuclear cell infiltration, which is one part of the inflammatory process (Newham, 1988).

Muscle weakness has also been seen following repetitive eccentric exercise. Maximum voluntary contraction decreased significantly in the elbow flexor musculature following eccentric exercise and remained decreased for up to 21 days post-exercise (Lauritzen et al., 2009). Decreased strength of the infraspinatus could result in decreased internal rotation range of motion, posterior capsule tightness, and a malpositioned scapula which have been identified as risk factors for shoulder injury (Burkhart et al., 2003a, 2003b; Dines et al., 2009; Mihata et al., 2012).

Repetitive eccentric contractions of the infraspinatus have been shown to result in damage and edema to the muscle (Oyama et al., 2011; Yanagisawa, Niitsu, et al., 2003). Oyama, et al. simulated a bout of pitching with 225 repetitions of isokinetic eccentric external rotation exercises. This study showed that infraspinatus cross-sectional area as seen by ultrasound increased immediately after the exercises (Oyama et al., 2011). Yanigisawa, et al. had subjects complete a simulated game with 15 pitches per inning and 5 minutes rest between innings for 9 innings and 135 total pitches. Following this simulated game, edema and damage to the muscle were seen in the external rotator group (teres minor and infraspinatus) by magnetic resonance imaging (Yanagisawa, Niitsu, et al., 2003).

### **Infraspinatus Role in Shoulder Mechanics**

The infraspinatus provides joint compression, especially when the shoulder is in 90 degrees of external rotation (Labriola et al., 2005; Lee et al., 2000). The infraspinatus also minimizes anterior shear force during overhead motion. Anterior shear force is at its greatest during the late cocking phase of pitching, and the infraspinatus and teres minor muscles

provide a posterior shear force to counteract that positional anterior shear force (Labriola et al., 2005; Lee et al., 2000). Finally, the infraspinatus minimizes superior migration of the humeral head, and subsequently minimizes the risk of subacromial impingement, during overhead motion (Lee et al., 2000).

The infraspinatus muscle has a very specific role during the pitching motion. During the cocking phase, the infraspinatus concentrically contracts to get the shoulder into external rotation (Jancosko & Kazanjian, 2012). Following ball release, the muscle must then eccentrically contract to decelerate the arm. Because of this, the infraspinatus must endure a large eccentric load during deceleration and follow-through (Laudner et al., 2006; Myers et al., 2007). During the pitching motion, the largest percentage of maximum voluntary isometric contraction of the infraspinatus occurs during the cocking phase, and that percentage remains high through the deceleration phase (Escamilla & Andrews, 2009).

Weakness of the infraspinatus could decrease the amount of compressive force and posterior translation force acting on the shoulder, allowing for more distraction and anterior translation (Escamilla & Andrews, 2009). Damage to the infraspinatus muscle resulting from these repetitive eccentric contractions could result in decreased shoulder internal rotation and horizontal adduction (Oyama et al., 2011; Yanagisawa, Niitsu, et al., 2003). Finally, posterior shoulder tightness from muscle stiffness and shortened connective tissue in the infraspinatus following repetitive eccentric contractions can result in altered scapular and humeral kinematics (Borich et al., 2006; Oyama et al., 2011; Yanagisawa, Niitsu, et al., 2003). All of these factors can be the result of the repetitive eccentric contractions the infraspinatus experiences during pitching, and all have been identified as risk factors for upper extremity injuries (Clarkson et al., 1992; Crockett et al., 2002; Dines et al., 2009; Grossman et al.,

2005; Lauritzen et al., 2009; Mihata et al., 2012; Myers et al., 2005, 2006; Newham, 1988; Oyama et al., 2011; Reinold et al., 2008; Thomas et al., 2010b; Yanagisawa, Niitsu, et al., 2003).

### **Recovery and Treatment**

There are various recovery methods utilized by pitchers following a bout of game pitching. In Little Leagues, the recommendation is to perform a whole-body cool-down; do static stretching of upper and lower extremity; ice the shoulder and/or elbow; and perform strength, balance, and coordination exercises during off days (Ronai, 2009). For collegiate pitchers, electromuscular stimulation has been shown to decrease blood lactate levels and be perceived as a better recovery method than both active and passive recovery methods (Warren et al., 2011). Another study involving amateur pitchers showed that internal rotation range of motion was improved following active recovery with an upper body ergometer and with active recovery plus ice. Also, the external rotator group (teres minor and infraspinatus) had a decreased cross-sectional area in the active recovery plus ice group (Yanagisawa, Miyanaga, et al., 2003).

Shoulder recovery and rehabilitation for pitchers focuses on decreasing pain and/or inflammation, normalization of motion through stretching, and aggressive strengthening (Wilk et al., 2002). Many shoulder maintenance and rehabilitation programs have utilized all or parts of the advanced thrower's ten program. Exercises in this program include internal/external rotation at 0 degrees of abduction, full can exercises, lateral raises to 90 degrees, side-lying external rotation, prone row into external rotation, shoulder extension in external rotation, shoulder extension in 45 degrees of external rotation, wall circle slides, low rows, table press-downs with scapular depression, biceps curls and triceps extensions, and

wrist flexion, extension, pronation, and supination (Wilk, Yenchak, et al., 2011).

## **Instrumentation**

### *Internal Rotation*

Internal rotation can be measured with a digital inclinometer, and has been shown to be a valid and reliable measure when the subject is supine with the scapula stabilized (Laudner et al., 2006; Myers et al., 2007). This method is performed with the participant lying supine and the arm in 90 degrees of abduction and 90 degrees of elbow flexion. The scapula is stabilized by applying a posteriorly directed force against the coracoid process and clavicle, minimizing scapular anterior/posterior tilting (Oyama et al., 2011).

### *Horizontal Adduction*

Horizontal adduction can be measured using a digital inclinometer, and has been shown to be a valid and reliable measure of posterior shoulder tightness. This is performed with the participant supine, the arm horizontally adducted, and the scapula stabilized with a medially directed force against the lateral border of the scapula (Laudner et al., 2006; Myers et al., 2007; Tyler et al., 1999).

### *Infraspinatus Cross-Sectional Area*

Infraspinatus cross-sectional area has been previously assessed using ultrasound imaging. This is measured with the participants prone with their arms at their sides. The acromion angle, trigonum spinae, and inferior angle of the scapula are identified and marked. A line is then drawn connecting the acromial angle and inferior angle, with a second line drawn perpendicular to the first line intersecting with the trigonum spinae. A custom-made template with hypo-echoic markers placed 4 centimeters apart is then placed along the second line and serial images are taken between each marker (Oyama et al., 2011). Oyama, et

al. ran a pilot study in which ultrasound measurements of infraspinatus cross-sectional area had an intra-class correlation of 0.984 and a standard error of measure of 0.26 square centimeters (Oyama et al., 2011).

### **Clinical Relevance**

Many studies have looked at the acute effects of pitching and pitch count recommendations have been made from these studies. However, following a review of the literature, information on how many pitches it takes to see these acute effects is still unknown. More information about the acute effects of pitching following varying pitch counts is necessary in order to validate or suggest changes to current pitch count recommendations. Also, understanding these acute effects in relation to pitch count can allow for a better consensus about proper recovery methods and time following pitching in order to prevent the development of several injury risk factors. Therefore, the purpose of this study is to examine the relationship between pitch count and the change in infraspinatus cross-sectional area and shoulder range of motion following a single bout of game pitching.

## **CHAPTER III**

### **Participants**

Pitchers on the University of North Carolina at Chapel Hill baseball team were recruited for this study. The inclusion criteria was males between the ages of 18 and 22 years old regardless of previous history of injury, years of baseball and/or pitching experience. Also, all pitchers were used regardless of status on the team as a starter, reliever, or closer. Exclusion criteria was pitchers that did not pitch in the game; therefore, did not have a post-game measurement.

### **Instrumentation**

An ultrasonographic imaging device (LOGIQe, General Electric, Milwaukee, WI, USA) with a 4 cm linear array transducer was used for measurement of the infraspinatus cross-sectional area. Ultrasonographic imaging was chosen because it is a cost-effective, non-invasive, field measurement.

A digital inclinometer (Saunders Group, Chaska, MN, USA) was used to measure shoulder internal rotation and horizontal adduction range of motion.

### **Design**

This study was a repeated-measures correlational design with pitchers measured prior to the game and after being removed from the game. Percent changes in infraspinatus cross-sectional area, shoulder internal rotation range of motion, and shoulder horizontal adduction range of motion were correlated with number of pitches thrown in a single bout of game pitching.

## **Procedures**

Prior to participation, subjects signed an informed consent form that was approved by the University of North Carolina-Chapel Hill Biomedical Institutional Review Board.

Members of the research team went to the University of North Carolina-Chapel Hill's home stadium and set up for data collection each home game. The starter was measured pre-game and post-game. Projected relievers were selected for pre-game measurements based off information from the coaches, players, and athletic training staff. Players who did not pitch in the game were not measured post-game and were excluded from the data collected that day.

### *Internal Rotation*

Shoulder internal rotation range of motion was measured with the participant supine and his throwing arm in 90 degrees of abduction and 90 degrees of elbow flexion. The scapula was stabilized by applying a posteriorly directed force against the coracoid process and clavicle to prevent elevation and tilting of the scapula. A second tester aligned the digital inclinometer with the forearm and three measurements were taken per session (Figure 2). The reliability and validity for measuring shoulder range of motion for internal rotation ( $ICC_{3,1}=0.985$ ,  $SEM=1.51^\circ$ ) has been previously established (Myers et al., 2007). Our own pilot study yielded an  $ICC_{3,1}=0.984$  and a  $SEM=0.786^\circ$ .

### *Horizontal Adduction*

Shoulder horizontal adduction range of motion were measured with the participant supine and his throwing arm in 90 degrees of abduction. The scapula was stabilized by applying a medially directed force against the lateral border of the scapula to prevent upward rotation and medial rotation of the scapula. A second tester aligned the digital inclinometer with the humerus and three measurements were taken per session (Figure 3). The reliability



and validity for measuring shoulder supine horizontal adduction ( $ICC_{3,k}=0.91$ ,  $SEM=1.1^\circ$ ) has been previously established (Myers et al., 2007). Our own pilot study yielded an  $ICC_{3,1}=0.951$  and a  $SEM=0.826^\circ$ .

#### *Infraspinatus Cross-Sectional Area*

A diagnostic ultrasound unit (LOGIQe, General Electric, Milwaukee, WI, USA) was used for the assessment. A 4 cm linear array ultrasound transducer was used with the frequency of 12 Megahertz and depth of 5.0 centimeters in order to take images of the infraspinatus. Ultrasonographic imaging of the infraspinatus was taken with each participant lying prone with their throwing arm at their side. The acromial angle, trigonum spinae, inferior angle of the scapula were identified and marked. A line was drawn from the acromial angle to the inferior angle. A second line was drawn perpendicular to the first line and connected with the trigonum spinae. A custom-template with hypo-echoic markers placed at 4 cm intervals was placed along the second line. Four serial images along the template were then taken (Figure 4). A pilot study was previously conducted by Oyama et al. (2011), and showed an intra-class correlation coefficient ( $ICC_{2,1}=0.984$ ) and standard error of measurement ( $SEM=0.26 \text{ cm}^2$ ) (Oyama et al., 2011). Our own pilot study yielded an  $ICC_{3,1}=0.985$  and a  $SEM=0.567 \text{ cm}^2$ .

#### *Pitch Counts*

Pitch counts during the game were counted by managers on the University of North Carolina at Chapel Hill baseball team staff.

#### **Data Reduction**

A full image of the infraspinatus cross-sectional area was constructed from the series of overlapping images using Adobe Photoshop (Adobe, San Jose, CA, USA) (Figure 5).

Cross-sectional area was calculated by calibrating the field area to a known distance, then tracing the inside of the epimysium using Image J software (National Institutes of Health, Bethesda, MD, USA). This has been shown as a valid and reliable data reduction procedure for muscle cross-sectional area in previous literature (Blackburn et al., 2009).

The three trials for shoulder internal rotation and horizontal adduction range of motion measurement were averaged for each testing session. Change in infraspinatus cross-sectional area, internal rotation range of motion, and horizontal adduction range of motion were calculated by subtracting the pre-game mean measurement from the post-game mean measurement. The percent change in infraspinatus cross-sectional area, internal rotation range of motion, and horizontal adduction range of motion was calculated by dividing the change value by the pre-game value and multiplying by 100.

### **Statistical Analysis**

An a priori power analysis was run to determine an appropriate sample size. Using  $r = 0.40$ , an alpha level of 0.05, a one-tailed statistical analysis, and a power of 0.80 it was determined that at least 34 pre- and post-game measurements would be needed. Statistical analysis was run using SPSS 21.0 (SPSS Science Inc., Chicago, Ill, USA). Three simple linear correlations were calculated between pitching count and percent change in infraspinatus cross-sectional area, shoulder internal rotation range of motion, and shoulder horizontal adduction range of motion.

## CHAPTER IV

### OVERVIEW

**Context:** High pitch counts are a risk factor for shoulder/elbow injuries, but physical and physiological responses immediately after pitching are not well understood. Due to the role the infraspinatus has during pitching, it is important to understand the effect of an acute bout of pitching on infraspinatus cross-sectional area (ICSA) and the clinical measures of glenohumeral range of motion (ROM) to determine how physical/physiological characteristics change following pitching.

**Objective:** To examine the relationship between pitch count and ICSA, shoulder internal rotation ROM, and shoulder horizontal adduction ROM.

**Design:** Cross-sectional repeated measures

**Setting:** Athletic Training Room

**Participants:** 14 collegiate baseball pitchers during 36 bouts of game pitching (age=19.4 ± 0.94yrs, height=188.1 ± 6.6cm, mass=89.0 ± 12.3kg).

**Interventions:** ICSA (diagnostic ultrasound) and shoulder internal rotation (IR) and horizontal adduction (HA) ROM (digital inclinometer) measured before and after game pitching.

**Main Outcome Measures:** 3-trial means were calculated for pre and post pitching shoulder IR and HA ROM. ICSA was calculated by tracing the inside of the epimysium before and

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after game pitching. Percent change scores were calculated for each variable, and three linear correlations were calculated between pitch count and the percent change scores for IR ROM, HA ROM, and ICSA.

**Results:** There was a significant relationship between percent change in ICSA and pitch count ( $r_{36}=0.467$ ,  $p=0.004$ ). No significant relationships were seen between pitch count and percent change in IR ROM and HA ROM.

**Conclusions:** The correlation between ICSA and pitch count indicates that as pitch count increases, the damage as seen as an increase in ICSA, increases. Inflammation, sarcomere damage, and passive muscle stiffness may limit ROM know to be risk factors for injury. These findings, along with future research on the role of pitch type, mechanics, and velocity on ICSA, can assist in making pitching recommendations and tracking recovery following pitching.

**Word Count:** 300/300

## INTRODUCTION

Baseball is one of the most popular sports in the United States with over 4.5 million participants annually and about 27,000-31,000 of those participants are collegiate baseball players (Dick et al., 2007; Seefeldt V, 1992; *Student-Athlete Participation: 1981-1982 - 2010-11*, 2011; "USA Baseball Final Report," 2009). With baseball, a large number of injuries and lost time are attributed to throwing-related upper extremity injuries, and are found more among pitchers (Chambless et al., 2000; Conte et al., 2001; McFarland & Wasik, 1998; Posner et al., 2011). These time lost injuries include internal impingement, rotator cuff tendinopathies, shoulder instability, labral tears, and elbow ulnar collateral ligament injuries (Chambless et al., 2000; Conte et al., 2001; Dick et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McFarland & Wasik, 1998; Posner et al., 2011). In collegiate baseball, 36% of all complaints and missed days are attributed to shoulder and elbow pain (McFarland & Wasik, 1998) and that number only increases in minor leagues and major leagues (Chambless et al., 2000; Conte et al., 2001; Posner et al., 2011). Several studies have correlated pitch count with injury and have made recommendations for the numbers of pitches to be thrown per game and per week at various levels of baseball, yet there is little evidence connecting pitch count to the acute effects of pitching that lead to injury (Limpisvasti et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McNeil, 2006; *USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006*, 2006).

Pitch count is correlated with upper extremity injury due to the tremendous loading that is placed on the shoulder and elbow during the throwing motion (Fleisig et al., 1995; Lyman et al., 2002; Lyman et al., 2001; McNeil, 2006; Olsen et al., 2006; *USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006*, 2006). The late cocking phase

occurs when the arm is maximally externally rotated and horizontally abducted and creates a large anterior shear force and compressive force (Fleisig et al., 1995; Werner et al., 2010). This compressive force more than doubles during the deceleration phase of pitching (Fleisig et al., 1995). The infraspinatus muscle helps decrease these forces by providing joint compression and minimizing anterior shear force and superior migration of the humeral head (Labriola et al., 2005; Lee et al., 2000). The largest percentage of maximum voluntary isometric contraction of the infraspinatus occurs during the cocking phase and that percentage remains high through the deceleration phase (Escamilla & Andrews, 2009).

In order to help decelerate the arm, the infraspinatus contracts eccentrically following ball release (Laudner et al., 2006; Myers et al., 2007). The effects of repetitive eccentric contractions are well documented and include sarcomere damage, shortened connective tissue, passive muscle stiffness, and decreased range of motion (ROM) (Clarkson et al., 1992; Lauritzen et al., 2009; Newham, 1988). Edema has been shown by increased cross-sectional area seen on both diagnostic ultrasound (Oyama et al., 2011) and magnetic resonance imaging and the damaged sarcomeres were also viewed on magnetic resonance imaging (Chleboun et al., 1998; Yanagisawa et al., 2003). Following eccentric exercises of the biceps brachii, deficits in maximum voluntary isometric contraction have been observed immediately following exercise and remain for a significant period of time (Lauritzen et al., 2009). These deficits in strength were hypothesized to be due to damage to the muscle sarcomere, which was seen by muscle biopsy (Lauritzen et al., 2009). Damage to muscles in the shoulder such as the infraspinatus could lead to inflammation, a decrease in maximum voluntary isometric contraction, less effectiveness in slowing the arm during deceleration, and eventually shoulder and elbow injuries (Oyama et al., 2011).

Effects of repetitive eccentric exercise are important because the combination of sarcomere damage, passive muscle stiffness, and decreased ROM in the infraspinatus could lead to risk factors previously identified in the literature (Burkhart et al., 2003a; Clarkson et al., 1992; Dines et al., 2009; Grossman et al., 2005; Lauritzen et al., 2009; Myers et al., 2006; Newham, 1988). Decreased shoulder internal rotation, horizontal adduction, total arc of motion, and posterior capsule tightness have been linked to pathologic conditions and injuries to the shoulder and elbow (Burkhart et al., 2003a; Dines et al., 2009; Grossman et al., 2005; Myers et al., 2006).

Currently we know that pitch count is related to injury, but we do not clearly understand what physical changes occur with increased pitch count that predisposes the athlete to injury. Because of the role of the infraspinatus in pitching, and the cascade of events that may occur due to high pitch volume, it is important to understand how pitch count is related to changes in the infraspinatus cross-sectional area (ICSA), as well as ROM that may be altered due to edema in the infraspinatus. Research is needed to evaluate the effects of eccentric loading during baseball pitching on the infraspinatus and evaluate the effect of pitch count on alterations in these physical characteristics. Therefore, the purpose of this study is to examine the relationship between pitch count and the change in ICSA and shoulder ROM following a single bout of game pitching by collegiate pitchers. We hypothesize that as pitch count increases, ICSA will also increase, while shoulder internal rotation and horizontal adduction ROM will decrease. Understanding the relationship between pitch count and the acute effects on the infraspinatus may help in the development of evidence-based pitching recommendations and lead to further research studies looking into the proper recovery time and recovery methods following a bout of game pitching.

## **METHODS**

### ***Design***

A cross-sectional repeated measures design was used in this study. Glenohumeral internal rotation ROM, horizontal adduction ROM, and ICSA were measured in Division I baseball pitchers prior to a game and after being removed from the game.

### ***Participants***

Fourteen pitchers on a collegiate baseball team were recruited for this study (age=19.4 ± 0.94yrs, height=188.1 ± 6.6cm, mass=89.0 ± 12.3kg). Subjects were included in the research study if they were a pitcher on the baseball team, currently pitching in games with no restrictions, between the ages of 18 and 22, and not currently being treated for shoulder/elbow pain or injury. The starter for each game was measured prior to the game and following removal from the game. Projected relievers were selected for pre-game measurements based off information from the coaches, players, and athletic training staff. Players who did not pitch in the game were not measured post-game and were excluded from the data collected that day. These fourteen pitchers were measured for a total of 36 pre- and post-game measurements, which was deemed appropriate by our a priori power analysis.

### ***Procedures***

Prior to participation, subjects read and signed an informed consent form that was approved by the University Institutional Review Board. Members of the research team went to the home stadium and set up for data collection each home game. Prior to the game and following an acute bout of pitching, participants were evaluated on ICSA using diagnostic ultrasound. Internal rotation ROM and horizontal adduction ROM was assessed using a digital inclinometer. Detailed descriptions of the testing procedures are discussed below.



### *Internal Rotation*

Shoulder internal rotation ROM was measured with the participant supine and his throwing arm in 90 degrees of abduction and 90 degrees of elbow flexion. The scapula was stabilized by applying a posteriorly directed force against the coracoid process and clavicle to prevent elevation and tilting of the scapula. A second tester aligned the digital inclinometer with the forearm and three measurements were taken per session (Myers et al., 2007). Our pilot study yielded an  $ICC_{3,1}=0.984$  and a  $SEM=0.786^\circ$ .

### *Horizontal Adduction*

Shoulder horizontal adduction ROM was measured with the participant supine and his throwing arm in 90 degrees of abduction. The scapula was stabilized by applying a medially directed force against the lateral border of the scapula to prevent upward rotation and medial rotation of the scapula. A second tester aligned the digital inclinometer with the humerus and three measurements were taken per session (Myers et al., 2007). Our pilot study yielded an  $ICC_{3,1}=0.951$  and a  $SEM=0.826^\circ$ .

### *Infraspinatus Cross-Sectional Area*

A diagnostic ultrasound unit (LOGIQe, General Electric, Milwaukee, WI, USA) was used for the assessment, using a method previously identified in the literature (Oyama et al., 2011). A 4 cm linear array ultrasound transducer was used with the frequency of 12 Megahertz and depth of 5.0 centimeters in order to take images of the infraspinatus. Ultrasonographic imaging of the infraspinatus were taken with each participant lying prone with their throwing arm at their side. The acromial angle, trigonum spinae, inferior angle of the scapula were identified and marked. A line was drawn from the acromial angle to the inferior angle. A second line was drawn perpendicular to the first line and connected with the

trigonum spinae. A custom-template with hypo-echoic markers placed at 4 cm intervals was placed along the second line (Oyama et al., 2011). Four serial images along the template were taken (**Figure 1**). Our pilot study yielded an  $ICC_{3,1} = 0.985$  and a  $SEM = 0.567 \text{ cm}^2$ .

### *Pitch Counts*

Pitch counts during the live game pitching were counted by managers on the baseball team staff. Warm-up pitches were not included in the pitch counts data utilized for analysis.

### *Data Reduction*

The measures of glenohumeral internal rotation ROM, horizontal adduction ROM, and ICSA were used to evaluate changes from pre-pitching to post-pitching. Percent change values of internal rotation ROM, horizontal adduction ROM and ICSA were calculated for a correlation analysis evaluating the relationship between the number of pitches thrown in a single bout of game pitching and these variables.

The three trials for shoulder internal rotation and horizontal adduction ROM measurement were averaged for each testing session. The percent change score was calculated by subtracting the pre-game measurement from the post-game measurement, dividing by the pre-game measurement, and multiplying by 100.

A full image of the ICSA was constructed from the series of overlapping images using Adobe Photoshop (Adobe, San Jose, CA, USA) (**Figure 2**). Cross-sectional area was calculated by calibrating the field area to a known distance, then tracing the inside of the epimysium using Image J software (National Institutes of Health, Bethesda, MD, USA). This has been shown as a valid and reliable data reduction procedure for muscle cross-sectional area in previous literature (Blackburn et al., 2009; Oyama et al., 2011). The percent change

score was calculated by subtracting the pre-game measurement from the post-game measurement, dividing by the pre-game measurement, and multiplying by 100.

### ***Statistical Analysis***

Statistical analysis was run using SPSS 21.0 (SPSS Science Inc., Chicago, Ill, USA). Three simple linear correlations were calculated between pitching count and percent change in ICSA, shoulder IR ROM, and shoulder HA ROM percent change variables.

## **RESULTS**

The pre-pitching and post-pitching mean values and the mean differences are presented in **Table 1**. The correlation results for percent change are presented in **Table 2**. There was a significant relationship between percent change in ICSA and pitch count ( $r_{36}=0.467$ ,  $p=0.004$ ). There was not a significant correlation between pitch count and percent change in internal rotation ROM ( $r_{36}= -0.313$ ,  $p=0.063$ ) or horizontal adduction ROM ( $r_{36}=0.091$ ,  $p=0.597$ ).

## **DISCUSSION**

Shoulder injuries in baseball are caused by overuse and repetitive microtrauma to both the static and dynamic stabilizing structures of the shoulder such as the joint capsule and rotator cuff muscles (Burkhart et al., 2003a; Dines et al., 2009; Grossman et al., 2005; Myers et al., 2006). This microtrauma, as seen on diagnostic ultrasound following isokinetic eccentric exercise (Oyama et al., 2011), can lead to predisposing risk factors previously identified in the literature such as decreased internal rotation and horizontal adduction ROM. However, no studies to date have evaluated ICSA following an acute bout of live game pitching. High pitch counts have been identified as a risk factor for injury (Limpisvasti et al., 2007; Lyman et al., 2002; Lyman et al., 2001; McNeil, 2006; *USA Baseball Medical &*

*Safety Advisory Committee Guidelines: May 2006, 2006*); therefore, the objective of this study was to evaluate changes in ICSA and shoulder ROM before and after game pitching and to examine the relationship between pitch count and these changes in ICSA and shoulder ROM.

It has been previously identified in the literature that repetitive eccentric contractions of muscle leads to muscle damage, swelling, and decreased ROM (Chleboun et al., 1998; Clarkson et al., 1992; Lauritzen et al., 2009; Oyama et al., 2011). Due to the eccentric contractions the infraspinatus must undergo in order to decelerate the arm during follow-through (Escamilla & Andrews, 2009), rotator cuff muscle damage and trauma to the posterior capsule could lead to loss of shoulder internal rotation and horizontal adduction ROM (Burkhart et al., 2003b; Michener et al., 2003; Thomas et al., 2011; Thomas et al., 2010a; Thomas et al., 2010b; Tyler et al., 1999). Therefore, we hypothesized that as pitch count increases, ICSA would increase, while internal rotation and horizontal adduction ROM would decrease.

This study shows that the pitching motion induces a similar amount of edema and tissue damage as isokinetic eccentric contractions on the infraspinatus muscle (Oyama et al., 2011). Oyama, et al. saw that ICSA increased by an average of 1.9 cm<sup>2</sup>(Oyama et al., 2011), while our study showed that ICSA increased approximately 1.6 cm<sup>2</sup> between pre- and post-game measurements (**Table 1**). This is evidence that pitch count is associated with infraspinatus microtrauma and swelling following pitching. Also, ICSA percent change increased as pitch count increased ( $r_{36}=0.467$ ,  $p=0.004$ ). The percent change in ICSA went from approximately 10% increase at the low pitch counts to about 20% at the pitch counts over 100 (**Figure 3**). This shows that any amount of pitching leads to muscle damage as

evidenced by the swelling seen on diagnostic ultrasound, and increasing pitch counts leads to more damage and swelling in the muscle. These results for change in ICOSA were similar to the study by Oyama, et al (Oyama et al., 2011).

The small mean differences in the percent change scores for IR ROM and HA ROM can be attributed to the increased tissue temperature of the muscle, which has been shown to increase ROM (Bleakley & Costello, 2013; Robertson et al., 2005). While the positive correlation between pitch count and ICOSA was the only statistically significant result, the relationship between pitch count and shoulder ROMs yielded interesting results. As shown by **Figure 4**, the percent change in internal rotation ROM goes from gaining approximately 10% with the very low pitch counts, to 0% (no gain or loss) at pitch counts around 100 pitches. The percent change in horizontal adduction ROM was highly variable, showed almost no correlational relationship, and the trend was for no change in ROM regardless of pitch count (**Figure 5**).

The lack of statistical significant results for the changes in shoulder ROM may be attributed to the combined effects of the resultant muscle damage following pitching and the increased tissue temperature following activity. Increased tissue temperature following the bout of game pitching may have contributed to the results seen in the ROM measures, as increased tissue temperature has been shown to increase ROM (Bleakley & Costello, 2013; Robertson et al., 2005). We believe that the fact that internal rotation increases at low pitch counts is due to the increased tissue temperature following activity, while the damage to the muscle and joint capsule is minimal at these low pitch counts. As pitch count increases, the amount of damage to the rotator cuff musculature and joint capsule increases; therefore, the ROM remains the same at pitch counts around 100 pitches. The pitching motion has been

shown to involve a large amount of horizontal adduction motion following ball release (Oliver & Keeley, 2010). The previously described muscle damage and increased tissue temperature combine with the effect of repetitive horizontal adduction stretching, especially with high pitch counts, leads to an increase in horizontal adduction ROM as pitch count increases. Finally, the participants in the current study all typically participate in a regimented arm care program provided by the clinical staff that includes internal rotation and horizontal adduction stretching. The average pre-game measurement of internal rotation was 45.6 degrees, higher than many values seen in current literature. Other research has shown a range from 20.5-42.2 degrees at various points throughout a collegiate baseball season (Freehill et al., 2014; Myers et al., 2007; Thomas et al., 2011). It is possible that statistically significant results were not seen for the range of motion variables in this study due to a ceiling effect because of the increased amount of range of motion present in our participants.

The major strength of this study is the fact that measurements were taken before and after actual game exposures. Also, the completion of this study shows that the use of diagnostic ultrasound can be a quick, non-invasive clinical tool for use in various scenarios within an athletic training room. Assessments were able to be completed in under five minutes, and did not interfere in the participants' ability to go through their pre-game routines. The overall goal of this study and future research to follow is to identify markers of fatigue and recovery that a clinician can use and can validate clinical decisions to coaches and players. These markers could be infraspinatus cross-sectional area, echo intensity of various muscles seen on diagnostic ultrasound, physiological blood or saliva markers, performance measures such as pitch velocity and percentage of pitches for strikes, or any combination of these measures. Given the results of the current study, infraspinatus cross-

sectional area may be a potential marker that reflects both throwing arm trauma as well as a trackable means to signal arm recovery after pitching.

However, there were some limitations to the study. First of all, there was no control over how many pitches were thrown by each participant. Because this was during the regular season with a collegiate baseball team, we were unable to dictate how many pitches each participant threw during each outing. Many of the high pitch counts came from the same individuals who would start the game, while many of the low pitch counts came from the same relief pitchers. In the future, we would like to measure pitchers during simulated games. We would be able to assess each pitcher at different pitch count increments, and perhaps being able to see each individual having pitch counts throughout the continuum. Also due to the fact that this study took place during regular season games, we were unable to control for pre-game warm-ups and pitches thrown in the bullpen to warm up. Some pitchers would perform their arm care strengthening exercises after our pre-game assessments, and some relief pitchers would warm up multiple times in the bullpen before entering the game. Again, recreating this study during simulated games could control for these confounding factors. Also, measuring individuals who only warm up in the bullpen and do not actually play in the game could provide insight into whether warming up also results in cross-sectional area changes to the infraspinatus. Although the number of warm-up pitches and number of times a relief pitcher warmed up would be valuable information, it was deemed difficult to track without causing disruptions to the participants who were preparing to enter in a live game. Following removal from the game, all variables were measured as soon as possible and prior to performing any post-game treatments.

This study was innovative due to the fact that we were able to take pre-game and post-game measurements during the actual event of pitching in a game. In the future, research can be conducted during simulated games in order to better control for warm-up activities and have individuals with more variability in their pitch counts. Also, future research can follow players throughout the course of the season to determine if the repetitive act of pitching results in continual increases in ICSSA and the development of injury risk factors such as GIRD and posterior shoulder tightness. Hopefully this study can begin a process of measuring the amount of damage and edema that results in the shoulder following pitching, and can lead to either validating or suggesting changes to current pitch count recommendations. Also, tracking the acute effects related to pitch count over time can allow for a better consensus about proper recovery methods and time following pitching in order to prevent the development of several injury risk factors.

## **CONCLUSIONS**

Following single bouts of pitching in collegiate games, ICSSA increased as pitch count increased. Changes in shoulder ROM were not significantly correlated with pitch count. Future research can be done to track recovery of the infraspinatus muscle over time, and also determine proper methods of recovery following pitching. Also, shoulder ROM can be tracked daily following a single bout of pitching to determine if ROM deficits exist once the tissue temperature has returned to normal. Finally, future research in these areas can help create evidence-based pitch count recommendations at various levels of baseball.



**TABLES AND FIGURES**

Table 1.

	Pre-Game Mean	Post-Game Mean	Mean Difference
IR (°)	45.6	47.4	1.8
HA (°)	103.2	103.6	0.4
ICSA (sq. cm)	13.4	15.0	1.6

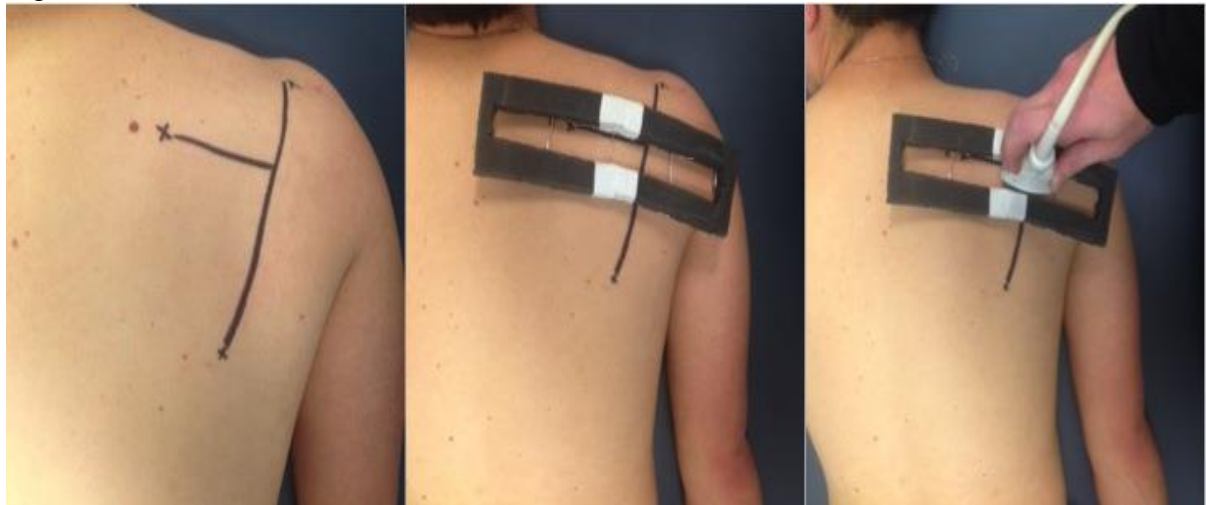
IR = Internal Rotation, HA = Horizontal Adduction, ICSA = Infraspinatus Cross-Sectional Area.

Table 2.

Correlation Results			
	r	R <sup>2</sup>	Significance
Pitch Count & IR	-.313	.098	.063
Pitch Count & HA	.091	.008	.597
Pitch Count & ICSA	.467	.218	.004*

IR = Internal Rotation, HA = Horizontal Adduction, ICSA = Infraspinatus Cross-Sectional Area. \*Significant at p<0.01.

Figure 1



**Figure 1 – Methods for measurement of infraspinatus cross-sectional area. Landmarks identified. Template placed along line drawn from trigonum spinae to line connecting acromial angle and inferior angle on posterior shoulder. Four serial images were taken and overlapped to display full cross-sectional image of infraspinatus muscle**

Figure 2.

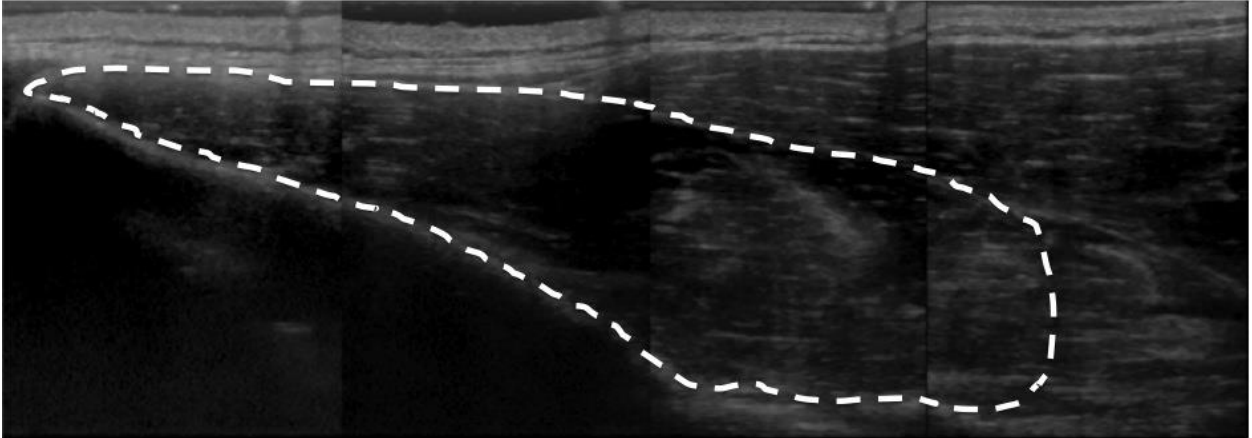


Figure 2 - Cross-sectional image of the infraspinatus muscle constructed from the series of overlapping images of the infraspinatus muscle guided by the hypo-echoic markers.

Figure 3

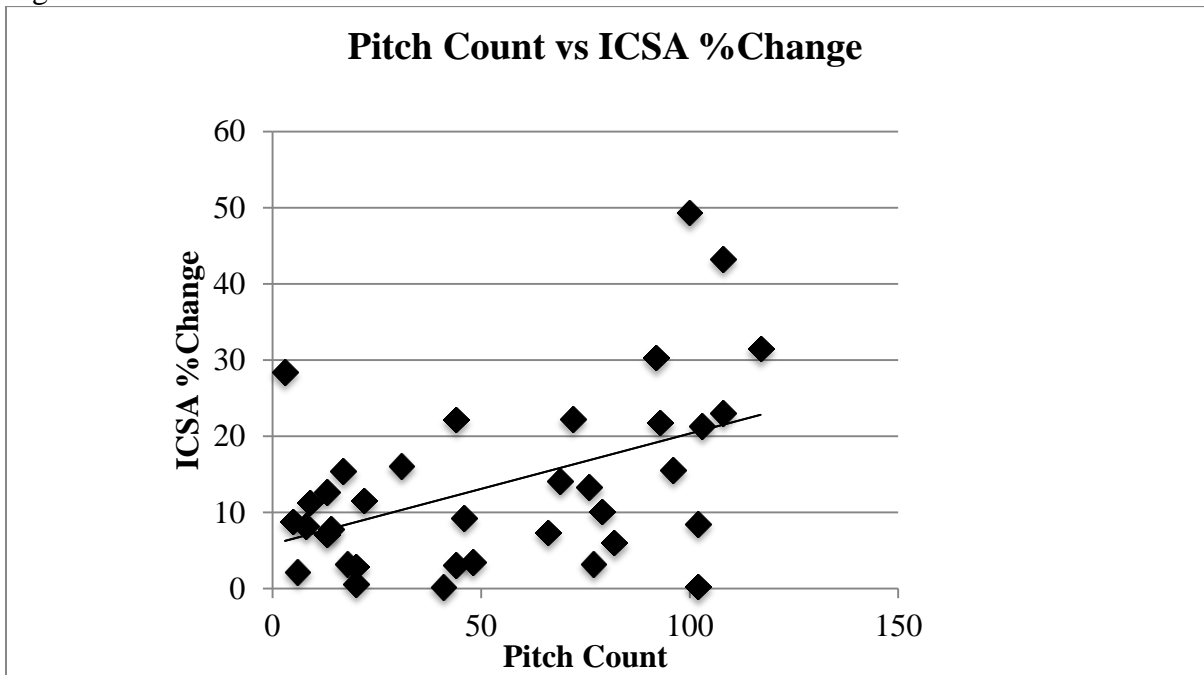


Figure 3. Pitch count and infraspinatus cross-sectional area correlation ( $r_{36}=0.467$ ,  $p=0.004$ ). ICSA %Change = percent change in infraspinatus cross-sectional area.

Figure 4

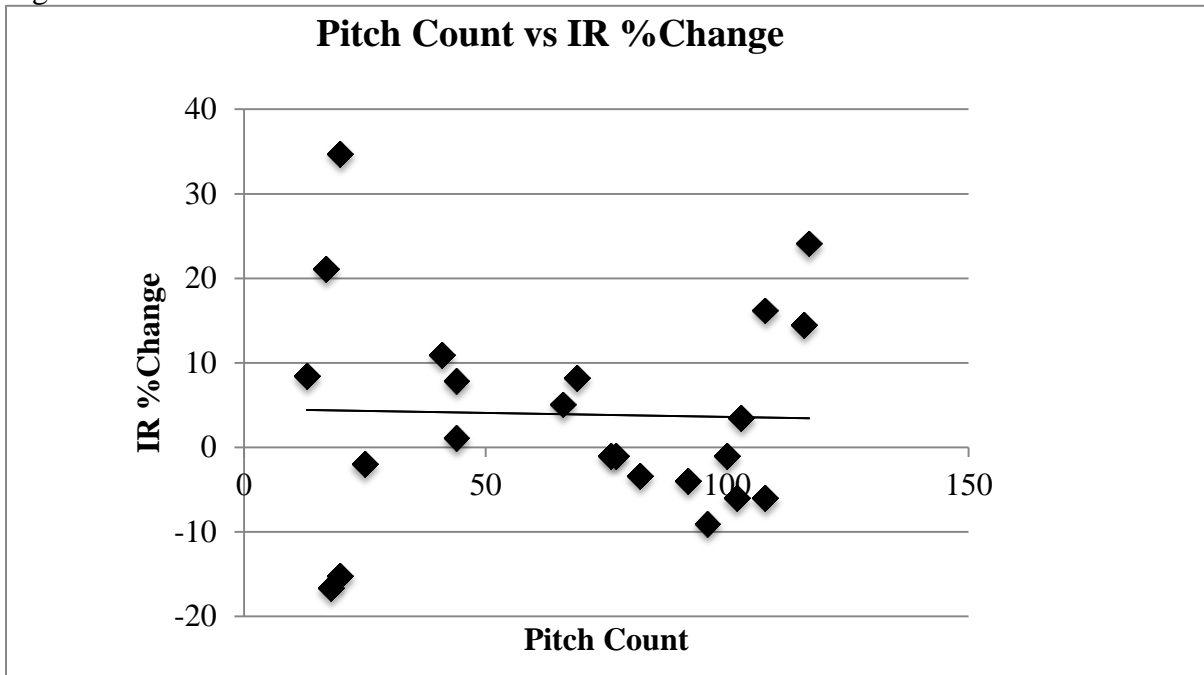


Figure 4. Pitch count and internal rotation range of motion correlation ( $r_{36}=-.313$ ,  $p=.063$ ). IR %Change = percent change in internal rotation range of motion.

Figure 5.

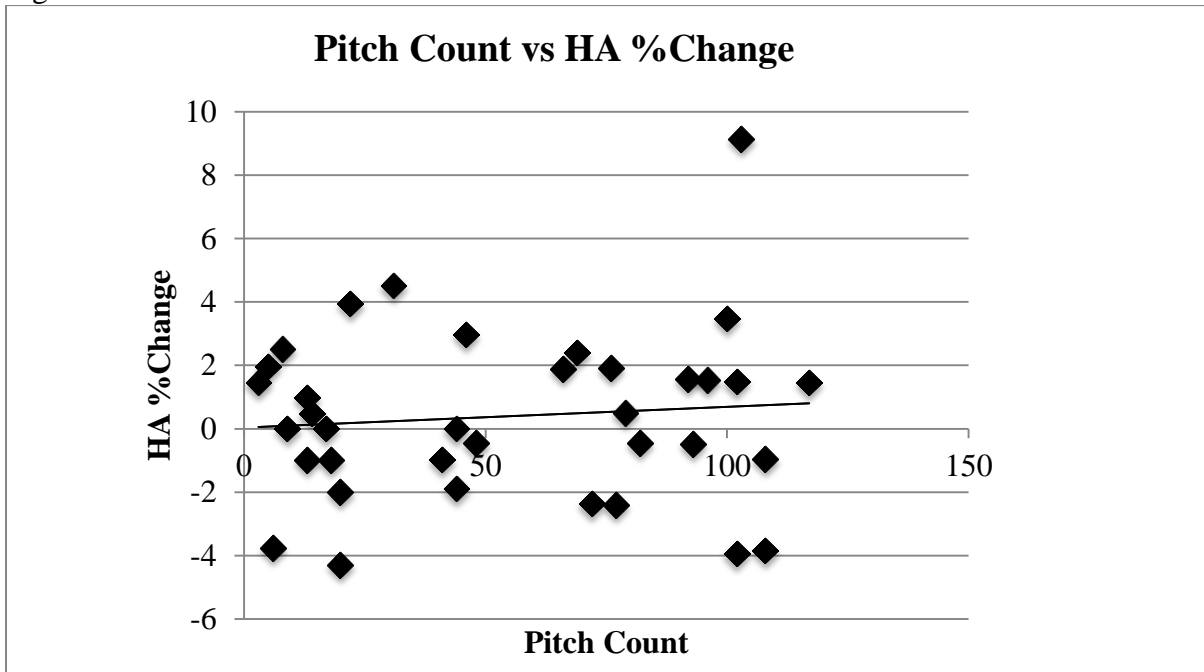


Figure 5. Pitch count and horizontal adduction range of motion correlation ( $r_{36}=-.091$ ,  $p=.597$ ). HA %Change = percent change in horizontal adduction range of motion.

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## FIGURES



**Figure 1 – Phases of Pitching. 1. Wind-up prior to knee maximum height. 2. Stride beginning with knee maximum height. 2. Arm cocking beginning with lead foot contact. 4. Arm acceleration beginning with shoulder maximum external rotation. 5. Arm deceleration following ball release. 6. Follow-through at shoulder maximum internal rotation.**



**Figure 2 – Glenohumeral internal rotation range of motion measurement with stabilization of the scapula**

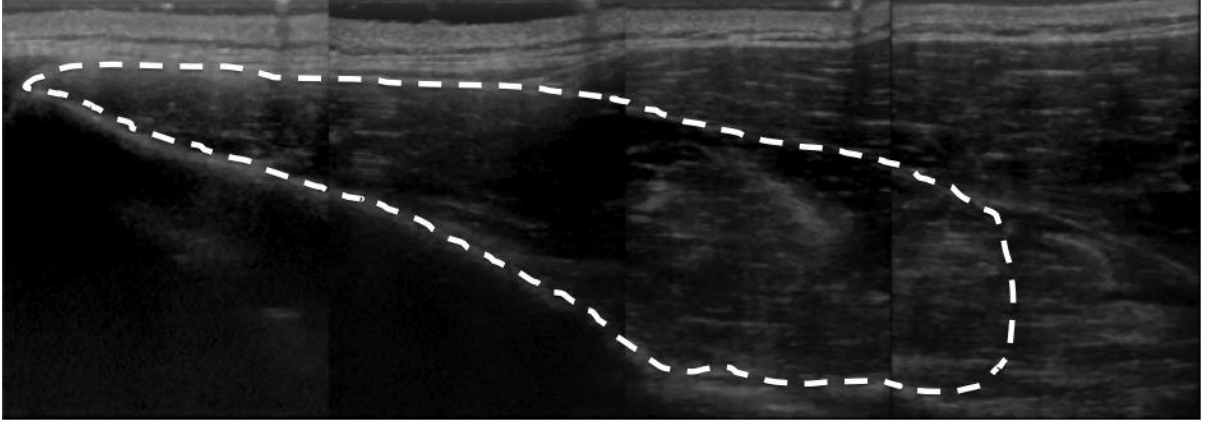




**Figure 3 – Glenohumeral horizontal adduction range of motion measurement with stabilization of the scapula**



**Figure 4 – Methods for measurement of infraspinatus cross-sectional area. Landmarks identified. Template placed along line drawn from trigonum spinae to line connecting acromial angle and inferior angle on posterior shoulder. Four serial images were taken and overlapped to display full cross-sectional image of infraspinatus muscle**



**Figure 5 - Cross-sectional image of the infraspinatus muscle constructed from the series of overlapping images of the infraspinatus muscle guided by the hypo-echoic markers.**

## TABLES

Table 1. Statistical analyses used for relationship between pitch count and infraspinatus cross-sectional area and shoulder range of motion				
<u>Question</u>	<u>Description</u>	<u>Data Source</u>	<u>Correlation</u>	<u>Method</u>
1	What is the relationship between pitch count during a single bout of game pitching and percent change in infraspinatus cross-sectional area?	Percent change in infraspinatus cross-sectional area from pre-game to post-game (Diagnostic Ultrasound)	Pitch Count (Box Scores) and percent change in infraspinatus cross-sectional area	Linear Correlation
2	What is the relationship between pitch count during a single bout of game pitching and percent change in shoulder internal rotation range of motion?	Percent change in shoulder internal rotation range of motion from pre-game to post-game (Digital Inclinometer)	Pitch Count (Box Scores) and percent change in shoulder internal rotation range of motion	Linear Correlation
3	What is the relationship between pitch count during a single bout of game pitching and percent change in shoulder horizontal adduction range of motion?	Percent change in shoulder horizontal adduction range of motion from pre-game to post-game (Digital Inclinometer)	Pitch Count (Box Scores) and percent change in shoulder horizontal adduction range of motion	Linear Correlation

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