THE EFFECTS OF HUMERAL RETROVERSION ON RANGE OF MOTION IN THE THROWING ATHLETE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

The purpose of this study was to examine the relationship between shoulder rotational range of motion once accounting for humeral retroversion (HR) and the Functional Arm Scale for Throwers (FAST). The following research questions guided the study: Is there a correlation between shoulder rotational range of motion (ROM) after HR is accounted for, and the total FAST pitcher's subscale score? What specific questions on the FAST pitcher's subscale can help sports medicine professionals predict the chance of rotational deficiencies in the throwing shoulder? Are pitchers with more years of college baseball more likely to see changes in total rotational ROM than pitchers with less years of college baseball? No relationship was found between rotational ROM and the FAST score or rotational ROM and total number of years playing college baseball. The findings suggest further research that needs to be performed on patient reported outcomes specific to changes in rotational ROM.

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LIST OF ABBREVIATIONS

ER ....External rotation

IR ....Internal rotation

TRROM ....Total rotational range of motion

HR...Humeral retroversion/retrotorsion

ROM ....Range of motion

FAST ....Functional Arm Scale for Throwers

1. INTRODUCTION

1.1. Overview of the Problem

The act of throwing a baseball is a physically demanding motion that requires detailed coordination of muscles, joints, and places high loads of stress throughout the body.[3,4,28] Baseball pitchers tend to suffer from a high amount of throwing injuries, and their injury rate seems to continue to rise as time goes on.[28] Pitchers may throw more than 400 pitches in a season, which ultimately can lead to an increased injury risk due to the compound exposure of high velocity throwing, which is one of the fastest recorded movements.[28,30] The high velocities are combined with the accelerations and decelerations of the arm during the throwing motion every time a ball is thrown.[28] Proper biomechanical analysis of the throwing motion is crucial to identifying movement dysfunctions.[33-35] Furthermore, this analysis should include bilateral measurements of total shoulder rotation and humeral retroversion to enable clinicians to implement appropriate interventions to reduce injury risk.[33-35] Total shoulder rotation and humeral retroversion can be measured using diagnostic ultrasound and an inclinometer. [36] Measures of humeral retroversion using diagnostic ultrasound may provide clinicians with objective data beyond traditional range of motion testing using goniometry alone. Bilateral comparisons of range of motion and humeral retroversion between the throwing and non-throwing shoulders may also elucidate new insights into the biomechanics of the throwing athlete.

In the baseball pitcher, there are many factors outside of structural and objective measurements that factor into the overall performance and health of the athlete. For example, although the biomechanics of the throwing motion is very important, how the pitcher feels while throwing is another factor that can affect his health and performance.[28,40] Pitchers have specific throwing motions that are unique for each individual, and they also have a specific “feel” for how each type of pitch is thrown.[28, 40] One tool that has been validated in the literature to evaluate the pitcher's reported outcome is The Functional Arm Scale for Throwers (FAST). This qualitative tool has been used by clinicians in both preventive medicine and rehabilitation settings to provide objective data.[40]

1.2. Statement of Purpose

In overhead sports like baseball understanding proper arthrokinematics of the shoulder is essential to preventing and treating shoulder injuries.[28] Based on prior research, using diagnostic ultrasound in conjunction with a handheld dynamometer has been named the gold standard to have accurate measures of ROM collection.[34-37] Previous research has been conducted to determine the effects of bony adaptations on the shoulder in overhead athletes.[34-37]

The purpose of this study is to investigate the relationship between corrected shoulder rotational range of motion (external rotation, internal rotation, and total rotation) and the total FAST patient reported outcome subscale for pitchers. Furthermore, a secondary analysis of the rotational range of motion values at a Midwest Division I baseball university once humeral retroversion is accounted for using diagnostic ultrasound. Lastly, an analysis of each specific of the FAST subscale will be performed to determine any relationships between shoulder rotational deficits that could provide valuable data for shoulder examination for sports medicine professionals.

1.3. Research Questions

Q1: Is there a correlation between shoulder rotational range of motion after bony adaptations are accounted for and the total FAST pitcher's subscale score?

HYPOTHESIS: If there is a total subscale score greater than 10 then there will be a decrease in ER once HR is accounted for.

Q2: What specific questions on the FAST pitcher's subscale can help sports medicine professionals predict the chance of rotational deficiencies in the throwing shoulder?

HYPOTHESIS: If pitchers report that they are moderately affected by a decrease in velocity or feel that they have a decrease in feel of pitches being thrown, then there will be a rotational deficit present in the dominant shoulder.

Q3: Are pitchers with more years of college baseball more likely to see changes in total rotational range of motion once humeral retroversion than pitchers with less years of college baseball?

HYPOTHESIS: If pitchers have more years of college baseball experience, then they are more likely to have a total rotational deficit.

1.4. Limitations

Several limitations will be present in this study and may affect the strength of findings. First, the consistency of the researcher to determine a firm end point during internal and external rotation, as well as the ability of the additional examiners to provide the containment force and limit scapulothoracic movement during range of motion testing. Previous studies performed using end feel to examine rotational motion in the shoulder have determined the intrareader relatability to be and the interrater reliability to be from 0.91 to 0.99.[34] Another notable limitation was the participants were actively competing in-season and their pitch count or workload could not be changed or altered. Some previous studies performed clinical measurements of rotational range of motion during pre-season, where they were able to account for the pitcher's workload. Current research suggests that baseball pitchers may see adaptations in range of motion and strength in the shoulder up to four days after throwing. These athletes were in the start of their season and some players had their measurements collected a day or two after throwing which may have contributed to their range of motion values. Furthermore, only shoulder external and internal rotation range of motion values were measured in this study. In the throwing motion there are other clinical range of motion measurements that contribute to the throwing motion such as shoulder flexion, extension, adduction, and abduction. Another limitation to this study is that the participants in this study was from one university in the Midwest. Regional factors such as weather and availability to play baseball year-round may also contribute to the data that was collected, since the outdoor baseball training season may be limited. The FAST score was modified from a 9-question scale to a 7-question scale because of the relevance of two questions that could not be answered at the time of data collection. Results may have yielded different results if the complete 9-question subscale could have been used.

1.5. Delimitations

Research regarding ultrasonic measurement of humeral retroversion, range of motion, and their relationship to FAST outcome scores is limited; therefore, the researchers of this study chose to examine this subject in a single population of NCAA Division 1 baseball pitchers. Therefore, the results of this study may not be generalized to other sports that involve overhead motions or different levels of athletes other this population. The study is also limited to those baseball pitchers without any current shoulder injury or pathology in either shoulder.

1.6. Assumptions

Since subject self-perception will be measured by questionnaire (FAST), the researchers will assume each subject will answer each item truthfully and accurately. Assuming that the athletes answer the questionnaire truthfully ensures that the descriptive statistics will be accurate and useful to form correlations between descriptive and objective data that is collected during data collection by the research team.

1.7. Variables

The independent variables of the current study will be, number of years playing college baseball, and what arm they use to throw a baseball with. The dependent variables in the current study will be angle of humeral retroversion, shoulder internal rotation measurements, shoulder external rotation measurements, total corrected rotation measurements, corrected IR measurements, corrected ER measurements, and scores from the FAST outcome assessment for pitchers.

1.8. Significance of Study

Prevention and care of the athlete, including movement screening and rehabilitation, is one of the five domains in athletic training. In baseball, athletic trainers are often tasked with examining baseball athletes' shoulder range of motion during preseason screenings. Therefore, it is necessary for athletic trainers to collect these measurements in the most accurate way. Accurate collection of range of motion is imperative to not only help athletic trainers create corrective programs to treat motion dysfunctions, but also for establishing baseline values. Another important factor is the athletes' perception of their shoulder function. After an extensive literature search, there were studies found that describe the relationship among humeral retroversion, shoulder range of motion and the functional arm scale for the throwing athlete (FAST). Therefore, this research may elucidate any relationship between humeral retroversion, total range of motion measurements, and the throwing athlete's perception of their shoulder function.

1.9. Definitions

Athletic Trainer (AT): A healthcare professional "who collaborates with physicians to optimize patient physical capacity, health, and well-being […through] the prevention, examination and diagnosis, treatment and rehabilitation of emergent, acute, subacute, and chronic neuromusculoskeletal conditions, and certain medical conditions in order to minimize subsequent impairments, functional limitations, disability, and societal limitations”.[35]

Humeral retroversion: the rotational difference in the relative position of the humeral head and the axis of the elbow at the distal humerus.[33,34]

Diagnostic ultrasound: imaging method that uses high-frequency sound waves to produce images of structures within your body.[33]

Inclinometer: an instrument used for measuring angles of slope, elevation, or depression of an object with respect to gravity's direction.[33]

Hyperechoic: Refers to echoes returning to a structure. Hyperechoic tissues generate a greater echo that usually is displayed on the ultrasound screen as a lighter color.[37]

Hypoechoic: Structures or tissues that have a lower echogenicity that are represented as a darker color on the ultrasound machine.[37]

Shoulder Internal Rotation: The movement of the humerus when the arm is flexed at 90 degrees at the elbow. The movement occurs when the humerus rotates towards the midline of the body.[33]

Shoulder External Rotation: The movement of the humerus when the humerus rotates away from the midline of the body.[33]

Total rotation: The sum of internal rotation and external rotation.[10,16]

Refraction: Light waves that are deflected obliquely when they pass though the interface between one medium and another.[37]

Reflection: the bouncing back from a surface without absorbing it.[37]

Scattering: Occurs when a sound wave strikes another structure with a different acoustic impedance to the surrounding tissue which is smaller than the wavelength of the incident sound wave. [37]

Absorption: Reduction in intensity of sound waves as it passes through tissues.[37]

2. THE SHOULDER

2.1. Overview

The shoulder is considered one of the most complex, but dynamic joints in the body. The structures of the shoulder complex allow the joint to have the greatest range of motion of any of the joints throughout the body, thus increasing its functionality. However, because of the large degree of motion present, there is often a risk for injury to the joint and its surrounding structures. To comprehend the etiology of shoulder injuries, it's essential for clinicians to understand the anatomy of the shoulder and adaptations that may occur to the joint over time.

2.2. Bony Anatomy

Although the shoulder can be a complex joint when discussing its functionality, it is only comprised of three main bones; the humerus, clavicle and scapula.[1,2] The humerus is the largest and longest bone in the upper extremity of the body. Along the humerus are anatomical landmarks for the origins and insertions of the dynamic and static soft tissue stabilizers of the joint.[1] The proximal end of the humerus is the primary portion of the bone that is crucial for the overall function of the shoulder.

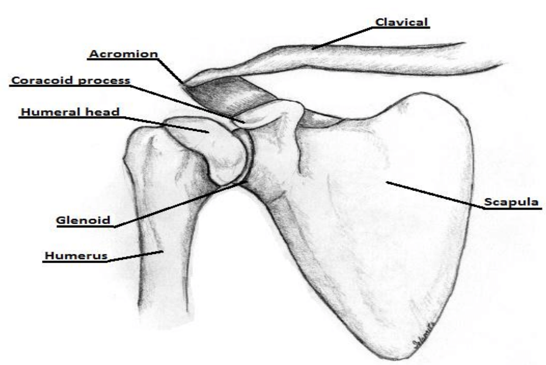

Figure 2.1. The Shoulder (Terry GC, Chopp TM. Functional anatomy of the shoulder. *J Athl Train*. 2000;35(3):248-255. doi:10.1016/B978-0-323-28683-1.00037-0)

Along the proximal end of the humerus, both the greater and lesser tuberosities create an anchor for the rotator cuff muscles. More specifically, the greater tuberosity has three facets, which three of the four rotator cuff tendons insert; the supraspinatus, infraspinatus, and teres minor.[1] The lesser tuberosity provides the insertion site for the subscapularis tendon.[1] Splitting the tuberosities lies the intertubular groove, or as it is commonly known as, the bicipital groove.[1,2] The long head of the biceps brachii tendon passes through the groove laterally and distally from its origin on the superior lip of the glenoid.[1] Although the humerus is the largest bone in the upper extremity and is the attachment site for soft tissue structures in the shoulder, it is still susceptible to injury because of the extreme forces placed upon it.

The scapula is a large, thin bone with a triangular shape and lies along the proximal posterolateral aspect of the thorax, resting on the posterior surfaces of ribs two through seven.[1] Similar to the humerus, the scapula serves as an attachment site for soft tissue structures, which provide stabilization to the scapula and maintains proper scapulohumeral rhythm. During overhead motions, the scapula is the link between the pelvic and trunk and the smaller localized segments of the arm that produce mobility and apply force.[3–5]

The spine of the scapula primarily functions as a partial insertion site for the trapezius muscle, while also separating the supraspinous and infraspinous fossae. Just proximal and slightly anterolateral to the spine of the scapula lies the acromion. The acromion is a lever arm for the deltoid muscle group and also has an articulation with the distal end of the clavicle.[1,3] However, in shoulder arthrokinematics, the acromion is a crucial component of the acromial space, which the rotator cuff musculature passes through.[1] Due to the osseous positioning and numerous attachment sites along the bone, the scapula is placed in a unique position to assist or alter how the shoulder joint moves.

Furthermore, the final anatomical landmark on the scapular that must be discussed is the glenoid fossa. The fossa acts as the articulating surface for the humerus and scapula, creating the glenohumeral joint. Its articular surface is only one third to one fourth of the size of the humeral head, providing only a small contribution to glenohumeral stability.[1] However in baseball athletes, hypermobility is thought to allow for greater arm cocking, creating an increase in velocity upon release of the ball. [6] Altering the equilibrium of external to internal range of the glenohumeral joint in the overhead athlete will ultimately compromise the shoulder and have the potential to cause shoulder and elbow pathologies.

The smallest bone of the shoulder complex is the clavicle, as it is only around 15cm long.[5] In relation to the humerus and scapula, the clavicle may seem insignificant to motion at the shoulder; however, the clavicle is the sole bony structure that connects the shoulder girdle to the trunk via its articulations of the sternoclavicular joint medially and the acromioclavicular joint laterally.[1] The clavicle's role in shoulder movement is to increase the power and stability of the arm by providing attachment to important dynamic stabilizing muscles such as the deltoid, trapezius, sternocleidomastoid, pectoralis major, subclavius.[7] In addition, the clavicle is needed to assist in upward rotation and full elevation of the shoulder.[7] Besides its soft tissue attachments, the clavicle also provides a barrier to protect underlying neurovascular structures such as the subclavian vessels, the brachial plexus and the apex of the lung.[7] The clavicle also plays a role as a strut to stabilize the shoulder complex and prevent it from displacing medially.[1,7] Although the clavicle is primarily a synergist and stabilizer of the shoulder complex, it still plays an important role in facilitating proper shoulder function.

2.3. Musculature of the Shoulder

2.3.1. Rotator Cuff

When discussing the musculature of the shoulder, the rotator cuff must be examined because of its level of importance with shoulder movement and dynamic stabilization for the joint. As mentioned previously in the bony anatomy section, the rotator cuff is comprised of four muscles, the supraspinatus, infraspinatus, teres minor, and subscapularis.[1] All four rotator cuff muscles originate from the scapula and the tendons of the muscles blend together within the subjacent capsule as they insert to the greater or lesser tuberosities of the humerus.[8] The insertions of the rotator cuff tendons create a continuous cuff around the humeral head that allow muscles to the rotate the humerus while also opposing any unwanted or excessive musculature forces exerted by the pectoralis major or deltoid muscles. [8]

When examining the rotator cuff from a kinematic standpoint, the rotator cuff assists with arm elevation, while creating a force couple by compressing and stabilizing the glenohumeral joint during functional movement.[12] The supraspinatus acts a primary abductor of the humerus in the first 20 to 30 degrees of motion, whereas the infraspinatus and teres minor are primary external rotators of the glenohumeral joint.[9–11] The sole internal rotator of the rotator cuff is the subscapularis muscle.[5,12] Thus, all of the motions created by the rotator cuff allow dynamic stability of the glenohumeral joint; however, their wide range of motion predisposes the muscles to injury.

As constant stresses are placed on the rotator cuff, a risk exists for the one of the rotator cuff muscles to be damaged due to the chronic changes that occur over an athlete's career. In overhead athletes, repetitive eccentric muscle activity from slowing the arm during the deceleration phase of the throwing motion often leads to damage of the contractile elements of the muscle cell.[4] When there is damage to the muscle cells, a decrease in force output of the posterior shoulder occurs, which leads to a higher load transfer to the posterior joint capsule, anterior labrum, biceps tendon, or other non-contractile soft tissues.[4] In a case control study,[9] researchers examined major league baseball pitchers (n=33) with documented surgery to treat rotator cuff tears and control pitchers (n=133) who did not have documented rotator cuff tears. The researchers reported the pitchers with rotator cuff injuries often were older, more experienced, more likely to be starting pitchers, and performed at higher pre-index (seasons 1,2,3) levels than the average MLB pitcher.[9]

Table 2.1. Demographics of Pitchers in the Rotator Cuff Surgery and Control Groups[9]

VARIABLE	ROTATOR CUFF SURGERY (N=33)	CONTROL (N=117)	T	X^2	P
BASELINE ERA	3.93 ± 1.01	5.95 ± 2.41	4.71	NA	<.001
AGE, Y	30.87 ± 3.88	28.57 ± 4.17	2.82	NA	.005
PRE-INDEX MLB SEASON	7.82 ± 3.32	5.43 ± 4.04	3.16	NA	.001
BODY MASS INDEX	25.41 ± 2.10	26.92 ± 1.99	3.77	NA	.001
ALL-STAR	17 (51.5%)	17 (14.5%)	NA	18.0	<.001
NOT ALL-STAR	16 (48.5%)	100 (85.5%)			
RIGHT	26 (78.8%)	88 (75.2%)	NA	0.03	.84
LEFT	7 (21.2%)	29 (24.8%)			
STARTING PITCHER	24 (72.7%)	48 (41%)	NA	9.13	.003
RELIEVER	9 (27.3%)	69 (59%)			

(Namdari S, Baldwin K, Ahn A, Huffman GR, Sennett BJ. Performance after rotator cuff tear and operative treatment: A case-control study of major league baseball pitchers. *J Athl Train*. 2011;46(3):296-302. doi:10.4085/1062-6050-46.3.296)

These results support the concept of repetitive, high-volume motions create a breakdown of soft tissue structures over time. Similarly, Wright et al[13] investigated plain radiographic findings in the shoulders of major league pitchers (N=57) and noted that a greater number of innings pitched was associated with increased degenerative changes of the dominant shoulder (r = 0.46; P =.0004) and elbow (r = 0.38; P=.003). These changes included osteophytes, cystic changes, joint space narrowing, and loose bodies. Constant stressors placed on the shoulder can cause changes in the rotator cuff structure, leading to changes in shoulder function, and could eventually predispose individuals to overuse upper extremity injuries.

2.4. Range of Motion

When examining overhead athletes, it is imperative to understand normal ranges of motion for this population. As mentioned previously, there is excessively high amounts of angular velocities placed on the shoulder during the throwing motion. More specifically, shoulder internal rotation (IR) during a pitch is the fastest human movement recorded and, it occurs in excess of 7,250 degrees per second.[16] As a result of these stressors, there is often a change in the normal arc of motion present at the glenohumeral joint. In a non-overhead athlete population, normative values for shoulder range of motion often range from: internal rotation 74-80° external rotation 83-94°, forward flexion 165-180°, extension 54-60°, and abduction 174-180°.[5,10,17] However, most throwers exhibit an obvious motion disparity between the dominant and non-dominant arm, where external rotation is excessive and internal rotation is limited at 90° of abduction.[10] This disparity of less internal rotation of the throwing shoulder has been referred to as glenohumeral internal rotation deficit (GIRD). Burkhart et al[16] defined GIRD as "a loss of IR of the throwing shoulder of 20° or more as compared with the non-throwing shoulder."[18] In a three-year case series conducted on professional baseball pitchers (N=122), passive range of motion measurements were evaluated on the dominant and non-dominant shoulder using a goniometer.[16,17] The researchers reported range of motion values for external rotation ($M_{dominant}$ =136.1° ± 11.2°, $M_{non\text{-}dominant}$=128.6° ± 11.0°) and internal rotation ($M_{domininat}$=47.5° ± 10.6, $M_{non\text{-}dominant}$=59.1° ± 11.0°).[16] The researchers correlated range of motion measurements to injury rates among pitchers and reported pitchers with GIRD (n = 40) were nearly twice as likely to be injured as those without; however, this finding was not statistically significant (P = .17).[16] Thus, this information provides differing results that a loss of shoulder internal rotation will likely increase the risk of injury.

In a similar case series conducted over one season, Wilk and Arrigo et al assessed the range of shoulder motion of professional baseball players (N=372). The researchers found, by taking passive goniometric measurements, that pitchers exhibited an average of 129.9° ± 10° of external rotation and 62.6° ± 9° of internal rotation.[5] Wilk and Arrigo et al. also noted pitchers had external rotation approximately 7° greater in the throwing shoulder when compared with the non-throwing shoulder, while internal rotation is 7° greater in the non-throwing shoulder.[5] It can be suggested that these motion adaptations are likely the result of a combination of repetitive torque and velocity placed on the pitcher's shoulder during the pitching motion.

2.5. Mobility

Despite the shoulder needing mobility to create arm torque, it also needs to be stable to prevent subluxation of the joint. In the overhead population, the principle of combining an equal balance of mobility with stability is commonly referred to as the throwers' paradox.[5,6,10] The thrower's paradox can be compared to ''the 180° rule,'' meaning for each degree of internal rotation lost, a degree of external rotation must be gained, thereby maintaining an equal arc of total motion.[10,19]

Clinical measures of shoulder mobility have become important to screen and assess in the throwing shoulder to identify athletes at risk for shoulder injury.[19] Recently, new clinical measurement techniques have been described for determining scapular upward rotation and posterior shoulder tightness.[19] Scapular upward rotation is necessary during overhead activity to prevent impingement of the rotator cuff tendons between the greater tuberosity, acromion, and coracoacromial ligament.[5,6,10,19] In a study performed on professional baseball players (N=27,

$n_{pitchers}$= 20, $n_{position\ players}$= 7) with no previous medical history of a shoulder or elbow injury, researchers evaluated shoulder mobility differences between throwing and non-throwing arms.[19] First, the researchers used modified handheld digital inclinometers to measure four static positions of scapular upward rotation (60, 90, 120° and at rest).[19] Then, researchers measured posterior capsule tightness by placing the subject in a side-lying position with the arm placed in 90° of abduction at neutral humeral rotation.[19] The scapula of the test arm was stabilized in the fully retracted position with the primary tester passively lowering the humerus into horizontal adduction. Meanwhile, the second tester used a standard carpenter's square to measure the distance from the treatment table to the medial epicondyle to compare posterior shoulder capsule tightness.[19] Lastly, the researchers used standard goniometry to measure internal and external rotation bilaterally with the shoulder and elbow both positioned at 90°of flexion and abduction, while instructing the subjects to internally and externally rotate the shoulder.[19]

After collecting data, researchers used paired *t*-test's to evaluate scapular upward rotation and posterior capsule tightness measurements between the throwing and the nonthrowing shoulder. Lastly an independent *t*-test was conducted to compare the total arc of motion (ER + IR).[19] The researchers reported that scapular upward rotation was significantly greater in the throwing shoulder (14.2 ± 6.5°) than in the nonthrowing shoulder (10.6 ± 6.1°) at 90° of humeral elevation (P = .04).[19] The researchers also noted no statistically significant differences occurred in posterior shoulder tightness between the throwing (30.2 ± 4.6 cm) and the nonthrowing (28.0 ± 4.8 cm) shoulder (P= .09).[19] However, the throwing shoulder exhibited a statistically significant decrease in internal rotation (56.6 ± 12.5°) compared with the nonthrowing shoulder (68.6 ±12.6°) (P= .001), and an increased external rotation (throwing = 108.9 ± 9.0°, non-throwing = 101.9 ± 5.9°, P= .0014).[19] The analysis of the total arc of shoulder motion (IR + ER) revealed no statistically significant difference between sides (P=.15).[19] Thus, researchers concluded that regardless of external rotation gain or internal rotation loss, a total range of motion arc of approximately 170° is necessary to maintain normal kinematics. However, one limitation the researchers noted is using the digital-inclinometer measurement method only allows examiners to obtain two-dimensional static measurements.[19] Three-dimensional kinematic analysis would enable dynamic measurement of scapular anterior-posterior tilting and internal-external rotation. The use of three-dimensional analysis would provide researchers better descriptive and quantitative data of adaptive changes within the throwing shoulder.[19]

2.6. Throwing Mechanics

Proper throwing mechanics are an integral part of baseball to maximize peak performance, as well as decrease the risk of injury to the upper extremity. Pitching mechanics can be described as a coordinated sequence of body movements and muscular forces that have the ultimate goal of achieving high velocity and target accuracy.[20] To have an effective throwing motion, there needs to be a kinetic relationship between the upper and lower extremities to transfer strain potential energy with the purpose of creating maximal velocity during ball release.[20,21] One group of researchers described the kinetic relationship as "the linkage system is described as the sequential acceleration and deceleration of anatomical segments from the ground up with each transferring its energy to the more distal segment until the point of ball release."[2020] Due to the complexity of the throwing motion, clinicians should understand pitching biomechanics to maximize performance and minimize the risk of injury.

Biomechanics of the pitching motion can be broken down into six specific motions with each having equal importance for proper throwing kinematics. The six phases of pitching include the wind-up, stride (early cocking), late cocking, acceleration, deceleration, and followthrough.[20–22] During the wind-up phase, the primary objective is to place the pitcher in a proper starting position. The windup begins when the pitcher initiates the first motion and ends with maximum knee lift of the stride leg.[20–23] The pitcher typically begins with the weight evenly distributed on both feet, followed by pivoting the stance foot to a parallel position with the pitching rubber.[10,20,21]

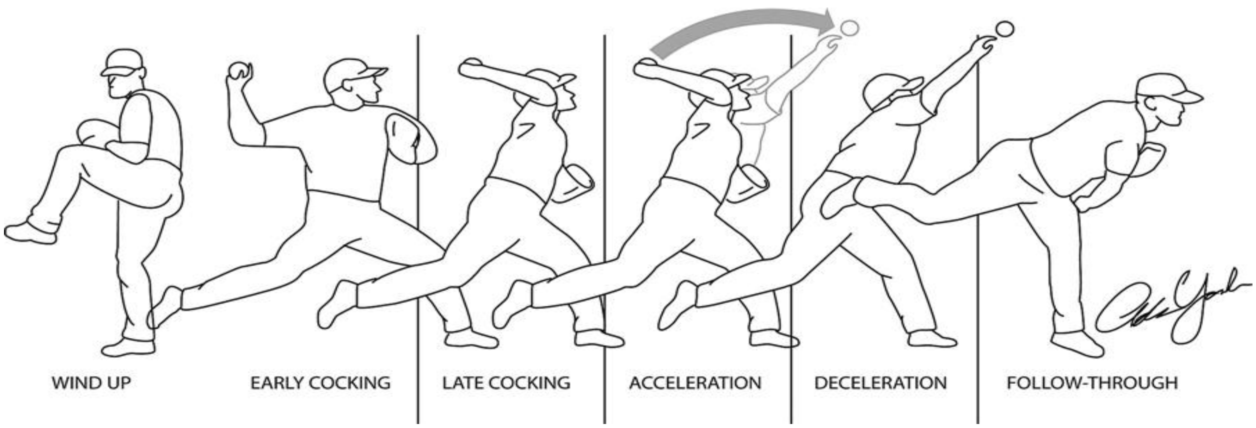

Figure 2.2. Phases of Throwing (Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. Sports Medicine. 1996 Jun 1;21(6):421-37.)

The wind-up phase is complete once the thrower's lead leg reaches maximal knee flexion, while simultaneously maintaining a stable base with the plant leg on the rubber of the mound.[20] It has been reported by several researchers[20, 24] that this segment is rather quick, where the thrower is only in this position for approximately 0.5 to 1.3 seconds, making it a low risk position for injury to occur. [20,24] However, in the final segment of the wind-up, the pitcher must maintain a balance point position where their shoulders should be aligned between home plate and second base with the hands together at chest height demonstrating a stable center of gravity (COG).[20,21] If the COG is positioned posteriorly or anteriorly, the body segment sequence timing and transfer of torque in the kinetic chain will be transferred to the upper extremity, thereby predisposing the shoulder and elbow to injury.[21,22]

During the wind-up phase, several variations can occur depending on the game scenario. If there is a baserunner, pitchers will often choose to start from a different throwing position known as the stretch.[20,23] In comparison to the wind-up position, the pitcher starts with his back foot parallel and against the rubber, front foot facing to home plate, and trunk facing perpendicular to the direction of the throw in the stretch position.[23] From this new starting position, the pitcher lifts his front leg, lengthens his stride, and separates while abducting both arms during the stride.[23] The main difference is that the pitcher will likely have an abbreviated leg lift, which may cause greater forces on the upper extremity, increasing injury risk.[21,22]

In a controlled laboratory study, researchers collected three-dimensional (3D) motion-analysis on professional baseball pitchers (N= 28, 22.1 ± 2.8 years) to compare injury risk between the wind-up and stretch positions. Researchers asked subjects to throw fastballs from both the wind-up and stretch positions in an indoor laboratory setting.[23] A three-dimensional motion analysis was used to measure and compare kinematic variables between position at lead-foot contact and temporal variables.[23] Each subject was instructed to pitch with maximum effort from the mound to a circular target zone placed behind home plate at a regulation distance of 18.4 m (60 feet, 6 inches). The researchers reported no differences between positions for ball velocity (P = .46), stride length (P = .68), lead-foot position (P = .98), shoulder external rotation (P = .15), or pelvis orientation (P = .32).[23] From these results, the researchers concluded the starting position has no significant effect on the forces placed on the upper extremity and should not change injury risk.[22,23]

Immediately following the wind-up phase comes the stride or late cocking phase. During the stride phase, a pitcher's main goal is to begin to generate initial linear force to lead into the early cocking phase.[20,25,26] The stride phase begins once the front leg that is facing the catcher reaches maximal knee flexion, while simultaneously removing the ball from the glove.[26–28] Once the front leg has reached maximum knee flexion, it strides forward towards the catcher creating an angular or linear force.[26] The linear force created during the stride phase accounts for roughly 50% of the total velocity created. Once the leg begins to stride forward, the pelvis begins to tilt and rotate to create mobility.[28] Simultaneously, the torso shifts to create torque through the kinetic chain.[26] At the same time that the lower extremity and torso are moving, the upper extremity begins to move with the deltoid. The deltoid creates abduction of the shoulder, while the rotator cuff muscles start to externally rotate the shoulder.[20,26] The stride phase is considered completed once the lead foot comes in contact with the ground.[10,20,26] A thorough understanding of the stride phase allows clinicians to critically analyze optimal stride phase mechanics to enhance performance and decrease injury risk.

Arguably the most important component of the stride phase is stride length distance. Evidence suggests that highly skilled baseball pitchers throw with stride lengths between 80-85% of their body height.[29] Several researchers have examined the correlation between stride length, injury risk, and ball velocity.[29,30] In an experimental observational study performed on healthy former competitive baseball players (M=18), researchers measured ground reaction forces of the stride leg to predict throwing velocity.[29] To collect data regarding ground reaction force, researchers placed 54 reflective three-dimensional markers on the subjects' body.[29] Then, two sensors were placed within the optimal landing zone of the stride leg to measure ground force reaction.[29] Next, the subjects were asked to throw seven sets of 15 pitches off the mound into a net that was placed 9 meters from the rubber.[29]

To calculate ball speed, the researchers measured peak wrist velocity from maximum external rotation of the shoulder until ball release using the three-dimensional sensors placed on the wrist and forearm.[29] Similar experiments have utilized radar gun speed analysis to determine ball velocity; however, the researchers of this study chose to use three-dimensional motion analysis because previous studies have validated its use to determine ball velocity.[29] Ground reaction forces were calculated with the assistance of a laboratory coordinate system.[29] During the stride of the throw, ground reaction force was calculated as the combined magnitude of the force vectors from each of the three force directions (vertical, anterior-posterior, and medial-lateral).[29] To calculate the correlation of stride length to ball velocity, researchers used several statistical analyses.[29] Peak medial force on the stride leg was correlated with peak wrist velocity using a Spearman's rank correlation.[29] Pearson product-moment correlations were performed between all other peak ground reaction force variables and peak wrist velocity.[29]

The researchers discovered that stride leg ground reaction forces during the arm-cocking and arm-acceleration phases were strongly correlated with ball velocity ($r^2 = 0.45$–0.61), whereas drive leg ground reaction forces showed no significant correlations.[29] The linear regression analysis performed by the researchers indicated peak stride leg ground reaction force during the arm cocking phase was the best predictor of ball velocity ($r^2 = 0.61$) among drive and stride leg ground reaction forces.[29] This study demonstrated the importance of ground reaction force development in pitching with stride leg forces being strongly predictive of ball velocity.[29] However, one limitation of this study was not all the participants were pitchers. This may have skewed some of the results because other position players will likely have different throwing mechanics than pitchers. Nevertheless, researchers presented promising evidence that a decrease in stride length is correlated to decreased ball velocity and increased stress on the upper extremity.

In a similar blinded randomized study, researchers examined changes in stride length of pitchers (N=19, $n_{collegiate}$=15, $n_{highschool}$=4) to determine correlations between stride length, velocity, accuracy, and throwing injuries.[30] Researchers assigned subjects into two groups with each subject throwing an 80-pitch simulated game with either a 25% increased or 25% decreased stride length.[30] After 72 hours, the researchers switched groups to the opposite starting test position.[30] Similar to the study performed by McNally et al., the researchers utilized three-dimensional analysis to analyze full body motion and throwing mechanics.[29,30] However, in contrast to the previous study, this study used an 8-camera motion capture system integrated with two force plates that were used in conjunction with a radar gun to track each throw.[30] The researchers then calculated segmental linear momentums in each plane of motion for the throwing arm and total body momentum.[30]

Researchers used Pearson product-moment correlations to examine the relationship between hallmark events (peak knee height, stride foot contact, maximal shoulder external rotation, ball release) and throwing phases (peak knee height to stride foot contact, stride foot contact to maximal shoulder external rotation, maximal external rotation to ball release).[30] Based off these calculations, hallmark events and phases identified significantly different linear movements ($P < .05$) as a result of manipulating stride length (25% decrease, 25% increase from normal stride length).[30] Pitchers with shorter strides generated lower forward momentum before stride foot contact, whereas greater upward and lateral momentum were more prominent during the acceleration phase.[30] The researchers noted that altering the transfer of energy from the distal extremities to upper extremities, resulting from manipulating stride length, appeared to influence the contribution of throwing arm momentum relative to the total body.[30] When there is an alteration in energy transfer, upper extremity joints become overwhelmed and are placed at an increased injury risk.[30] Based on the results of this study, the researchers concluded that shortened stride lengths increased the forward momentum of the throwing arm; therefore, sacrificing the potential health of the arm.

Following the stride phase is the late cocking phase, which begins when the lead stride foot makes contact with the ground and ends with maximum external rotation of the shoulder.[20,25,26,28]During the late cocking phase, the scapula is retracted and the rhomboids, levator scapulae, and trapezius muscles tilt the scapula and the rotator cuff muscles simultaneously abduct and externally rotate the humerus.[20,26,28] While the upper extremity is preparing to launch the ball forward, the lower extremity is maintaining a stable base and the pelvis is reaching its maximal rotation.[26] The late cocking phase is considered finished once an eccentric contraction of the internal rotators of the shoulder (latissimus dorsi, subscapularis, pectoralis major) ceases external rotation.[26] However, the transition of the late cocking phase to the acceleration phase is considered the most vulnerable phase for throwers due to increased risk of injury. [20,21,26,28] Injury risk increases due to high amounts of valgus torque on the elbow and compressive forces on the shoulder.[20,21,26] Limiting the excessive torques and forces on the shoulder during the late cocking phase is an important consideration for injury reduction in pitchers.

In a laboratory study performed on highly skilled adult baseball pitchers (N=26), researchers used motion analysis to determine the effects of throwing on the upper extremity. [27] The researchers attached reflective markers to both the upper and lower extremities to analyze body movement during the entire throwing motion.[27] The researchers used a radar gun to calculate ball speed as it left the pitchers hand.[27] To measure the effects of throwing on the upper extremity, the researchers used kinematic variables of angular displacement and velocity.[27]

Additionally, they performed calculations of kinematic values of joint force and torque at the glenohumeral and elbow joints.[27] Based off the data collected on each subject's three fastest pitches, the researchers reported large forces of internal rotation (67± 11N-m), anterior force (310 ± 100 N), shear force (250 ± 80 N-m) and compressive forces (480 ±130 N) on the glenohumeral joint between the late cocking and early acceleration phases.[27] The researchers also reported a maximum valgus torque on the elbow of 64 ± 12 N-m during both phases of throwing.[27] The researchers' analysis of the data revealed compressive and angular forces during the late cooking and early acceleration phases high enough to disrupt normal soft tissue physiology in both the elbow and shoulder. [27]

2.7. Bony Adaptations in the Overhead Athlete

Both clinicians and researchers once believed that thickening and stiffening in the posterior shoulder in baseball athletes altered glenohumeral arthrokinematics and range of motion. Takenaga et al examined thickness and elasticity of the posterior capsule (PC) and posteroinferior capsule (PIC) in male college baseball players (N=45). To examine the thickness and elasticity of the capsules, measurements were taken with participants seated upright in a chair with their shoulders in a neutral position, arms at their sides, and with no shoulder abduction and adduction.[31]A single orthopedic surgeon carried out all ultrasound measurements using diagnostic ultrasound (SuperSonic Imagine). This device was equipped with shearwave elastographic technology, which enabled the researchers to measure tissue elasticity quantitatively without probe compression.[31] Additionally, the researchers measured glenohumeral internal rotation and external rotation at 90° of shoulder abduction using a goniometer with participants in a supine position.[31] Researchers reported the posterior and posteroinferior capsules were stiffer, as well as thicker in the throwing shoulder (PCT:

M=1.34mm, PC elasticity: M=40.0 kPa, PICT: M=1.40 mm, PIC elasticity: M=39.4 kPa P=.001) compared with the non-throwing shoulder (PCT M=1.04 mm PC elasticity: M=32.2 kPa, PIC: 1.04 mm PIC elasticity: 31.6 kPa, P=.001).[31] It was also noted that posterior capsule elasticity appeared to have a greater effect on GIRD than did posterior capsule thickness (PC elasticity: r= 0.46 [P = .0015] and 0.48 [P=.001]), (difference in PC thickness: r = –0.13 [P = .38] and 0.17 [P = .28]) [31]

A similar experimental design was also performed where researchers analyzed the relationships between PC thickness (PCT) and glenohumeral range of motion (ROM) in horizontal adduction (HAdd) and internal rotation (IR) in college baseball players (N=33).[32]

The study utilized diagnostic ultrasound to measure PCT by placing the transducer on the posteromedial aspect of the scapula. The transducer was moved superior and laterally to visualize the posterior capsule. [32] The posterior capsule was defined as the tissue found immediately lateral to the glenoid labrum between the humeral head and rotator cuff.[32] Once the capsule was identified, the image was paused and PCT was measured using the computer software.[32] The researchers concluded there was no correlation between PC thickness and HAdd ROM (r = 0.156, p = 0.343), but PC thickness was significantly correlated with IR ROM (r = −0.351, p = 0.028). [32] Therefore, the researchers concluded that the throwing shoulder of baseball players demonstrated greater IR ROM deficits that is most likely induced by posterior shoulder tightness.[32] These results and the results from similar studies have attributed loss of range of motion solely to the thickening and hypertrophy of the posterior capsular structures, without investigating other possible adaptations to the throwing shoulder.

In contrast, there have been several recent studies that have attributed humeral retroversion (HR) and osseous adaptations to the loss of ROM at the shoulder.[33–35] Humeral retroversion is defined as the rotational difference in the relative position of the humeral head and the axis of the elbow at the distal humerus.[33,34] These anatomical adaptations are caused by the stressors that are placed on the shoulder from repetitive overhead motions that occur prior to the athlete becoming skeletally mature.[34] As Wolff's Law states, bone growth is influenced by applied mechanical forces either through muscular forces or external stress.[33,34] When humans develop from birth, there is a natural de-rotation of the humerus from a retroverted position to a more anteverted position. One group of researchers reported that approximately 80% of the humeral de-rotation process is completed by the age of 8 years.[33] However, the de-rotation process can be altered if excessive throwing occurs before the growth plate is closed, thereby leading to a decrease in humeral anteversion, thus causing an increase in retroversion in the dominant shoulder.[33–35] During the throwing motion, baseball athletes have the ability to generate humeral angular velocities of up to 7,000 deg/sec and torques that exceed 14,000 inch-pounds, placing a proximal force on the humerus often reaching over 100% of the athlete's body weight, ultimately making pitching one of the fastest and most violent movements of the human body.[4,22] Consequently, the repetitive stressors applied on the proximal portion of the humeral head lead to osseous adaptations, creating a larger angle of retroversion and creating a shift in glenohumeral range of motion in the dominant arm.

Often, there is an observed shift in available end range of motion from the direction of decreased internal rotation to increased external rotation once accounting for humeral retroversion (HR).[34] Reuther et al.[34] evaluated major and minor league professional baseball players (N=30) for HR, PC thickness, and glenohumeral IR and ER in the dominant and non-dominant shoulders of each subject using diagnostic ultrasound and a digital inclinometer for HR measurements. [35] HR was measured by placing the subject supine with 90° of shoulder abduction and elbow flexion, while the researcher positioned the transducer on the anterior shoulder, perpendicular to the long axis of the humerus in the frontal plane.[35] The same researcher manually rotated the humerus so the bicipital groove was centered on the ultrasound image. Lastly, a second researcher placed a digital inclinometer on the ulnar side of the forearm to record the forearm inclination angle, which defines the amount of HR present.[35] Internal and external range of motion was measured using a digital inclinometer with the subject positioned supine in 90° of shoulder abduction and flexion in conjunction with 90° of elbow flexion.[35] Then, the forearm was rotated for IR and ER with the scapula stabilized so that all motion was coming from the glenohumeral joint.[35] All of the athletes examined had no previous history of any shoulder or elbow surgical procedures that may have altered ROM.[35] Researchers performing this study reported that the dominant arm had significantly more HR ($M_{Dominant}$= – 10.9° ± 11.1°, $M_{Non\text{-}dominant}$= – 28.3° ± 10.6°, P = .0001), ER ($M_{Dominant}$=98.5° ± 8.6°, $M_{Non\text{-}dominant}$=96.2° ± 7.1°, P = .0001), and PC thickness ($M_{Dominant}$=0.22 ± 0.04 mm, $M_{Non\text{-}Dominant}$=0.18 ± 0.03 mm, P = .001) than the non-dominant arm.[35] The dominant arm had significantly less IR ($M_{Dominant}$=49.6° ± 7.9°, $M_{Non\text{-}dominant}$=60.7° ± 9.3° , P = .01) and total ROM than the non-dominant arm ($M_{Dominant}$ =148.1° ± 9.9°, $M_{Non\text{-}dominant}$=156.9° ± 9.1°, P = .0001). The HR-corrected GIRD and external rotation gain (ERG) were significantly different than non-corrected GIRD and ERG, respectively (–11.1° ± 9.1° for non-corrected GIRD vs 6.4° ± 9.0° for corrected GIRD, P = .0001; and 2.3° ± 6.7° for non-corrected ERG vs –15.2° ± 9.1° for corrected ERG, P = .0001).[35] The TM difference was significantly correlated with HR-corrected GIRD (0.477, P = .01) and ERG (0.457, P = .01).[35] The results indicated changes in shoulder ROM can often be accounted for by correcting IR and ER motion with HR, rather than the thickening of the PC.[35] It also leads to the question of when HR is accounted for, what soft tissue structure is causing this loss of ROM? Currently, there was very limited research found on what is causing the loss of IR, but some experts hypothesized that the loss of ER-gain may be caused by tight internal rotator musculature such as the latissimus dorsi.[33–35] However, there is currently limited research regarding this hypothesis, thus creating a need to examine what structures are limiting range of motion at the shoulder.

The bony adaptations that occur in the shoulder are an area of examination of the shoulder that can often be overlooked. Clinicians who work in the overhead athlete population need to be aware of these adaptations occurring and be able to understand how bony adaptations can contribute to changes in range of motion at the shoulder joint. Understanding these adaptations will provide clinicians with a better understanding on how to care for and treat overhead athletes that are presenting with a decrease in range of motion at the shoulder.

2.8. Diagnostic Ultrasound

2.8.1. Introduction

In recent history, diagnostic ultrasound has been recognized as an effective imaging technique that can be used to evaluate both bony and soft tissue structures around the shoulder joint.[37] It has been shown to be useful in a wide range of rotator cuff diseases, as well as non-rotator cuff abnormalities.[33-37] Shoulder ultrasound has several advantages: it is a relatively cheap and widely available technique, free from ionizing radiation, and can reach excellent diagnostic accuracy when compared to magnetic resonance imaging.[37] Moreover, it is the only imaging technique that allows dynamic evaluation of musculoskeletal structures, which is important for the evaluation of impingement.[37] Also, due to the shoulder's superficial anatomical position, ultrasound can also be helpful in guiding interventional percutaneous procedures, both for diagnostic and therapeutic purposes.[37]

Specifically, when examining the shoulder to measure humeral retroversion (HR) it is necessary to have an understanding of the bony anatomy and the procedures for identifying the bicep tendon. When looking the long head of the bicep tendon on ultrasound, the structures that need to be identified on the monitor are the long head of the biceps tendon, as well as the greater and lesser tuberosity.[37] The greater and lesser tuberosities are located on the sides of the bicipital groove and are very hyperechoic in color.[37] The bicep tendon lies between these two bony landmarks and is also hyperechoic in color.[37]

2.8.2. Application of Ultrasound

There are many components that contribute to the evaluation of a shoulder when using diagnostic ultrasound. The first component is choosing a correct sized transducer head for the depth of sonographic penetration to view the structures below the skins surface. [37,38] A clinician will choose diagnostic ultrasound transducers based on the depth of the structures that they would like to view, whether it's a bony structure or a soft tissue structure.[37] When selecting a transducer frequency to use, frequencies that are higher than 10 mHz cannot penetrate deep into the tissues. However, they can provide greater resolution and structural view for superficial structures, such as some bony areas in the hands or feet.[38] The next frequency that clinicians can use is a medium frequencies, which should be used for viewing deeper structures on smaller body parts.[37,38] However, it is important to note that as clinicians go to lower frequencies, there can be some loss of clarity of the images created by the ultrasound.[37] When using diagnostic ultrasound to examine the shoulder, it is likely that for most of the examination of the shoulder the clinician will be using a medium frequency to identify structures and landmarks in the shoulder.[35,38] The lowest ultrasound frequencies can be used to assess deeper structures. While examining structures of the hip or shoulder, the low frequency settings may be useful to see the integrity of some intraarticular structures like a labrum.[37,38] Choosing the highest frequency transducer possible is important in creating the clearest resolution image, thus providing the most accurate diagnosis. However, sometimes it is still necessary to choose a lower frequency because the deeper structures that are within several joints in the body are not able to be viewed with the higher transducer frequencies.[37] With diagnostic ultrasound being a dynamic point of care diagnostic modality, this allows the clinician to not have transducer fixed in one location which allows the clinician to move it around to find the image with the best possible resolution. With other diagnostic tests, such as magnetic resonance imaging and computed tomography scans or x-rays, the images are created with static motions.[38] For the best outcomes for the use of diagnostic ultrasound, the clinician performing the evaluation must have a great deal of knowledge of anatomy and the appearance of normal and abnormal musculoskeletal tissues when performing the ultrasound examination. [17,35,38]

2.8.3. How Diagnostic Ultrasound Works

In diagnostic ultrasound short pulses of electrical signals are converted to ultrasonic energy through a piezoelectric crystal that is in the ultrasound transducer head.[37] The image that is created on the ultrasound screen occurs by the ultrasound machine first sending signals to the transducer which then produces sound waves.[37] After this, the combination of the soft tissues structures and the ultrasound gel allows transmission of sound waves into the tissues that are being examined.[37] The interaction of sound waves with the soft tissue structures below are converted into an electrical current which produces and ultrasound images, which are then projected on the ultrasound screen.[37]

During ultrasound examination, one of the most important factors to ensure a clear image on the ultrasound is the frequency of the of the transducer that is being used. As mentioned previously, there are various ultrasound transducers that produce different frequencies which can be used on different structures depending on the depth of the structure needing to be examined. In terms of the ultrasonic waves, and the passage of waves through the tissue leads to refraction, reflection, scattering and absorption of energy; this is what essentially creates the image of the structures being examined.[37] Refraction, reflection, scattering, and absorption are created because human tissues are not homogeneous when it comes to ultrasonic waves being transmitted through human tissues.[37] A gel medium must also be used with the transducer to allow the passage of the sound waves to the soft tissues in the most accurate manner.

When ultrasonic waves produce waves into a structure, the amount of energy that is reflected determines how bright a structure appears visually on the screen. At in interface between tissues where there is a large difference in impedance, the sound beam is strongly reflected, and it produces a bright echo on the image know as hyperechoic.[37] An area on an image that has no echo and is black in color is called anechoic.[37] An area that has a weak and low echo is called hypoechoic.[37] When an area on the image is termed isoechoic is when there is equal echogenicity in the adjacent soft tissue structures.

When performing an ultrasound assessment, there are two different imaging techniques that the ultrasound transducer should be placed in. The two different views are called longitudinal axis view and short axis view.[37,39] The long axis view (LAX) allows for the clinician to see the overall appearance of the structure that is being examined. In LAX the transducer is parallel to the structure/target tissue.[37] When using the short axis view (SAX), clinicians are able to see the more fine structures of the examination that may not be visible through just examining in long axis view, because the transducer is perpendicular to the target structures, thus creating a transverse view of the structures.[37] Another important aspect of the ultrasound examination is making sure that the clinician has proper positioning of the transducer head. The clinician should hold the transducer with their dominant hand, and make sure that the transducer is being held between their thumb and forefinger.[37] The transducer should be stabilized by either a few fingers or heel of the imaging hand to maintain proper contact with the skin and placed perpendicular (SAX) or horizontal (LAX) to the fibers .[37]

2.8.4. Ultrasound Examination of Humeral Retroversion

When clinicians first began examining humeral retroversion, they started examining the humerus using CT scans. It was not until recently that researchers determined that the use of diagnostic ultrasound could be a safe and cost-effective way to take these measurements. In a cross-sectional cohort study performed by Greenberg et al.[38], researchers examined the effects of humeral retrotorsion on pitching velocity in youth baseball athletes (ages 8-14 years old). All the subjects in this study were playing baseball currently and were pitchers or had experience with pitching at the youth level of baseball.[38] Participants in this study were excluded if they had any current shoulder pathology or if they had a history of an humerus fractures or had joint hypermobility present in their shoulder.[38] For this study, researchers measured passive glenohumeral rotation at 90 degrees of abduction, moving the arm through both internal and external rotation of the joint.[38] To take these measurements a digital inclinometer was placed along the ulnar aspect of the forearm to obtain range of motion measurments.[38] This measurement method had great inter and intra rater reliability with ICC values >0.90 and a standard error of measurement value of 1.5 degrees to 2.6 degrees.[38] This method consisted of one researcher placing a transducer perpendicular to the long axis of the humerus, while the second examiner rotated the humerus so that the bicipital groove could be visualized directly with the apexes of the greater and lesser tubercles parallel to the horizontal plane.[38] This second examiner then placed a digital inclinometer against the ulna and the forearm inclination angle relative to the horizontal plane was recorded.[38] The measurement that was taken represented the difference between the proximal segment and distal segment of the humerus, giving the researchers the degree of humeral retrotorsion.[38] This study provides a basis for how clinicians can use diagnostic ultrasound to accurately assess humeral retroversion. By assessing retroversion, clinicians are able to more accurately collect values of internal and external rotation. When a clinician solely uses a goniometer, they cannot account for humeral retroversion and may not be accurately assessing ROM. More accurate measurement collection will provide clinicians with values that they can use to correct range of motion deficiencies if any are present.

2.8.5. Conclusion

Diagnostic ultrasound can be a beneficial tool for identifying different musculoskeletal conditions, as well as assisting in the measurement of shoulder range of motion measurements.[33-38] It is imperative that the clinician performing the ultrasound evaluation has experience with diagnostic ultrasound so that there are no conditions that are missed during the evaluation. Further research should be performed using diagnostic ultrasound as an objective measurement to determine its uses in preventative care for taking objective measurements of range of motion or angles of humeral torsion.

3. METHODOLOGY

3.1. Purpose of the Study

In overhead sports like baseball understanding proper arthrokinematics of the shoulder is essential to preventing and treating shoulder injuries.28 Based on prior research, using diagnostic ultrasound in conjunction with a handheld dynamometer has been named the gold standard to have accurate measures of ROM collection.34-37 Previous research has been conducted to determine the effects of bony adaptations on the shoulder in overhead athletes.34-37

The purpose of this study is to investigate the relationship between corrected shoulder rotational range of motion (external rotation, internal rotation, and total rotation) and the total FAST patient reported outcome subscale for pitchers. Furthermore, a secondary analysis of the rotational range of motion values at a Midwest Division I baseball university once humeral retroversion is accounted for using diagnostic ultrasound. Lastly, an analysis of each specific of the FAST subscale will be performed to determine any relationships between shoulder rotational deficits that could provide valuable data for shoulder examination for sports medicine professionals.

Q1: Is there a correlation between shoulder rotational range of motion after bony adaptations are accounted for and the total FAST pitcher’s subscale score?

HYPOTHESIS: If there is a total subscale score greater than 10 then there will be a decrease in ER once HR is accounted for.

Q2: What specific questions on the FAST pitcher’s subscale can help sports medicine professionals predict the chance of rotational deficiencies in the throwing shoulder?

HYPOTHESIS: If pitchers report that they are moderately affected by a decrease in velocity or feel that they have a decrease in feel of pitches being thrown, then there will be a rotational deficit present in the dominant shoulder.

Q3: Are pitchers with more years of college baseball more likely to see changes in total rotational range of motion once humeral retroversion than pitchers with less years of college baseball?

HYPOTHESIS: If pitchers have more years of college baseball experience, then they are more likely to have a total rotational deficit.

3.2. Participants

A convenience sample of 19 NCAA Division 1 baseball pitchers at one institution was recruited through convenience sampling. Exclusion criteria consisted of any current upper extremity musculoskeletal conditions that were diagnosed by a physician, which may impede an accurate shoulder range of motion test. Participants were compensated with ten dollars after completion of the study. Informed verbal and written consent were obtained from each subject before enrollment. Clinical and baseline demographic data were collected by a participant demographic form.

3.3. Equipment and Instruments

3.3.1. Diagnostic Ultrasound

A Terason uSmart 3300 MSK ultrasound machine (Burlington, MA, USA) was used to identify the subject's bony anatomy of the shoulder. The unit is equipped with shoulder examination shoulder imaging programs that will allow for researchers to identify the bicipital groove and use that anatomical landmark to calculate the amount of humeral retroversion present in the subject's shoulder. The software on the machine can allow the researcher to freeze the picture on the screen as well use a grid to provide accurate measurements of retroversion angle at the shoulder.

3.3.2. Handheld Inclinometer

A digital handheld inclinometer was used to measure both the angle of humeral retroversion, as well as internal and external range of motion measurements at the shoulder to provide an overall value to total rotation. The digital inclinometer is a highly accurate tool that will provide the researchers will be easy to read measurements versus a goniometer that is subject to low interrater reliability and is less likely to yield accurate measurements. Previous studies using this technique to measure rotational motion at the shoulder have yielded results of moderate to excellent interrater ($ICC_{2,3}$ = 0.50-0.95) and intrarater ($ICC_{2,3}$ = 0.74-0.94) reliability.[43]

3.3.3. Functional Arm Scale for Throwers (FAST)

The FAST patient reported outcome scale was created by Sauers et al.[40], to provide an upper extremity region specific patient reported outcome scale that accounts for the demands that overhead throwing athletes go through, as well as their overall health related quality of life regarding their shoulder.[40,41] The FAST scale is a 22-question questionnaire that asks questions ranging from how their shoulder effects their baseball performance to how it affects their everyday life with activities that are outside of sport.[40-41] It provides the researchers and clinicians with more data on how the patient perceives their shoulder function outside of the objective data that is taken during a physical examination, thus providing a clearer picture into the overall health of the subject or patient.[40-41] The researchers that developed this patient reported outcome assessment had very good reliability and validity scores of an ICC , 0.91-0.98 respectively.[41] In a study performed by Croci et al.[43], researchers in this study used the FAST to determine the effect of sport specialization on subjective throwing function.[43] This study found that college baseball players that were highly specialized in baseball by the age of 13 years reported worse subjective throwing arm function on the FAST questionnaire and were over 5 times more likely to have a history of shoulder injury than college baseball players that reported moderate or low specialization by 13 years. [44] A similar study performed by Huxel et al.[44] also used the FAST to examine if the FAST could differentiate healthy baseball players with no throwing issues.[45] This research group found Mean FAST scores for current upper extremity (UE) injury (n = 142) and currently healthy (n = 415) throwers were 33.5 ± 18.5 and 7.3 ± 10.4, respectively.[44] They also found mean FAST Pitchers subscale scores for current UE injury (n = 62) and currently healthy (n = 163) pitchers were 52.8 ± 35.0 and 7.2 ± 14.2, respectively.[45] Huxel et al. reported an ICC of 0.91, 95% C.I. P <.001, and reported that a FAST pitchers score of 10.0 is 87% sensitive and 78% specific for predicting injury status.[44] The researchers suggest that a FAST pitchers score above 10.0 total points means that there is an increase the likelihood that a player has UE injury that is affecting their overall shoulder health quality of life.[44]

However, because this study is using solely baseball pitchers, only the 9-question pitcher-specific subscale questionnaire will be used.[40-41] Sauers et al.[41] also found this subscale to be 87% sensitive and 78% specific for predicting shoulder injury.[40-41] While the subscale was developed with 9 questions, our study only used 7 of the questions because the two of the questions are not applicable to the study's research questions (Appendix 2). The subjects were given the FAST, and answered questions based off a 1 to 5 Likert scale, with 1 representing that they are not affected and 5 being that they are severely affected.[40-41] Although researchers looked at the values on each individual question on the FAST, a total FAST score was calculated as well, with the minimum score that could be calculated being a 7 and the highest score being a 35.

The higher the score on the questionnaire, the greater the subject is affected. For this study, the questionnaire was filled out online using a website called "Ortho Toolkit", which provides pdf copies of the subjects scores, and made it easier for the researchers to perform statistical analysis of the FAST.

3.4. Procedures

Prior to the start of data collection, the study was approved by the North Dakota State University Institutional Review Board. The recruitment of the subjects was from the institution's baseball program through a volunteer basis. When subjects arrived at the site of data collection, subjects were given an informed consent form to read and sign. The researcher of this study was available prior to the data collection to answer any questions subjects may have regarding the study. After giving informed consent, subjects were asked to fill out a demographic questionnaire to collect information such as age, gender, years of playing baseball, and their throwing arm. (Appendix 1) The demographic information provided by the subjects was used during data analysis. After filling out the demographic form, the research team measured both height (cm) and mass (kg). Finally, the subjects were asked to fill out a modified FAST throwers scale (Appendix 2) which was also be used during the statistical analysis of the study.

Once the paperwork was completed, subjects were asked to remove articles of clothing that may hinder obtaining measurements from their upper extremities, and then lay supine on the exam table. The researcher first measured humeral retroversion by having the subject lay supine on a treatment table. The subject's arm was actively be placed at 90 degrees of humeral abduction and 90 degrees of elbow flexion. One examiner placed the ultrasound probe on the anterior aspect of the subject's shoulder. The examiner using the ultrasound machine then identified the bicipital groove using a short axis view technique. Once the bicipital groove was identified, the researcher used the grid mode to align the greater tuberosity in line with the horizontal grid line on the ultrasound screen. While this was being performed a second examiner measured the vertical and horizontal distance on the patient's forearm and mark the middle point, to create a landmark where the inclinometer was placed for accurate measurements. The examiner that is holding the inclinometer then rotated the subject's arm into external rotation until the examiner performing the ultrasound exam observed that the bicipital groove is pointed vertically on the ultrasound screen, and that the greater and lesser tuberosities were in line with the horizontal grid. The second examiner then used the digital inclinometer that was along the shaft of the ulna to note the degree of rotation, which provided researchers with the angle of humeral retroversion. Following taking measurements of the dominant side, the researchers took measurements bilaterally for all patients using the same ultrasound method as used for the dominant arm.

Next, passive internal and external rotation measurements was recorded with the subject in the supine position and the glenohumeral joint in 90 degrees of abduction. The scapula was then stabilized by the tester's hand, and the arm was rotated until scapular motion was detected by one of the researchers. Scapular motion being detected is defined as the moment when the subject's scapula begins to lift off the exam table during range of motion measurements. A second researcher then placed a inclinometer on the shaft of the ulna, and the inclinometer was zeroed out. This measurement was repeated three times, and the mean of the three measurements was recorded for analysis. Glenohumeral range of motion techniques were performed bilaterally.

The data from each session was saved with a deidentified number in the system. For each session, the following values were recorded: humeral retroversion angle, external rotation degrees for the right arm, external rotation degrees for the left arm, internal rotation degrees for the right arm and internal rotation degrees for the left arm. Finally, participants received ten dollars as compensation for their cooperation in the study. If subjects were not able to be passively moved through the shoulder motions due to instability or pain, their failure was documented, and they were still compensated for their participation.

3.5. Statistical Analysis

Throughout the data collection process, all values collected were recorded and stored on a secure excel sheet. HR, ER, and IR were all measured bilaterally three times and an average was calculated for each measurement. Total rotation was calculated using the formula of IR Average + ER Average. Because a goal of this study is to examine the bony adaptions on rotational motion, ER (Average ER – HR angle), IR (Average IR + HR angle) and total rotation (HR corrected ER + HR corrected IR) were also calculated. All additional statistical analyses were conducted using Excel. A regression was performed to determine if there is a relationship between shoulder rotational ROM after bony adaptations are accounted for and the total FAST scale scores. A second correlation was performed to determine what specific questions on the FAST scale may have a relationship with rotational deficiencies in the shoulder after accounting for bony adaptations. Lastly, a final correlation was performed to examine if there are any relationship between years playing college baseball and total corrected range of motion after HR is accounted for in the analysis.

3.6. Conclusion

The purpose of this study is to investigate the relationship between rotational motion at the shoulder while accounting for bony adaptations and the FAST subscale for pitchers. No published studies could be found that compare relationships between objective shoulder range of motion measurements and the throwing athlete's perception of their shoulder function during throwing. Since preventing and correcting athletes' rotational motion dysfunctions is a critical skill to preventing shoulder injuries from occurring in baseball, every effort must be taken to help prevent these injuries from occurring. Thus, it is imperative to investigate any relationships between, rotational range of motion values after accounting for bony adaptions, the FAST pitcher's subscale and any demographics that may help clinicians better prevent injuries to the throwing shoulder.

4. MANUSCRIPT

4.1. Introduction

The act of throwing a baseball is a physically demanding motion that requires detailed coordination of muscles, joints, and places high loads of stress throughout the body.[3,4,28] Baseball pitchers tend to suffer from a high amount of throwing injuries, and their injury rate seems to continue to rise as time goes on.[28] Pitchers may throw more than 400 pitches in a season, which ultimately can lead to an increased injury risk due to the compound exposure of high velocity throwing, which is one of the fastest recorded movements.[28,30] The high velocities are combined with the accelerations and decelerations of the arm during the throwing motion every time a ball is thrown.[28]

In overhead sports like baseball understanding proper arthrokinematics of the shoulder is essential to preventing and treating shoulder injuries.[28] Based on prior research, using diagnostic ultrasound in conjunction with a handheld dynamometer has been named the gold standard to have accurate measures of ROM collection.[34-37] Previous research has been conducted to determine the effects of bony adaptations on the shoulder in overhead athletes.[34-37]

There are many factors outside of structural and objective measurements that factor into the overall performance and health of the baseball athlete. For example, although the biomechanics of the throwing motion is very important, how the pitcher feels while throwing is another factor that can affect his health and performance.[28,40] Pitchers have specific throwing motions that are unique for each individual, and they also have a specific "feel" for how each type of pitch is thrown.[28, 40] One tool that has been validated in the literature to evaluate the pitcher's reported feel outcome is The Functional Arm Scale for Throwers (FAST). This qualitative tool has been used by clinicians in both preventive medicine and rehabilitation settings to provide objective data.[40]

The purpose of this study is to investigate the relationship between corrected shoulder rotational range of motion (external rotation, internal rotation, and total rotation) and the total FAST patient reported outcome subscale for pitchers. Furthermore, a secondary analysis of the rotational range of motion values at a Midwest Division I baseball university once humeral retroversion is accounted for using diagnostic ultrasound. Lastly, an analysis of each specific question of the FAST subscale will be performed to determine any relationships between shoulder rotational deficits that could provide valuable data for shoulder examination for sports medicine professionals. The following is a list of the specific research questions and hypotheses that were examined in this study.

Q1: Is there a correlation between shoulder rotational range of motion after bony adaptations are accounted for and the total FAST pitcher's subscale score?

HYPOTHESIS: If there is a total subscale score greater than 10 then there will be a decrease in ER once HR is accounted for.

Q2: What specific questions on the FAST pitcher's subscale can help sports medicine professionals predict the chance of rotational deficiencies in the throwing shoulder?

HYPOTHESIS: If pitchers report that they are moderately affected by a decrease in velocity or feel that they have a decrease in feel of pitches being thrown, then there will be a rotational deficit present in the dominant shoulder.

Q3: Are pitchers with more years of college baseball more likely to see changes in total rotational range of motion once humeral retroversion than pitchers with less years of college baseball?

HYPOTHESIS: If pitchers have more years of college baseball experience, then they are more likely to have a total rotational deficit.

4.2. Methods/Materials

4.2.1. Study Population

Nineteen male NCAA Division I collegiate baseball pitchers were recruited to participate in the study. The sample was one of convenience, and all pitchers were members of the same baseball team. Exclusion criteria consisted of any current upper extremity musculoskeletal conditions that were diagnosed by a physician, which may impede an accurate shoulder range of motion test. The mean reported age was 21.21 ± 1.58 years old. The mean height and mass measured was 187.55 ± 5.55 cm, and 95.62 ± 9.97 kg, respectively. The sample contained both right-handed pitchers (n=13) and left-handed pitchers (n=6), all of which were participating in the baseball season. Participant's average years of collegiate baseball experience was 3.26 ± 1.52 years. All participants reported that they throw a fastball as a primary pitch. Ninety-five percent of participants reported that they throw a change-up, while 58% reported they throw a curveball, and 53% reported they throw a change-up. Complete demographic information values are reported in Table 4.1. The North Dakota State University Institutional Review Board approved the study, and all participants provided written informed consent.

Table 4.1. Demographics

Category	Mean ± SD
Age	21.21 ± 1.58 years
Right Arm Pitchers	68.4% (N=13)
Left Arm Pitchers	31.57% (N=6)
Height	187.55 ± 5.55cm
Weight	95.62 ± 9.67 kg
BMI	27.17 ± 2.38
Years of College Baseball	3.26 ± 1.52 years
Fastball	100% of participants
Curveball	58% of participants
Changeup	95% of participants
Slider	53% of participants
Number of Types of Pitches	3.05 ± 1.25

4.2.2. Methods

Subjects were asked to fill out a demographic questionnaire to collect information such as age, years of playing collegiate baseball, and throwing arm. After filling out the demographic form, the researchers measured both height (cm) and mass (kg). Finally, the subjects were asked to complete a modified FAST throwers scale. The modified FAST score consisted of 7 questions, that participants each used a Likert type scale to answer for each question. The Likert scale started with a 1 being not affected at all, to a 5 being unable to perform. The individual questions are combined to create a sum total FAST pitchers score. The highest possible score a participant could achieve is a 35 and the lowest they could achieve is a 7. The lower the total score means the less they are affected and the higher the total score means they are affected more.

Humeral retroversion was measured with the subject's lying supine on a treatment table. The subject's arm was placed at 90 degrees of humeral abduction and 90 degrees of elbow flexion. One examiner placed the ultrasound (Terason uSmart 3300 MSK ultrasound machine Burlington, MA, USA) probe on the anterior aspect of the subject's shoulder and identified the bicipital groove using a short axis view technique. Once the bicipital groove was identified, the grid mode was used to align the greater tuberosity with the horizontal grid line on the ultrasound screen. While this was performed a second examiner measured the vertical and horizontal distance on the patient's forearm and marked the mid-point, to create a landmark where the inclinometer was placed for measurement. The subject's arm was rotated into external rotation until the examiner performing the ultrasound exam observed that the bicipital groove was pointed vertically on the ultrasound screen, and that the greater and lesser tuberosities were in line with the horizontal grid. The second examiner then used the digital inclinometer to measure the degree of rotation, which provided researchers with the angle of humeral retroversion. Following taking measurements of the dominant side, the researchers then took measurements contralaterally for all subjects using the same methods.

Next, passive internal and external rotation range of motion measurements were recorded with the subject in the supine position and the glenohumeral joint in 90 degrees of abduction. The subject's scapula was stabilized, and the shoulder rotated until scapular motion was detected. Scapular motion being detected was defined as the moment when the subject's scapula began to lift off the exam table. The second examiner placed the inclinometer on the shaft of the ulna to measure the rotational range of motion. This measurement was repeated three times, and the mean of the three measurements was recorded for analysis. These methods were repeated on the contralateral side.

4.2.3. Data Analysis

Throughout the data collection process, HR, ER, and IR were measured bilaterally three times and an average was calculated for each measurement. Total rotational range of motion was calculated using the formula of IR Average + ER Average. Because a goal of this study was to examine the bony adaptions on rotational motion, ER (Average ER – HR angle), IR (Average IR + HR angle) and total rotational range of motion (HR corrected ER + HR corrected IR) were also calculated. All additional statistical analyses were performed using Excel. Regression was performed to determine the relationship between total shoulder ROM, ER, and IR after bony adaptations are accounted for and the total FAST scale scores. A second regression was performed to determine the relationship of individual questions on the FAST scale to rotational ROM of the shoulder after accounting for bony adaptations. Lastly, a regression analysis was performed to examine the relationship between years playing college baseball and total corrected rotational ROM.

4.3. Results

4.3.1. FAST Scores

After examining the modified 7 question FAST pitchers' subscale (Table 4.2), the average total FAST score for participants was 13.37 ± 4.80 points and the mode was 20 points. The highest average scores for each individual question on the FAST were questions number 2 (Mean= 2.11 ± 0.99 points, Mode= 2), and question 4 (Mean=2.26 ± 1.15 points, Mode= 1).

Table 4.2. Individual and Total FAST Scores

Question Number	Mean ± SD	Mode
1	2.05 ± 0.71	2
2	2.11 ± 0.99	2
3	1.74 ± 1.10	1
4	2.26 ± 1.15	1
5	1.42 ± 0.51	1
6	1.79 ± 0.98	1
7	2.00 ± 1.05	2
Total Score	13.37 ± 4.80	20

4.3.2. Humeral Retroversion and Corrected Rotational Range of Motion

The average humeral retroversion value of the throwing arm was 11.62° ± 1.86°, while the average humeral retroversion angle of the non-throwing arm was 3.96° ± 0.96°. When compared bilaterally, the average external rotation of the throwing arm (98.42° ± 6.42°) was greater than the non-throwing arm (87.79° ± 6.86°). However, average throwing arm internal rotation (50.75° ± 5.73°) was less than the average non-throwing shoulder internal rotation values (53.96° ± 8.88°). The total average rotational range of motion value was greater on the throwing shoulder (149.18° ± 9.98°) than the non-throwing shoulder (141.35° ± 10.97°). After correcting for humeral retroversion values, the average corrected external rotation of the throwing arm (86.80° ± 5.54°) was greater than the non-throwing arm (83.82° ± 6.72°). Average corrected internal rotation of the throwing arm (62.38° ± 6.32°) was slightly greater than the non-throwing arm (57.33° ± 8.84°). All values that were collected during shoulder examination are reported in Table 4.3.

Table 4.3. Retroversion and Rotational Range of Motion Measurements

	Throwing Arm (Mean ± SD)	Non-Throwing Arm (Mean ± SD)
Humeral Retroversion	11.62 ± 1.86°	3.96 ± 0.96°
Internal Rotation	50.75 ± 5.73°	53.56 ± 8.88°
External Rotation	98.42 ± 6.42°	87.79 ± 6.86°
Total Rotation	149.18 ± 9.98°	141.35 ± 10.97°
Corrected Internal Rotation	62.38 ± 6.32°	57.53 ± 8.84°
Corrected External Rotation	86.80 ± 5.54°	83.82 ± 6.79°

4.3.3. Corrected Rotational Range of Motion and FAST Scores

When examining the relationship between total corrected rotational range of motion for the throwing arm and total FAST score, there was no significant relationship (r^2= 0.007, p= 1.80^-13) (Figure 4.1). There were also no significant relationships between either the throwing arm corrected external rotation and total FAST scores (r^2= 0.066, p=0.73) (Figure 4.2), or between throwing arm corrected internal rotation and total FAST scores (r^2= 0.009, p=0.13) (Figure 4.3).

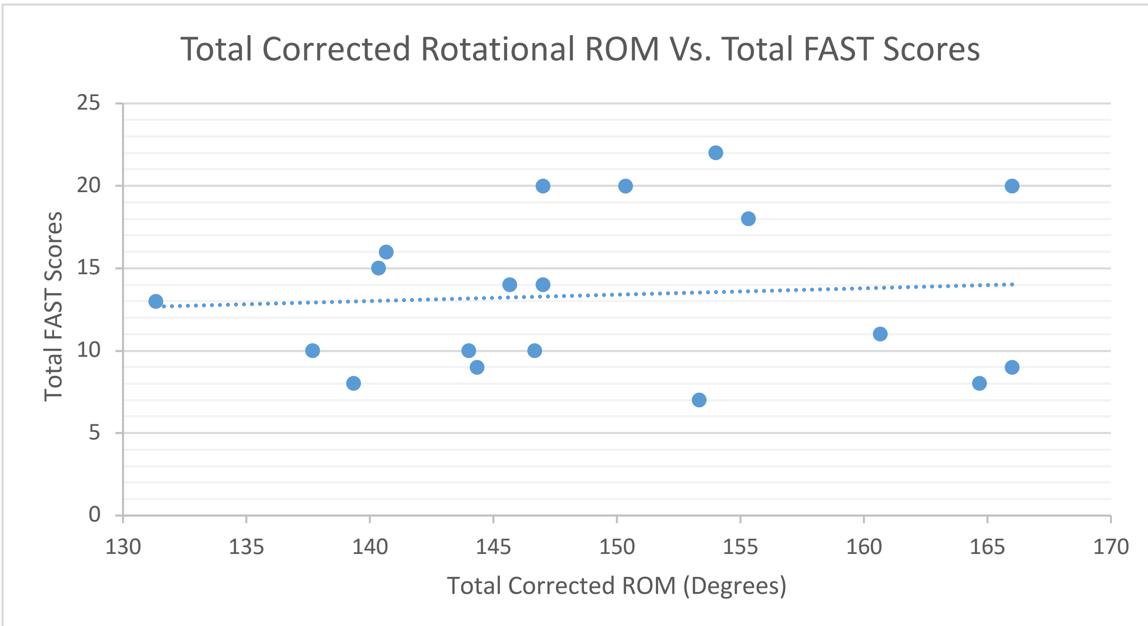

Figure 4.1. Total Corrected Rotational ROM vs. Total FAST Scores

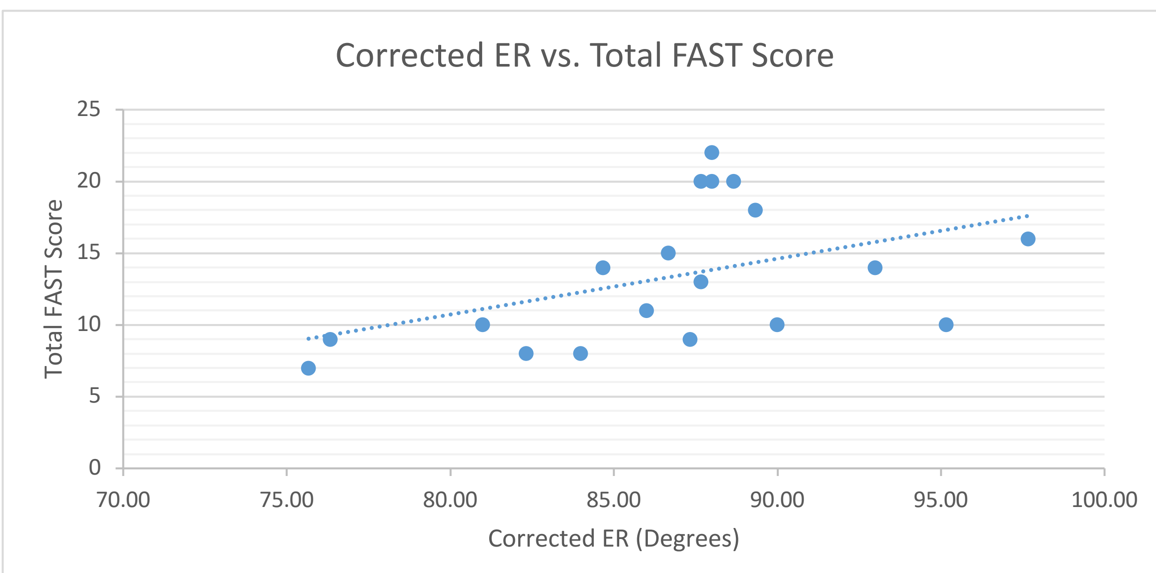

Figure 4.2. Corrected ER vs. Total FAST Score

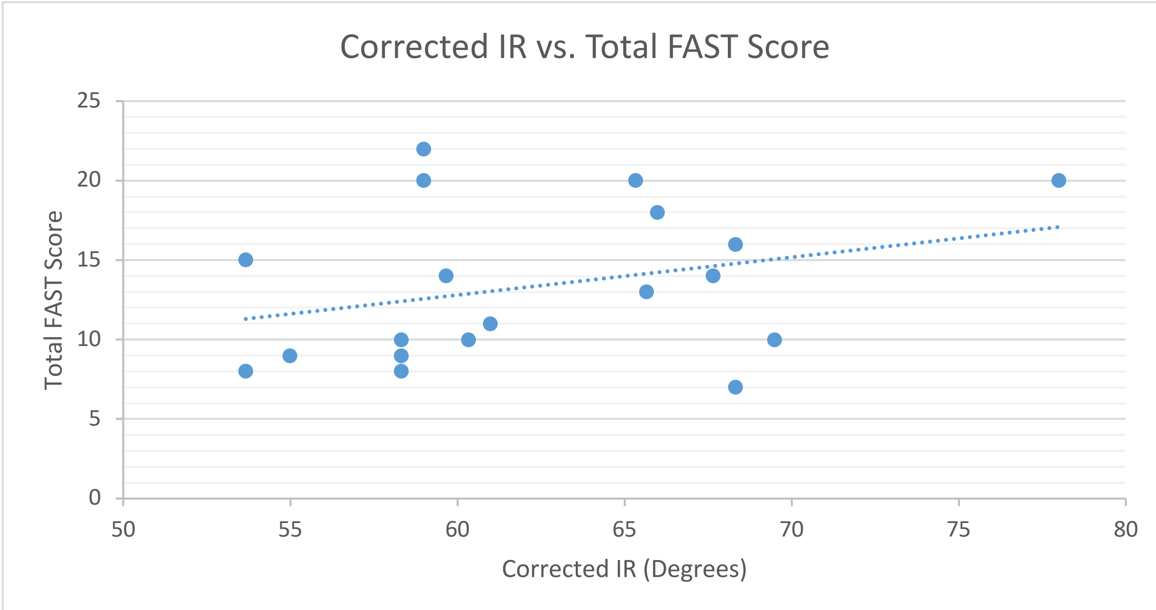

Figure 4.3. Corrected IR vs. Total FAST Score

There was also no significant correlation between any of the individual FAST pitcher's subscale questions and total shoulder rotation (Question 1: $r^2= 0.004$ $p=0.79$, Question 2: $r^2=0.027$ $p=0.50$, Question 3: $r^2= 0.03$ $p= 0.48$, Question 4: $r^2=0.007$ $p=0.73$, Question 5: $r^2=0.034$ $p=0.45$, Question 6: $r^2=0.018$ $p=0.59$, Question 7: $r^2=0.02$ $p=0.56$,(Figures 4.4- 4.13).

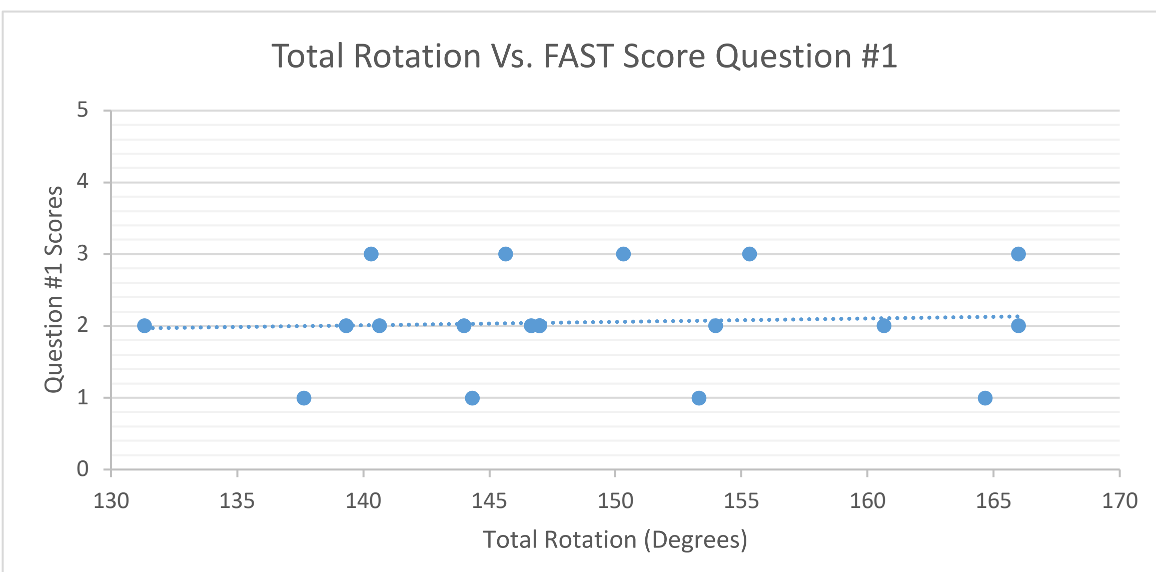

Figure 4.4. Total Rotation vs. FAST Question #1

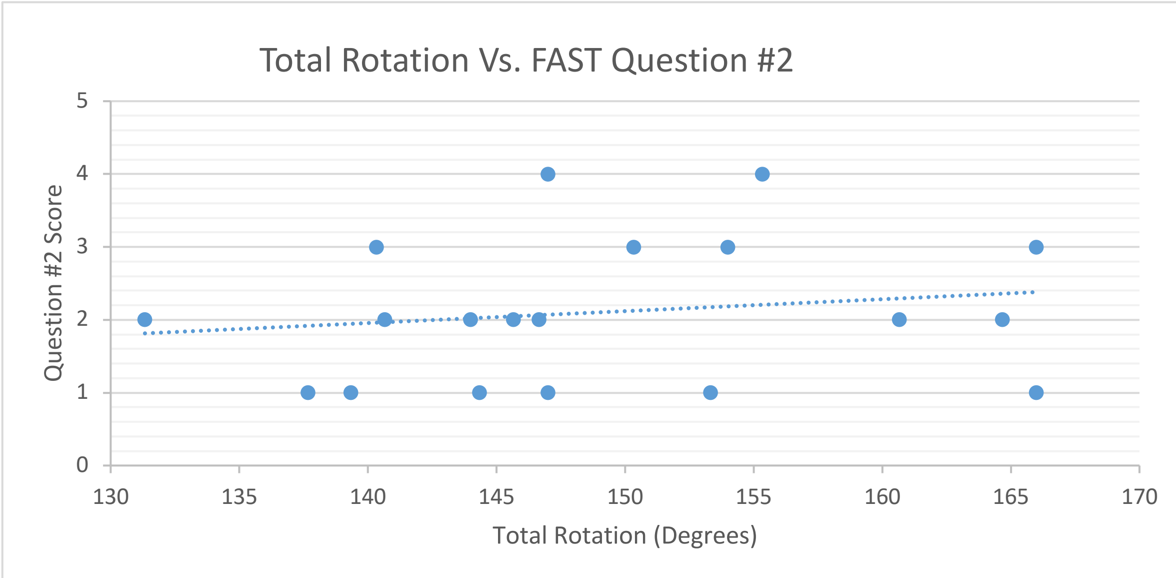

Figure 4.5. Total Rotation vs. FAST Question #2

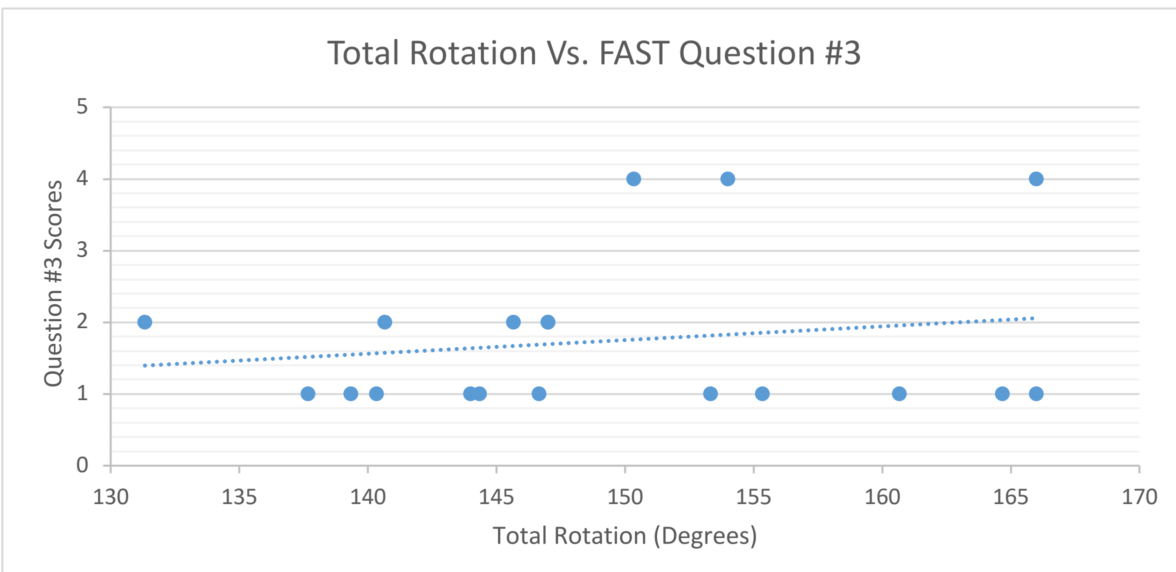

Figure 4.6. Total Rotation vs. FAST Question #3

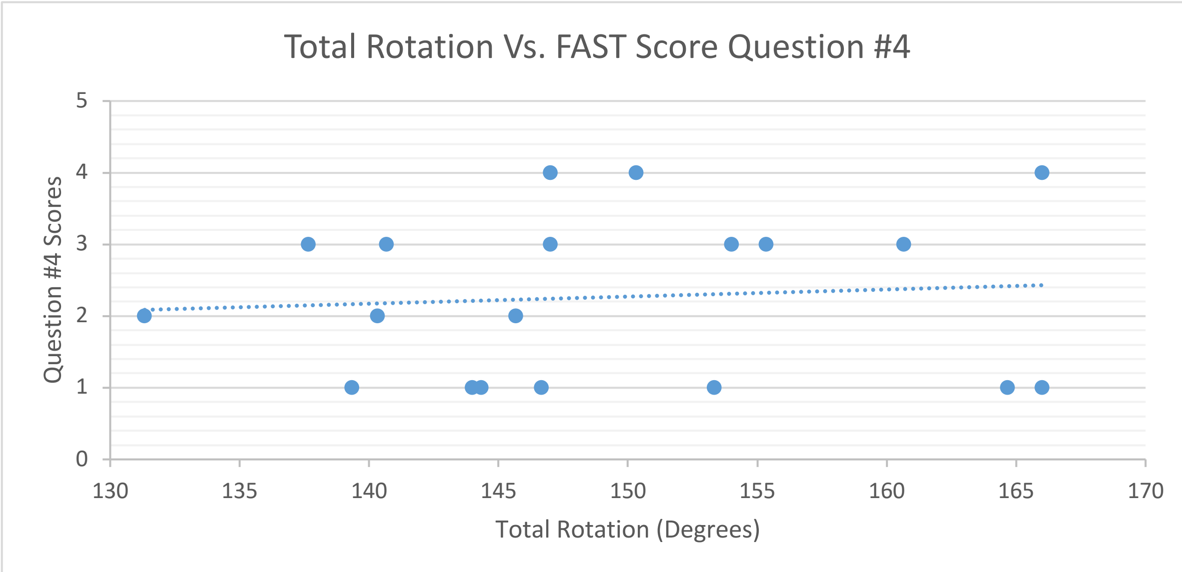

Figure 4.7. Total Rotation vs. FAST Question #4

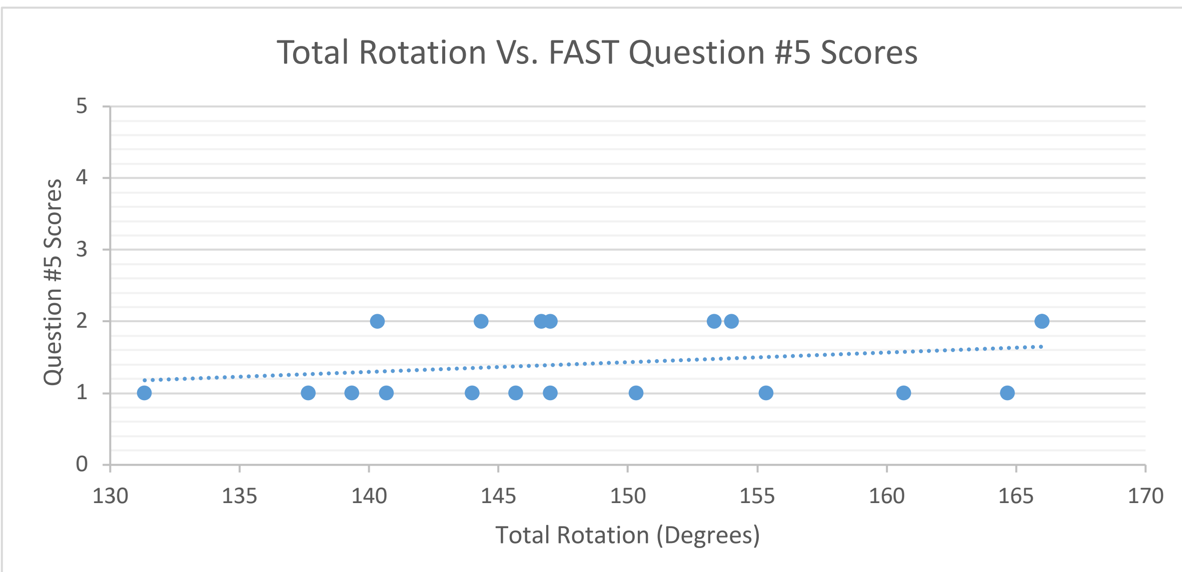

Figure 4.8. Total Rotation vs. FAST Question #5

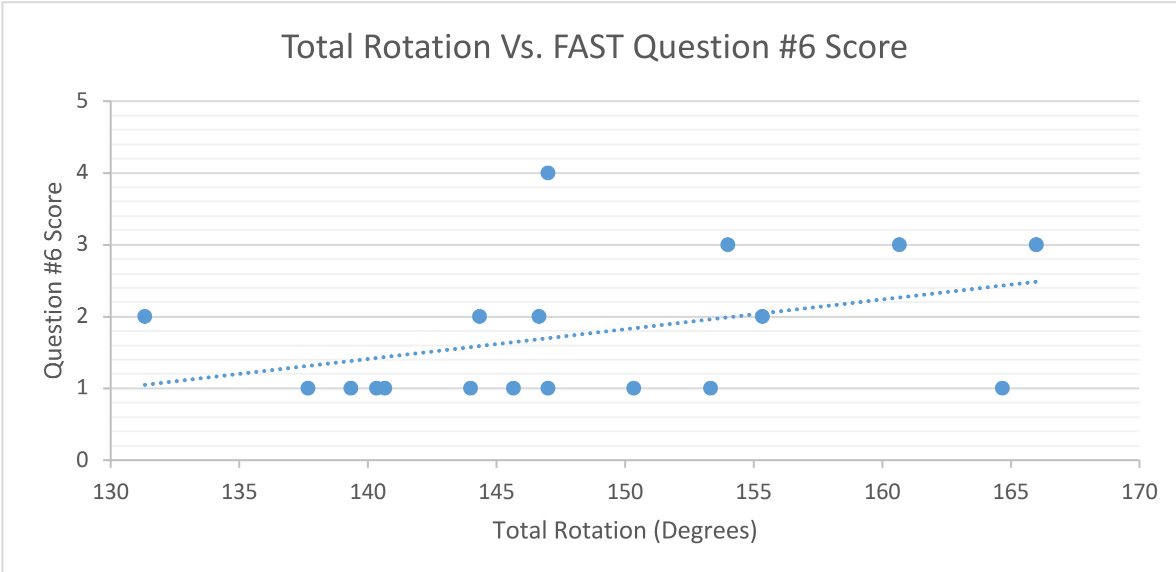

Figure 4.9. Total Rotation vs. FAST Question #6

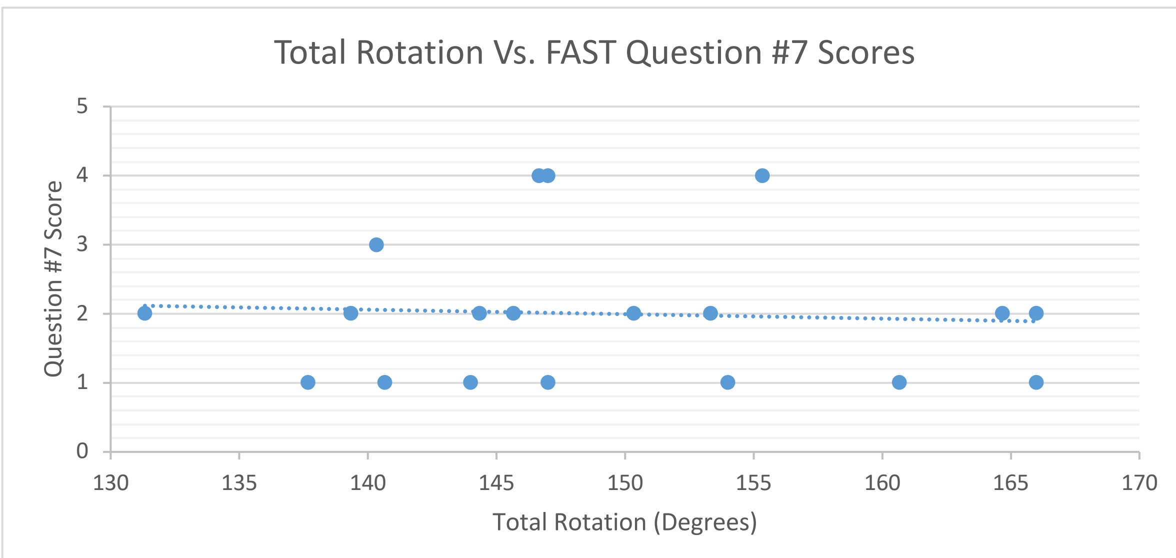

Figure 4.10. Total Rotation vs. FAST Question #7

Lastly, Figure 4.11 shows no significant correlation between number of years playing college baseball and total rotational range of motion (r^2= 0.06, p= 0.68).

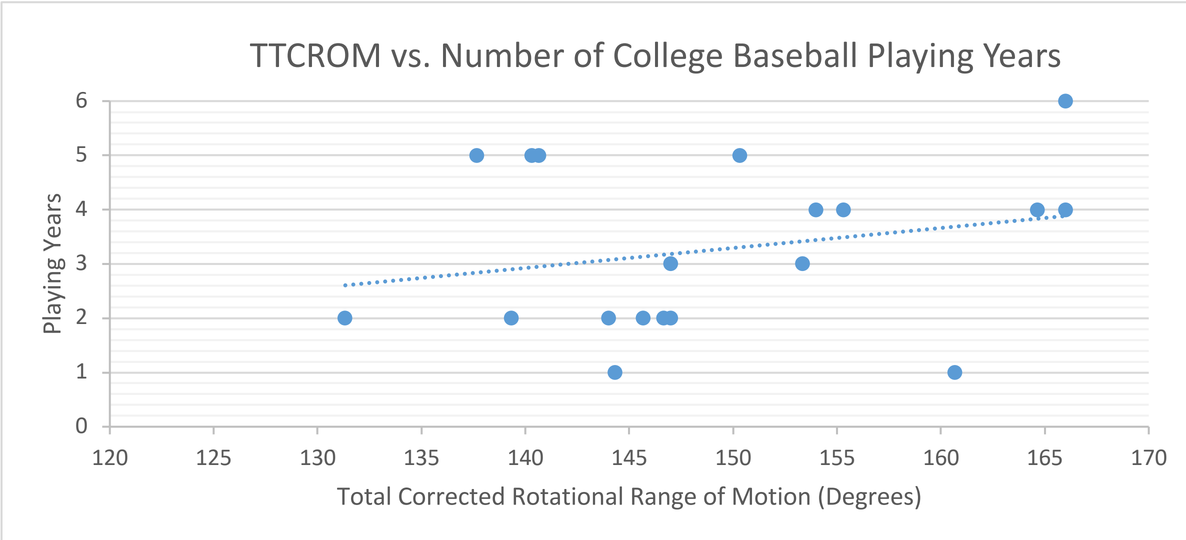

Figure 4.11. Total Corrected Rotational Range of Motion vs. Playing Years

4.4. Discussion

Increases in the rate of chronic shoulder injuries in college baseball pitchers has resulted in the need to examine the throwing shoulder more in depth, as sports medicine professionals search to find ways to prevent injury and identify risk factors that may predispose throwing athletes to shoulder injuries. For example, performing shoulder range of motion screenings can provide useful clinical measurements that athletic trainers may use to evaluate individual metrics of pitchers. Furthermore, the Functional Arm Scale for Throwers (FAST) has been shown to be a reliable tool in evaluating throwing athletes' subjective perceptions.[41,42]

In this study we examined the FAST pitchers' subscale to determine if this patient-reported outcome assessment predicted pitchers' total corrected range of motion. However, no significant correlations between total FAST scores (or individual FAST questions) and shoulder corrected rotational range of motion were identified (including external rotation, internal rotation, or total rotational range of motion). Although this was apparently the first study that looked to examine the relationship between the FAST and measures of ROM, the researchers who developed the scale have found it to be a valid tool to measure patient perceptions of their throwing function.[40,41] Because this scale has been found to be very specific and sensitive for measuring patient reported outcomes, it still could be a valid measurement tool to be used during a rehabilitation process following injury. However, the data that we collected did not find this outcome to be useful for determining changes in rotational range of motion. The data collected (FAST pitchers subscale mean= 13.37 ± 4.80) did however match up somewhat similarly to the values reported by Huxel et al.[44] (FAST pitchers subscale mean= 7.2 ± 14.2). Although our data showed slightly higher values for FAST pitchers' subscales, it will still contribute to the data regarding the mean scores in healthy pitchers.

Results from this study also did not find any correlation between the number of years an athlete has played college baseball and their total rotational range of motion once accounting for humeral retroversion. Although some players may have more experience and potentially more pitches from playing college baseball, it does not mean that they will have greater or lesser total corrected range of motion than players with lesser experience.

Data from this study did provide meaningful values that contribute to previous published research on shoulder rotational range of motion. In this study one variable that was examined was total shoulder rotational range of motion. In research performed by Wilk et al.[10,16] reported average throwing arm total rotational range of motion values of 183.7 ± 14.5 ° and our study found average values to be 149.18° ± 9.98°. There may be a few factors that could lead to differences in findings including time of the season when these measurements were taken, and the clinicians' methods for measuring rotational range of motion.

Another aspect of rotational range of motion in our study we examined was internal and external rotation. We found that pitchers had an average external rotation of 98.42 ± 6.42° and an average internal rotation of 50.75 ± 5.73° on their throwing arm prior to accounting for HR.

Downnar et al.[19] also found similar values of internal rotation (56.6 ± 12.5°) and external rotation (108.9 ± 9.0°) when they did not account for HR in professional baseball players throwing arms.[19] This supports the idea that before accounting for HR sports medicine professionals are more likely to see an greater ER and a less internal rotation in the shoulder.

However, similarly to the study performed by Reuther et al.[34], we found that once accounting for HR the difference in ER and IR is not as much as sports medicine professionals may think. This may suggest that sports medicine professionals should consider changes in range of motion with this correction in mind, instead of simply assuming posterior capsule thickening and/or anterior shoulder instability as a culprit.

4.4.1. Limitations

Several limitations were present in this study and may have affected the strength of findings. First, the consistency of the researcher to determine a firm end point during internal and external rotation, as well as the ability of the additional examiners to provide the containment force and limit scapulothoracic movement during range of motion testing. Previous studies performed using end feel to examine rotational motion in the shoulder have determined the intrareader relatability to be and the interrater reliability to be from 0.91 to 0.99.[34] Another notable limitation was the participants were actively competing in-season and their pitch count or workload could not be changed or altered. Some previous studies performed clinical measurements of rotational range of motion during pre-season, where they were able to account for the pitcher's workload. Current research suggests that baseball pitchers may see adaptations in range of motion and strength in the shoulder up to four days after throwing. These athletes were in the start of their season and some players had their measurements collected a day or two after throwing which may have contributed to their range of motion values. Furthermore, only shoulder external and internal rotation range of motion values were measured in this study. In the throwing motion there are other clinical range of motion measurements that contribute to the throwing motion such as shoulder flexion, extension, adduction, and abduction. Another limitation to this study is that the participants in this study were from one university in the Midwest. Regional factors such as weather and availability to play baseball year-round may also contribute to the data that was collected, since the outdoor baseball training season may be limited. The FAST score was modified from a 9-question scale to a 7-question scale because of the relevance of two questions that could not be answered at the time of data collection. Results may have yielded different results if the complete 9-question subscale could have been used.

4.4.2. Clinical Relevance

The data found in this study contributes to additional data on clinical measurements of the shoulder in baseball athletes. Another important clinical relevance is that this study demonstrated that the method of the two-person ultrasound technique using an inclinometer on baseball athletes to calculate humeral retroversion and corrected rotational can be performed in just a matter of minutes. This can be extremely important to sports medicine professionals because these clinical measurements are measurements that could be included into pre-season screenings that could provide a baseline for athletes before the season starts. These measurements may aid in the creation of specific mobility stretching or strengthening programs to help with motion deficits to prevent injuries from occurring. Values of humeral retroversion and corrected internal and external range of motion will also be valuable if an athlete becomes injured. When an athlete becomes injured the sports medicine professional can use this technique to examine if there are changes in range of motion accounting for humeral retroversion rather than solely relaying on traditional goniometric measurements which may not yield the most accurate results.

4.4.3. Further Research

Further research needs to be done to determine when it is necessary to examine the range of motion in the shoulder. Most baseball sports medicine professionals collect baseline ROM data, however, there is no current literature to support ROM testing in a healthy and asymptomatic baseball athlete population. Athletic trainers try to prevent injuries from occurring, it could be hypothesized that if sports medicine professionals examine pitchers' range of motion, after pitchers' outings that they may be able to prevent more chronic shoulder injuries from occurring.

There also needs to be more research on what structures are limiting total motion in the shoulder. The idea that all pitchers lack internal rotation and have external rotation gain has been examined by more current research, and that research demonstrates that accounting for HR shows a deficit in external rotation rather than a loss of internal rotation.[34-36] Investigating structures and muscle architecture in the shoulder after pitching outings may give researchers a better idea on what structures sports medicine professionals need to focus on to restoring total motion in the shoulder.

Lastly, there needs to be more research on outcome assessments that can be used to track pitchers' perception of shoulder function throughout the season. By tracking patients' perception of shoulder function, it will give sports medicine professionals meaningful data that they can track changes over time and will allow the clinicians to create individualized programs to tailor to the specific needs of each individual pitcher during the season.

4.5. Conclusion

This research has supported previous data that baseball pitchers experience chronic bony adaptations in their throwing shoulder compared to their non-throwing shoulder. It was also shown that sports medicine professionals can measure humeral retroversion and other shoulder range of motion measurement's accurately within minutes using a two-person ultrasound technique with an inclinometer. There were no significant correlations between the FAST and shoulder rotational range of motion measurements, indicating that this patient reported outcome measure did not show a strong relationship to corrected rotational range of motion measurements. This encourages further research into patient reported outcome assessments specific to pitchers in baseball.

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APPENDIX A. STUDY DEMOGRAPHIC FORM

Participant Number: _______

1. Age: ____________________
2. Years of playing College Baseball: _________________________
3. Arm Dominance: ___________________________
4. Height ___________________________
5. Weight: ________________________
6. Pitch Types:____

APPENDIX B. QUESTIONNAIRE

	Not at All	Slightly	Moderately	Severely	Unable to Perform
How much has your arm limited velocity of pitches?	1	2	3	4	5
How much has your arm limited you to throw bullpen sessions?	1	2	3	4	5
How much has your arm limited your ability to hit your spots?	1	2	3	4	5
How much has your arm affected your pitch count?	1	2	3	4	5
How much has your arm limited your ability to throw different pitches?	1	2	3	4	5
How much has your arm changed how you feel throwing pitches?	1	2	3	4	5
Do you feel like you need more time to recover in between pitching outings?	1	2	3	4	5