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Relationships Between Humeral Retroversion, Anterior Glenohumeral Laxity, and Forward Scapular Posture in Collegiate Baseball Players

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RELATIONSHIPS BETWEEN HUMERAL RETROVERSION, ANTERIOR
GLENOHUMERAL LAXITY, AND FORWARD SCAPULAR POSTURE IN
COLLEGIATE BASEBALL PLAYERS

Yuya Mukaihara

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Context: Baseball players are prone to soft tissue and bony adaptations due to the forces accumulated during repetitive throwing. Such adaptations often include increased humeral retroversion, anterior glenohumeral laxity, and forward scapular posture.

Objective: To investigate if relationships exist among humeral retroversion, anterior glenohumeral laxity, and forward scapular posture in collegiate baseball players. Design: Cross-sectional correlation study. Setting: University athletic training facility.

Participants: Forty-eight asymptomatic NCAA Division-I baseball players (age: 20.2 ± 1.2 , height: 185.63 ± 6.69 cm, mass: 90.39 ± 8.92 kg) volunteered. Interventions:

Humeral retroversion and anterior glenohumeral laxity of the dominant shoulder and bilateral differences of forward scapular posture were measured during one testing session.

Main Outcome Measures: Humeral torsion angle and anterior humeral head displacement of the dominant shoulder and forward scapular displacement of both

shoulders were measured. Results: No significant multiple regression ($p > .68$) was found between humeral retroversion, anterior glenohumeral laxity, and forward scapular

posture. Conclusions: Humeral retroversion, anterior glenohumeral laxity, and forward scapular posture are not related to one another.

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GLENOHUMERAL LAXITY, AND FORWARD SCAPULAR POSTURE IN
COLLEGIATE BASEBALL PLAYERS

YUYA MUKAIHARA

A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

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2014

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GLENOHUMERAL LAXITY, AND FORWARD SCAPULAR POSTURE IN
COLLEGIATE BASEBALL PLAYERS

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CHAPTER I

INTRODUCTION: PURPOSE OF RESEARCH

The bones and soft tissue of the shoulder must withstand large amounts of torque^{1,2} and distraction forces³ during the baseball throwing motion. These large forces and the repetitive nature of baseball pitching often leads to alterations in glenohumeral range of motion (ROM), such as decreased internal rotation and increased external rotation when compared to the non-dominant arm.⁴ These changes in glenohumeral ROM have been associated with superior labrum anterior to posterior (SLAP) lesions, internal impingement, and subacromial impingement.⁵

Two structural adaptations that cause glenohumeral ROM changes in the throwing shoulder have been reported. The first adaptation relates to the soft tissues within the shoulder.⁵⁻⁹ Anteriorly, excessive external rotation at the end of the cocking phase causes lengthening of the anterior band of the inferior glenohumeral ligament complex, potentially leading to increased anterior glenohumeral laxity.⁹ Posteriorly, the large eccentric force during the deceleration phase of pitching causes thickening of the posterior capsule and contracture of the posterior rotator cuff.⁵⁻⁸ This tightness can reduce glenohumeral internal rotation ROM and cause a superoposterior shift of the humerus within the glenoid leading to increased external rotation.⁵ The second adaptation that can be caused by repetitive throwing is increased humeral retroversion.¹⁰⁻¹³ This

increase in retroversion of the dominant arm in baseball players often results in increased glenohumeral external rotation and a concomitant loss of internal rotation ROM due to altered bony geometry compared to the non-dominant arm, as well as non-throwing athletes.¹⁴ This adaptation is considered to be beneficial by some as it allows for more external rotation with less loading on the anterior glenohumeral joint capsule and ligaments.¹³

In addition, adaptations to scapular kinematics may also occur as a result of the repetitive throwing motion. Throwing athletes have demonstrated significantly more scapular upward rotation, internal rotation and retraction when compared to non-throwing control subjects.¹⁵ Baseball players have also been shown to have greater forward scapular posture in their dominant shoulders compared to their non-dominant shoulders, which may increase the risk of injury to the anterior glenohumeral joint during the cocking phase.¹⁶ This is because the static restraints of the anterior glenohumeral joint may experience increased stress when the scapula is protracted and the humerus is in maximal external rotation.¹⁷

Several studies have investigated the association between glenohumeral or scapular adaptations and posterior shoulder tightness.^{8,12,13,16} Positive relationships between posterior shoulder tightness and humeral retroversion,¹² anterior glenohumeral laxity,⁸ and forward scapular posture¹⁶ have been reported. Also, clinicians have hypothesized that greater humeral retroversion may result in less anterior glenohumeral laxity.¹³ However, despite the common presence of increased humeral retroversion, anterior glenohumeral laxity, and forward scapular posture among baseball players, no study to date has investigated if correlations exist among these characteristics. Therefore,

the purpose of this study was to investigate the strength of relationships between humeral retroversion, anterior glenohumeral laxity, and forward scapular posture in collegiate baseball players. We hypothesized that there would be 1) a negative relationship between humeral retroversion and anterior glenohumeral laxity, 2) a negative relationship between humeral retroversion and forward scapular posture, and 3) a positive relationship between anterior glenohumeral laxity and forward scapular posture.

CHAPTER II
REVIEW OF RELATED LITERATURE

Introduction

The dominant shoulders of baseball players accumulate large amounts of torque due to the repetitive nature of their sport. Such force has been shown to result in chronic adaptations of various tissues, such as bone, capsuloligamentous, and musculature. Furthermore, many clinicians have hypothesized about relationships between these adaptations. Understanding the relationships among adaptations in throwing athletes may provide a better understanding in the prevention, evaluation, and treatment of shoulder injuries among such athletes.

Shoulder Anatomy Review

Bony anatomy

The sternum is a flat cancellous bone that is 15-20 cm long.²⁵ This bone is slightly concave posteriorly and convex anteriorly and consists of the manubrium, body, and xyphoid process.²⁵

The manubrium is arranged superiorly with the jugular notch and articulates laterally with the clavicle at the manubrial articular notches.²⁵ The first and second ribs also articulate with the manubrium laterally, while the second rib also articulates with the sternal body.²⁵ There is fibrocartilage separating the manubriosternal junction, which calcifies in the elderly.²⁵

The sternal body is narrower than the manubrium bilaterally and consists of three ridges anteriorly, which are the sternal ossification centers that have fused.²⁵ The second through seventh ribs articulate with the lateral aspect of the sternal body.²⁵

The xyphoid process fuses with the sternal body at the xyphisternal junction later in life and varies largely with size, length, and degree of calcification among individuals.²⁵

The clavicle is a short tubular bone that is s-shaped.²⁶ Medially, the clavicle becomes round, enlarged and articulates with the sternum, forming the sternoclavicular joint.²⁶ This is the only connection of the shoulder girdle to the axial skeleton.²⁷ Laterally, the clavicle becomes flat, small and articulates with the acromion of the scapula, forming the acromioclavicular joint.²⁶ There are uneven ridges at the lateral half of the clavicle as insertion sites for the deltoid and trapezius muscles²⁶ whereas the medial side is tubular shaped to receive axial loading.²⁷

The scapula is a flat triangular bone that is thinner in the center and thicker at the periphery.²⁶ It is located over the posterolateral thorax and is level with the second through seventh ribs.²⁷

The scapular spine separates the supraspinous fossa from the infraspinous fossa.²⁶ The scapular spine then continues superolaterally to form the base of the acromion.²⁷

Inferiorly from the acromioclavicular joint, the acromion forms a coracoacromial arch with the coracoid process and coracoacromial ligament.²⁷ Tendons of the supraspinatus, infraspinatus, and long head of the biceps, as well as the subacromial bursa are located within subacromial space.²⁷ The acromion process is classified by its shape as

flat (type-I), curved (type-II), or hooked (type-III)²⁸ with majority being classified as type-II.²⁹

The coracoid process is located on the superolateral aspect of the scapula, forming its protuberance anterolaterally.²⁷ Medial to the base of the coracoid process is the scapular notch.^{26,27} The superior transverse scapular ligament runs across the notch to create the scapular foramen, where the suprascapular nerve runs through.²⁶

The glenoid fossa is an articular surface where the humeral head sits.²⁷ The size of the surface is one third or one fourth of the humeral head, providing small joint stability by its bony congruence.²⁷ The supraglenoid tubercle is located superior to the glenoid fossa where the long head of the biceps tendon intraarticularly originates whereas the infraglenoid tubercle is located 1cm below the glenoid fossa where the long head of triceps brachii tendon extraarticularly originates.²⁶

The humerus is a long bone and proximally consists of the hemispheric humeral head that is separated from the shaft by the anatomical neck.²⁶ Its articular surface is 20-30 cm² in size.²⁶ Blood and nutrient supply to the humeral head comes through the foramina within the anatomical neck.²⁶

The bicipital groove is located on the anterior aspect of the proximal humerus, where the tendon long head of the biceps tendon is located.²⁶ The transverse humeral ligament runs across the groove to hold the long head of the biceps tendon in place.²⁶

Lateral to the bicipital groove is the greater tubercle of the humerus. It consists of three facets.^{26,27} Medial to the bicipital groove is the lesser tubercle.^{26,27} The surgical neck of the humerus is located below the tubercles.²⁷

Joint Articulations

The sternoclavicular joint is a diarthrodial saddle joint, and is the only articulation between the upper extremity and the axial skeleton.^{30,31} Naturally, the sternoclavicular joint lacks bony stability because less than 50% of the medial end of the clavicle articulates with the clavicular notch; therefore requiring passive restraints.³² Passive stability of the joint is also provided by the interclavicular ligament, the intra-articular disc, and the anterior and posterior costoclavicular ligaments.^{30,31,33}

The joint has three degrees of freedom: elevation-depression, retraction-protraction, and axial rotation.³⁴ The joint has the capacity of 30°-35° of elevation, 35° of combined retraction-protraction, and 45°-50° of rotation on its axis.³⁵ Due to the shape and angle of the first rib, depression of the clavicle is accompanied with protraction whereas elevation of the clavicle is associated with retraction.³⁴ Additionally, the clavicle rotates less than 5° at the end of elevation or depression due to increased capsular tightness.³⁴ Most importantly, the majority of scapulothoracic motion comes from the sternoclavicular joint because there is very little motion between the clavicle and acromion.³⁶ Therefore, the scapula moves when the clavicle moves.³⁶ Active and passive arm elevation in the scapular plane displays a general pattern of clavicular retraction and elevation throughout the range of motion (ROM).³⁷

An intra-articular disc is located within the sternoclavicular joint and divides it into two synovial compartments.^{30,31} The disc is thicker superiorly, and inferiorly, and it runs around the inferior aspect of the medial clavicle and merges to the upper surface of the costal cartilage.³⁴ The disc absorbs force that is transferred from the clavicle.^{30,31}

The joint capsule of the sternoclavicular joint provides static stability. The capsule is thickened anterosuperiorly and posteriorly^{30,34} and thinnest anteriorly.³⁴ However, another resource states that the anterior capsular ligament is “heavier and stronger than the posterior portion.”³⁵ The posterior and anterior capsule provides most resistance to anterior translation of the clavicle, whereas the posterior capsule is solely responsible for resisting posterior translation of the clavicle.³³ Furthermore, the posterosuperior part of the joint capsule resists depression of the clavicle.³⁴

The interclavicular ligament connects both superomedial aspects of the clavicles and superior aspect of the sternum³⁵ and is a continuum with the superior capsules of the each sternoclavicular joint.³⁴ This ligament provides resistance to depression of the clavicle.³⁴

The anterior fibers of the costoclavicular ligament originate from the anteromedial surface of the first rib, run superolaterally, and connect to the inferior aspect of the medial end of the clavicle.³⁵ The posterior fibers of the costoclavicular ligament originate lateral to where the anterior fibers arise from the first rib, course superomedially, and insert on the inferior surface of the medial clavicle.³⁵ The anterior fibers of the costoclavicular ligament resist retraction, upward rotation and lateral displacement, whereas the posterior fibers resist protraction, downward rotation, and medial displacement of the clavicle.^{34,35} When the costoclavicular ligament is damaged, the posterior and anterior capsule provide stability to retraction-protraction and rotation.³⁴

The acromioclavicular joint is a diarthrodial joint that contains an intraarticular disc, separating the articular surface of the acromion and the distal clavicle.³¹ The joint is stabilized statically by the joint capsule, acromioclavicular ligaments, coracoclavicular

ligament, and coracoacromial ligament, as well as the deltoid and trapezius muscles.³¹ The joint capsule is thicker superiorly and anteriorly.²⁷ This joint has three degrees of freedom, including upward rotation-downward rotation, internal rotation-external rotation, and anterior-posterior tilt.^{38,39} However, only 5°-8° of upward-downward rotation occurs at this joint.⁴⁰

The intraarticular disc is classified as fibrocartilage³⁶ and may develop partially or completely; additionally, size and shape vary among individuals.²⁷ Early degeneration commonly occurs with this disc.²⁷

The superior, inferior, anterior, and posterior acromioclavicular ligaments support the acromioclavicular joint capsule. The superior and inferior acromioclavicular ligaments are stronger than the anterior and posterior portions.³¹ In addition, the superior acromioclavicular ligament is more developed than the inferior acromioclavicular ligament.⁴¹ This is due to the aponeurosis of the trapezius and the deltoid blending with the superior acromioclavicular ligament, providing superior stability of the acromioclavicular joint.^{36,41} The acromioclavicular ligament is the primary restraint for anterior and posterior forces at the acromioclavicular joint.^{42,43} In addition to horizontal stability, the acromioclavicular ligament provides a secondary restraint to superior force at the distal end of the clavicle.⁴³

The trapezoid and conoid ligaments form the coracoclavicular ligament.⁴¹ The trapezoid ligament connects between the superior surface of the coracoid process and the inferior surface of the clavicle, running from anterolateral to posteromedial. The conoid ligament runs directly superior from the base of the coracoid process to the conoid tuberosity on the inferior surface of the clavicle.⁴¹ In addition, the trapezoid ligament is

larger than the conoid ligament, and a bursa is located between the two ligaments.⁴¹ The coracoclavicular ligament resists superior displacement of the clavicle,⁴² specifically the trapezoid portion due to its attachment site and size.⁴¹ Once the acromioclavicular ligament is disrupted, the coracoclavicular ligament is a secondary restraint for anterior and posterior force at the acromioclavicular joint; specifically, the conoid portion resists against anterior and superior force while the trapezoid portion is responsible for resisting posterior force.^{42,43} Also, this ligament functions as a link between the clavicle and the scapula while glenohumeral and scapular movements occur.⁴⁰

The coracoacromial ligament arises from the lateral edge of the coracoid process, inserts on the inferior surface of the acromion, and blends with the inferior acromioclavicular joint capsule.⁴¹ It runs obliquely over the glenohumeral joint capsule and rotator cuff.⁴¹ The shoulders with rotator cuff tears from cadavers displayed deterioration of the coracoacromial ligament undersurface at the acromion process.^{41,44} From this observation, the coracoacromial ligament may function as a cushion between the rotator cuff and the acromion process.⁴¹ Also, the ligament provides additional stability to the inferior acromioclavicular joint capsule due to its attachment.⁴¹

The glenohumeral joint is a synovial ball-and-socket joint formed by the head of humerus and the glenoid fossa of the scapula.³⁸ This joint is the least stable but most mobile joint of the human body, relying on static and dynamic restraints for maintaining joint stability.⁴⁵ Also, females have more glenohumeral joint laxity than males.⁴⁶ Motions of the glenohumeral joint include: flexion-extension in the sagittal plane, abduction-adduction in the frontal plane, and horizontal abduction-horizontal adduction and external rotation-internal rotation in the transverse plane.⁴⁵

A lack of stability at this joint is the result of a small articular surface at the glenoid fossa relative to the large humeral head.⁴⁷ The glenoid fossa has greater depth superior to inferior compared to anterior to posterior.⁴⁸ The maximum depth of the glenoid, with labrum, is approximately 9 mm superoinferiorly and 5 mm anteroposteriorly.⁴⁹ The labrum contributes to about half of the depth in both directions.⁴⁹ For example, with the labrum removed, the depth of the glenoid in the anteroposterior direction is 2.4 mm,⁴⁹ which was first described by Bankart.^{47,50} Additionally, an effect of compressive loading of the humeral head on the glenoid fossa is more efficient against the superoinferior translational force than anteroposterior force.⁴⁸ This is one reason why anteroposterior directional instability is more common.⁴⁹

The glenoid labrum increases congruency between the humeral head and the relatively flat glenoid surface by adding a peripheral wedge.⁴⁷ Superiorly at the 12 o'clock position, the labrum directly attaches to the long head of the biceps tendon, just distal to the supraglenoid tubercle where the biceps tendon inserts, and loosely connects to the glenoid process with thin and tensile connective tissue.⁵¹ Similarly, the anterosuperior portion of the labrum does not attach to the glenoid rim, rather inserts to the middle or inferior glenohumeral ligaments.⁵¹ Inferiorly, the labrum, on the other hand, securely attaches to the glenoid rim and the inferior glenohumeral ligament complex (IGHLC).⁵¹ Furthermore, the glenoid labrum greater contributes to stability against inferior and posteroinferior translational forces than other directional forces.⁴⁸ When the labrum is removed, displacement of the humeral head is increased in all directions, even with compressive loading.⁴⁸ A complete lesion to the superior portion of the labrum significantly increases anteroposterior and superoinferior translations of the humeral head

with 0°, 45°, and 90° of arm elevation and affects the superior capsular structure, including the superior glenohumeral (SGHL) and middle glenohumeral ligaments (MGHL).⁵² In terms of its vascularity, blood supply to the labrum comes from the branches of the scapular circumflex artery, which is connected to the posterior circumflex humeral artery.^{51,53} Therefore, blood supply to the glenoid labrum is limited only to the periphery.⁵¹ The superior and anterosuperior parts of the labrum are less vascular compared to the posterior and inferior parts.⁵¹

The glenohumeral joint capsule is twice as large as the size of the humeral head and slackened inferiorly, permitting its large ROM.²⁷ Both the glenohumeral joint capsule and ligaments are often described separately; however, the ligaments are thickenings of the joint capsule.^{27,54,55} The capsule provides stability at the end of ROM while dynamic stabilizers are more active in the mid ROM.²⁷ Superiorly, the joint capsule, along with the coracohumeral ligament, stabilizes inferior displacement of the arm.³⁸ Anteriorly, the glenohumeral ligaments and the subscapularis tendon support the capsule, while the infraspinatus and teres minor muscles strengthen the capsule posteriorly.³⁸ However, the inferior portion of the capsule is the weakest.³⁸

Negative intra-articular pressure provides stability to glenohumeral joint.⁵⁶ Stable shoulders from fresh cadavers and patients have demonstrated a mean of -34 mmHg and -32 mmHg, respectively at 0° of shoulder abduction.⁵⁶ Intra-articular pressure was decreased to -111 mmHg for cadavers when the arm was abducted to 90° and also to -133 mmHg when traction was applied to the shoulder of patients under anesthesia.⁵⁶ However, patients diagnosed with shoulder instability, due to recurrent dislocations, have failed to show negative intra-articular pressure: 0 mmHg with the arm at rest and -2

mmHg with traction applied.⁵⁶ Furthermore, when the glenohumeral joint is punctured, passive translations of the humeral head are increased in all directions, specifically a 50.8% increase in the anteroposterior direction at 30° of glenohumeral abduction.⁵⁷

The SGHL arises from the superior tubercle of the glenoid and inserts on the fovea capitis of the humerus, by blending with the coracohumeral ligament⁵⁴ and attaching to the thin connective tissue of the subscapularis tendon.⁵⁸ More specifically, the SGHL has direct and oblique fibers.⁵⁹ The direct fibers originate from the superior fourth of the glenoid labrum and run parallel to the long head of the biceps tendon and insert onto the lesser tubercle. It also extends to the bicipital groove to form the upper part of the transverse humeral ligament.⁵⁹ The oblique fibers arise from the supraglenoid tubercle then course over the intra-articular part of the long head of the biceps tendon and insert under the coracohumeral ligament into the semicircular humeral ligament.⁵⁹ With the arm at 0° of glenohumeral abduction, external rotation lengthens the SGHL.^{60,61}

The MGHL arises from the anterosuperior glenoid labrum and inserts on the lesser tubercle of the humerus with the subscapularis tendon⁵⁴ and just superior to the insertion of the anterior band of the inferior glenohumeral ligament (AIGHL).⁶⁰ The MGHL runs parallel to the SGHL at 0° of glenohumeral abduction with neutral rotation.⁶⁰ At this arm position, ER lengthens the ligament, creating a more horizontal shape.⁶⁰ The MGHL is slightly lengthened when the arm is abducted to 45°; additionally, external rotation at the same arm position further lengthens the ligament.^{60,61} Once the arm is abducted to 90°, the MGHL displays little change compared to 45° of abduction.⁶⁰

The IGHLC is a capsular thickening of the inferior capsule.^{27,54,55} The IGHLC attaches to the anterior, inferior, and posterior portions of the glenoid labrum and the

surgical and anatomical necks of the humerus.⁶² The IGHL consists of the AIGHL, the posterior band of the inferior glenohumeral ligament (PIGHL), and the axillary pouch.⁵⁵ The AIGHL originates on the anterosuperior to anterior aspect of the glenoid rim, whereas the PIGHL arises from the posteroinferior to posterior aspect of the glenoid rim. Both insert on the humeral neck.^{55,60} At 45° of arm abduction, both the AIGHL and PIGHL lengthened compared to 0° of abduction.⁶⁰ Internal rotation at this position lengthens both the AIGHL and PIGHL, whereas external rotation lengthens only the AIGHL and positions the PIGHL inferior to the humeral head.⁶⁰ At 90° of arm abduction, both bands further lengthen; IR slightly shifts the AIGHL inferiorly and the PIGHL superiorly, as well as lengthens it.⁶⁰ External rotation orients the PIGHL inferior to the humeral head and the AIGHL horizontally above midline of the anterior humeral head with increase in length⁶⁰ and prevents anterior displacement of the humerus.⁶²

The coracohumeral ligament originates from the base of the coracoid process, deep to the proximal origin of the coracoacromial ligament.^{41,54} This ligament inserts into multiple structures: the fascia of the supraspinatus posteriorly, the lesser tubercle with the subscapularis tendon anteriorly, the greater tubercle laterally, and the SGHL inferiorly.⁵⁴ There is a firm connection between the SGHL and coracohumeral ligament at the mid portion of the ligaments where no separation exists.^{54,58} Additionally, the coracohumeral ligament is greater in cross-sectional area, stiffness, and ultimate load than the SGHL and requires six times more energy to fail than the SGHL.⁶³ These ligaments resist inferior translation and excessive external rotation of the humerus.⁶³

The subacromial bursa is located and attached above the supraspinatus muscle and underneath the acromion, the coracoacromial ligament, and the deltoid muscle.³⁸ It permits gliding between those structures and reduces friction.³⁸

The subscapularis bursa is located underneath the subscapularis tendon and anterior to the neck of the scapula,³⁸ between the SGHL superiorly and the MGHL inferiorly.⁵⁴ This bursa protects the subscapularis tendon against the coracoid process and the scapular neck.³⁸

The scapulothoracic articulation is not a true joint, but rather a representation of a space created by the concave shape of the anterior scapula on the convex shape of the posterior rib cage.²⁷ The muscular, bursa, and neurovascular structures of the articulation allows the scapula to move smoothly on the thoracic cage.²⁷ The scapulothoracic motions include: elevation-depression, upward rotation-downward rotation, anterior tilt-posterior tilt, internal rotation-external rotation, and retraction-protraction.⁶⁴

The scapulohumeral rhythm is defined by the slope of a relationship between the change in humeral elevation and the change in scapular rotation.⁶⁵ Classically, Inman *et al.*⁶⁶ has described the scapulohumeral rhythm as 2:1 relationship between humeral elevation and scapular upward rotation with 2-dimensional assessment. Recently, more 3-dimensional scapular kinematics with humeral elevation has been investigated rather than just scapular upward/downward rotation with humeral elevation.^{37,67} Active arm elevation up to 90° in the scapular plane demonstrates progressive upward rotation of the scapula, a small amount of posterior tilt and external rotation.³⁷ Passed 90° of scapular plane elevation, the posteriorly tilted scapula moves into more of an anterior tilted position and external rotation reaches its plateau.³⁷ With passive elevation, a similar pattern of

scapular kinematics is seen, except there is more internal rotation of the scapula.³⁷ Another study⁶⁷ has shown similar scapular motions with humeral elevation in the scapular plane, including a mean of 50° scapular upward rotation, 30° posterior tilt, 24° external rotation, 21° clavicular retraction, and 10° clavicular elevation. Humeral forward flexion has shown similar scapular and clavicular kinematics.⁶⁷ In terms of clavicular kinematics, retraction was the greatest between 130° and 150° humeral elevation and it did not begin its motion until around 25° of scapular plane elevation and 50° of forward flexion.⁶⁷ A classic study done by Imnan *et al.*⁶⁶ has reported similar scapular and clavicular kinematics, including 50° scapular upward rotation, 25° clavicular elevation, and 30° clavicular posterior rotation with forward flexion. When the middle deltoid, upper and lower trapezius, and serratus anterior muscles of healthy subjects are fatigued, there is increased upward rotation of the scapula at the mid and end range of humeral elevation.⁶⁵ This decreases scapulohumeral rhythm may be a coping mechanism to avoid subacromial impingement because a group with subacromial impingement has demonstrated decreased upward rotation and increased anterior tilt and internal rotation under loading humeral elevation.⁶⁵ Also, there were increased upper and lower trapezius activities and decreased serratus anterior activity.²⁰

Force couples at the scapulothoracic articulation are important in shoulder function. Scapular stabilization is achieved by activation of the upper and lower trapezius and rhomboid muscles paired with the serratus anterior muscle.⁶⁸ Also, balanced upward rotation of the scapula to elevate the acromion process is accomplished by activation of the lower trapezius and serratus anterior muscles paired with the upper trapezius muscle.⁶⁸ When these scapular stabilizers are not functioning properly due to muscle

imbalance or neural palsy, causing the scapular base to be unstable, the extrinsic and intrinsic muscle attachments pull on the scapula instead of at their distal attachment.⁶⁸ This results in tipping or winging of the inferomedial or the medial border of the scapula, increasing a risk of subacromial impingement, labral pathologies, and scapulothoracic dyskinesia.^{18,68}

The biomechanics of the scapulothoracic articulation is commonly affected by postural or tissue abnormalities. Excessive thoracic kyphosis, cervical lordosis, or posterior shoulder tightness causes excessive protraction of the scapula.⁶⁸ When excessive protraction occurs, the acromion is positioned anteroinferiorly during the acceleration and follow-through phases of throwing due to an oblique shape of the upper thoracic cage, increasing the risk of subacromial impingement.⁶⁸ This requires greater muscular activation to accomplish proper scapular retraction.⁶⁸ If full retraction is not achieved, then the full late cocking position will not be reached; therefore, less explosive movement occurs during the acceleration phase, but more eccentric loading during deceleration.⁶⁸ In addition, lack of coordination of both protraction and retraction during throwing causes functional anteversion of the glenoid, increasing shear forces to stabilizing structures of the anterior glenohumeral joint.⁶⁸

Another biomechanical abnormality is when the scapular link in the kinetic chain is diminished.⁶⁸ When the scapula is positioned or moves deficiently, a large energy that is transferred from the lower extremity to the upper extremity is lost.⁶⁸ Therefore, the upper extremity must generate greater force to make up for the energy lost at the scapular link.⁶⁸ This compensation may result in injuries.⁶⁸

Musculature of the Shoulder Girdle

The supraspinatus, infraspinatus, teres minor, and subscapularis muscles form the rotator cuff and function as a whole to dynamically compress the humeral head into the glenoid fossa.⁶⁹ The supraspinatus, infraspinatus, and teres minor tendons blend into the glenohumeral joint capsule.^{27,70} The resultant compressive force developed by the rotator cuff along with other shoulder girdle muscles must be coordinated to maintain centralization of the humeral head within the center of the glenoid fossa; therefore, achieving dynamic stability.^{69,71} Unbalanced or decreased shoulder muscle activation increases translational forces and decreases compressive force, which in turn destabilizes the joint.⁷¹

The supraspinatus abducts the glenohumeral joint.⁴⁵ It originates from the supraspinous fossa of the scapula and inserts onto the greater tubercle of the humerus and glenohumeral joint capsule.⁴⁵ It is innervated by the suprascapular nerve.⁴⁵ More muscle activation of the supraspinatus muscle occurs at the first 30° of glenohumeral abduction while the middle deltoid muscle has greater contribution toward the end of glenohumeral abduction in the scapular plane.⁷²

The infraspinatus originates from the infraspinous fossa of the scapula and inserts onto the greater tubercle of the humerus and produces external rotation of the glenohumeral joint.⁴⁵ Also, it stabilizes against posterior subluxation,²⁷ and produces horizontal abduction.⁷³ It is innervated by the suprascapular nerve.⁴⁵

The teres minor originates from the lateral border of the scapula and inserts onto the greater tubercle of the humerus and glenohumeral joint capsule.⁴⁵ It is innervated by

the axillary nerve.⁴⁵ It functions along with the infraspinatus to externally rotate the humerus²⁷ and also produces horizontal abduction.⁷³

The subscapularis originates from the subscapular fossa of the scapula and inserts onto the lesser tubercle of the humerus and glenohumeral joint capsule.^{45,58} The inserting tendon fibers continue to the medial wall of the bicipital groove as well as to the fovea capitis of the humerus.⁵⁸ Therefore, the insertion site of the subscapularis supports the long head of the biceps tendon, especially from an anteromedial dislocation of the tendon where it curves.⁵⁸ As the arm abducts from 0° to 90°, the subscapularis muscle becomes more taut, and external rotation further tightens the muscle to prevent anterior dislocation of the humerus.⁶² It is innervated by the upper and lower subscapular nerve and internally rotates the humerus.⁴⁵

The anterior, middle, and posterior deltoid abducts the shoulder.⁴⁵ The anterior deltoid originates from the anterior border of the lateral one third of the clavicle, the middle deltoid originates from the lateral margin and superior surface of the acromion, and the posterior deltoid originates from the posterior border of the scapular spine.⁴⁵ Those three deltoid fibers insert onto the deltoid tuberosity of the humerus and are innervated by the axillary nerve.⁴⁵ The anterior deltoid muscle also horizontally adducts the humerus while the posterior deltoid muscle horizontally abducts the humerus.⁷³

The sternal fibers of the pectoralis major originate from the sternum and costal cartilages of the first 6th or 7th ribs and insert onto the greater tubercle of the humerus.⁴⁵ It is innervated by the lateral pectoral nerve and adducts and horizontally adducts the humerus.⁴⁵ Further, the clavicular fibers of the pectoralis major originate from the anterior surface of the medial half of the clavicle and insert onto the greater tubercle of

the humerus.⁴⁵ It is also innervated by the lateral pectoral nerve and flexes, internally rotates, and horizontally adducts the humerus.⁴⁵

The long head of the biceps originates from the supraglenoid tubercle of the scapula while the short head originates from the apex of the coracoid process, and both insert onto the radial tuberosity and the lacertus fibrosus.⁴⁵ It is innervated by the musculocutaneous nerve and adducts and flexes the humerus.⁴⁵ The long head of the biceps tendon provides dynamic stability to the glenohumeral joint, as it runs over the superioanterior portion of the joint capsule.^{3,57,74,75} It compresses the humeral head into the glenoid fossa with the rotator cuff muscles.^{3,69,75} By adding a load to the tendon, it reduces humeral head translation in the anterior and inferior directions at 30° of glenohumeral abduction,⁵⁷ as well as translations in all directions when the arm is abducted at 0°, 45°, and 90° with cadavers⁷⁵ and with presence of a complete lesion to the superior glenoid labrum.⁵² Furthermore, at a position of the arm abduction with external rotation, the shoulder's torsional rigidity increases as the force of the biceps brachii increases, which requires greater external rotation torque to cause anterior dislocation.⁷⁶ When the activation of the long head of the biceps is diminished due to superior labral lesions, strain to the IGHLC increases at a position of arm abduction with external rotation.⁷⁶

The latissimus dorsi has a wide origin consisting of the T7 through T12 spinous processes, last three or four ribs, thoracolumbar fascia, posterior one third of the iliac crest, and the inferior angle of the scapula, and inserts onto the bicipital groove of the humerus.⁴⁵ It is innervated by the thoracodorsal nerve and adducts, extends, and internally rotates the humerus.⁴⁵

The teres major originates from the inferolateral border of the scapula and inserts onto the lesser tubercle of the humerus.⁴⁵ It is innervated by the lower subscapular nerve and adducts, extends, and internally rotates the humerus.⁴⁵

The anterior fibers of the upper trapezius elevate the clavicle.⁴⁵ It originates from the occiput and cervical vertebrae and inserts onto the lateral one third of the clavicle.⁴⁵ It is innervated by the accessory nerve and ventral ramus and elevates the clavicle.⁴⁵

The posterior fibers of the upper trapezius originate from the occipital protuberance, superior nuchal line, ligamentum nuchae, and C7 spinous process and inserts onto the acromion process.⁴⁵ These fibers are innervated by the accessory nerve and the ventral ramus and also elevate and upwardly and externally rotate the scapula.⁴⁵

The middle trapezius originates from the spinous processes of T1 through T5 and inserts onto the medial aspect of the acromion and scapular spine.⁴⁵ The accessory nerve and ventral ramus innervate the middle trapezius and retracts and externally rotates the scapula.⁴⁵

The lower trapezius originates from the spinous processes of T6 through T12 and inserts onto the scapular spine. The accessory nerve and ventral ramus innervate this part of the trapezius and depresses, retracts, upwardly and externally rotates the scapula.⁴⁵

The levator scapulae originates from the transverse processes of C1 through C4 and inserts onto the medial border of the scapula between the superior angle and the scapular spine.^{45,77} Cervical nerves from C3 and C4 and the dorsal scapular nerve innervate this muscle and it elevates and downwardly rotates the scapula.⁴⁵

The pectoralis minor originates from the 3rd through 5th ribs and inserts onto the coracoid process.⁴⁵ The medial pectoral nerve innervates this muscle and it protracts and downwardly rotates the scapula.⁴⁵ It also internally rotates the scapula.⁷⁸

The serratus anterior originates from the 1st through 8th or 9th ribs and inserts onto the anterior surface of the medial border of the scapula.^{45,77} It is innervated by the long thoracic nerve and protracts and downwardly and externally rotates the scapula.^{45,77}

The subclavius muscle depresses the clavicle.⁷⁹ It originates from the 1st costal cartilage and inserts onto the inferior surface of the medial clavicle.⁴⁵ It is innervated by the subclavian nerve and also protracts the scapula.⁴⁵

The rhomboid major originates from the spinous processes of T1 through T5 and inserts onto the medial border of the scapula.⁴⁵ It is innervated by the dorsal scapula nerve and elevates, retracts, and downwardly rotates the scapula.^{45,77}

The rhomboid minor originates from the ligamentum nuchae and spinous processes of C7 and T1 and inserts onto the medial border of the scapula by the base of the scapular spine.⁴⁵ It is innervated by the same nerve and functions as the rhomboid major.^{45,77}

Pitching/Throwing Mechanics

Phases of Pitching

Pitching mechanics consist of several sequential phases to deliver a pitch to the catcher with a high degree of velocity and accuracy. Coordination of each body segment, termed as the kinetic chain, is required.¹⁸ The ground, legs, and trunk generate force, the shoulder regulates force, and the arm delivers force.¹⁸

Pitching is a downhill throwing skill that occurs on a mound, which is 10" elevated off the field.² As a pitcher faces a batter and both feet are on the rubber, he steps a foot back (stride leg) where all body weight is placed.² The supporting leg is then placed laterally in front of the rubber.² Next, weight shifts from the stride foot to the supporting foot, which initiates the wind up phase.² This weight shift sets a rhythm for each pitch delivery.² After initiation of the wind up, the body rotates 90° so the non-throwing arm is facing the batter.² At the same time, the stride leg is flexed and elevated above the height of the pelvis.^{2,80} Keeping a good balance in this position is necessary to deliver the pitch to the catcher.²

After the wind up phase, the supporting leg is flexed and the stride leg is moving toward home plate, as the body is lowered.² Simultaneously, the trunk needs to stay close to the supporting leg to enhance pitch velocity as the trunk translates forward and rotates later in the sequence.² Also, as the stride leg moves down and forward, the throwing arm is set in the proper position to synchronize with the body, and the hand with the baseball begins to leave the glove.² There is about 100° of shoulder abduction and 50° of horizontal abduction.² With coordination of the stride leg and throwing arm, the semi-cocked position of the throwing arm should occur when the stride foot contacts the ground, which is about 55° of shoulder external rotation² and $86^\circ \pm 20^\circ$ of elbow flexion.⁸¹ The lead leg has about 50° of knee flexion at foot contact.⁸² Additionally, length of the stride is slightly less than the height of the pitcher, and the location of the stride foot is directly in front of the supporting foot and pointing slightly inward.² When the stride foot is turned in too much, the hips will not be able to rotate to generate a large force.² On the other hand, when the stride foot is rotated out too much, hip and trunk

rotation occur too early, resulting in poor energy transfer from the lower to upper extremity.²

After the stride foot contacts the ground, the trunk translates laterally toward the catcher and hip rotation occurs followed by trunk rotation.² Simultaneously, upper trunk extension, elbow flexion, and shoulder external rotation also occur as the trunk rotates.² With the trunk facing the batter, the shoulder reaches maximum external rotation, which is the completion of the arm cocking phase.² Also, this is where the biceps reaches peak activity.⁸³ During this phase, acceleration of the lower extremity and trunk are already initiated.²

During arm cocking, maximum external rotation can reach 178°.² Additionally, from foot plant to the end of arm cocking, the shoulder externally rotates from 90° to 160° on average of 60 ms.¹ At an instant near the end of arm cocking, there is 95 ± 10° of elbow flexion, 165 ± 11° of shoulder external rotation, 94 ± 21° of shoulder abduction, and 11 ± 11° of shoulder horizontal adduction (relative to frontal plane).³ There is also 64 ± 12 N-m of varus torque at the elbow, and 67 ± 11 N-m of internal rotation torque and 310 ± 100 N of anterior force at the shoulder are produced.³ In a study by Wener *et al.*⁸¹ on collegiate players, there was an average maximum shoulder external rotation of 158 ± 10° and 94 ± 9° of elbow flexion occurring during the late cocking phase. Also, a mean of 63 ± 12 % body weight of distraction force at the shoulder has been reported at this instant.⁸¹

The beginning of shoulder IR is the start of the arm acceleration phase.² This change in direction from maximum shoulder external rotation to accelerating shoulder internal rotation is a production of proximal shoulder IR torque.⁸⁴ The longer the arc from

late cocking to ball release, the greater the velocity of the distal segment; therefore, the greater the ball velocity.⁵ Also, a short delay between shoulder internal rotation and elbow extension is vital for greater angular velocity because a reduction of the inertia at the shoulder by elbow extension increases internal rotation torque production.² During this phase, shoulder abduction remains about 100° from foot contact to just before ball release.² Horizontal abduction decreases to about 14° as the trunk rotates and horizontal adduction is about 0° and shoulder external rotation is 110° at ball release.² Also at the instant of ball release, the trunk is flexed about 28°, elbow is flexed about 24°, and the knee of the stride leg is flexed about 46°.⁸² The acceleration phase is completed with release of the ball.²

During this phase, the average peak angular velocity of shoulder internal rotation has been reported as 6,180°/sec (range 3,340 to 9,189°/sec) and the average peak angular velocity of elbow extension was 4,595 °/sec (range 2,287 to 6,993°/sec).¹ Werner *et al.*⁸¹ has reported 2328°/sec ± 394°/sec of maximum elbow extension angular velocity and 6239°/sec ± 1577°/sec of maximum shoulder internal rotation angular velocity at ball release among collegiate pitchers. Similarly, maximum elbow extension angular velocity of 2200°/sec ± 400°/sec and maximum shoulder internal rotation angular velocity of 6100°/sec ± 1700°/sec has been reported in collegiate pitchers.⁸⁵ Also, a varus torque at the elbow during this phase is strongly related to shoulder internal rotation torque and it maintains the integrity of the elbow joint during the pitch.⁸⁴ In addition to rotational torque, a mean distraction force at the shoulder was 75 ± 11 % body weight.⁸¹

After ball release, the arm undergoes elbow extension and shoulder internal rotation.² During this phase, shoulder internal rotation angular velocity is decreased to

zero from its peak value at ball release.² A negative $500,000^\circ/\text{sec}^2$ has been reported at the shoulder and elbow, which is produced by the posterior shoulder muscles and biceps.¹ Also, the shoulder continues into horizontal adduction.² Arm deceleration is completed when the shoulder reaches approximately 0° internal rotation.² At this phase, the throwing arm is outstretched toward home plate, including $25 \pm 10^\circ$ of elbow flexion, $64 \pm 35^\circ$ of shoulder external rotation, $93 \pm 10^\circ$ of shoulder abduction, and $6 \pm 8^\circ$ of shoulder horizontal adduction (in the frontal plane).³ Fleisig *et al.*³ describes this phase as critical because maximum compressive force of 1090 ± 110 N is produced, which reduces anterior and inferior shear forces at the glenohueral joint. Werner *et al.*⁸¹ reported a mean peak distraction force of 81 ± 10 % body weight at the shoulder just after ball release with peak values ranging from 57 to 116% body weight. Another study by Fleisig *et al.*⁸⁶ have reported 350 ± 160 N of posterior force and 89 ± 49 N-m of horizontal abduction torque on the shoulder of the collegiate baseball players.

After the arm deceleration phase, the follow-through phase begins.² This phase ends with extension of the stride leg, hip flexion, shoulder adduction and horizontal adduction, and elbow flexion and supination.²

Scapular Kinematics and Functions

From initiation of the baseball throw, the scapula is positioned in 40° of internal rotation, 10° of upward rotation, and 5° of anterior tilt.⁸⁷ With progression of the throwing sequence, the scapula reaches maximum external rotation with maximum horizontal abduction, peak upward rotation of approximately 40° and posterior tilt with maximum shoulder external rotation.⁸⁷ During horizontal abduction, scapular angles are increased by 18° in external rotation, 13° in upward rotation, and 6° in posterior tilt; there

is an additional increase of 14° in upward rotation and 8° in posterior tilt from maximum horizontal abduction to peak shoulder external rotation.⁸⁷ A study done by Miyashita et al⁸⁸ has demonstrated that maximum scapular posterior tilt occurs before maximum glenohumeral external rotation is reached. This has been referred to as a whip-like motion. From peak shoulder external rotation to ball release, scapular internal rotation and anterior tilt are increased by 10° and 4°, respectively, and upward rotation remains the same.⁸⁷ From ball release to maximum shoulder internal rotation, the scapula moves to 21° of internal rotation, 20° of downward rotation, and 9° of anterior tilt.⁸⁷

The scapula plays an important role during the throwing motion.⁶⁸ First, the scapula provides a stable base for the glenohumeral joint and moves with the humerus in a coordinated manner to keep an instant center of rotation within the physiological limit during full ROM; therefore, achieving maximal concavity-compression at the glenohumeral joint.⁶⁸ Second, the scapula retracts and protracts on the thoracic cage to optimize throwing mechanics.⁶⁸ For example, retraction of the scapula should occur to assist the cocking phase of the throwing motion.⁶⁸ Third, elevation of the acromion process should occur as the scapula upwardly rotates during cocking and the acceleration phase of throwing to prevent subacromial impingement or compression.⁶⁸ Fourth, the scapula provides a stable base for muscular attachment sites.⁶⁸ The scapular stabilizers attach to the superior, medial, and inferior aspect of the scapula and control motion and position of the scapula.⁶⁸ Extrinsic muscles, such as the deltoid, biceps and triceps brachii, attach to the lateral aspect of the scapula.⁶⁸ Finally, a stable and controlled scapula efficiently transfers forces and energy from the proximal to distal segments along the kinetic chain.⁶⁸

Effects of Glenohumeral Instability

A comparison between throwing athletes with healthy shoulders and anterior instability during a baseball pitch demonstrates that both groups reach peak biceps activity during the late cocking phase; however, those with anterior instability maintain a moderate biceps activity while a healthy group decreases in activity.⁸³ This increased activity may be a compensatory mechanism to stabilize the glenohumeral joint.⁸³ There was also increased supraspinatus and infraspinatus activity during the arm cocking and acceleration phases in those with anterior instability.⁸³ The pectoralis major, subscapularis, and latissimus dorsi also showed decreased activity in those with anterior instability, which results in diminished dynamic stability of the anterior glenohumeral joint.⁸³ Furthermore, decreased activity in the serratus anterior was noted, leading to decreased scapular stability.⁸³

Throwing Shoulder Adaptations

Glenohumeral Internal Rotation Deficit (GIRD) is defined as a loss of glenohumeral internal rotation in the throwing shoulder compared to the non-throwing shoulder.⁵ A bilateral difference of more than 25° in shoulder IR is considered to increase the risk for injuries, and baseball players want to keep GIRD to less than 20° or 10% of total arc of motion of the non-throwing arm.⁵ GIRD can be caused by increased tightness of the PIGHL,⁵ increased posterior shoulder muscular tightness,⁶ increased humeral retroversion,^{14,89} or any combination of the three.⁴

Total arc of motion is the summation of glenohumeral external rotation and internal rotation ROM.⁹⁰ The total arc of motion of the dominant shoulder of baseball players is often equal to the non-dominant shoulder, but the dominant side is shifted into

more external rotation with a concomitant decrease in internal rotation.^{14,16,90-93} The cause of this shift is believed to be a result of increased humeral retroversion on the dominant arm.⁷ Equality and shift of total arc of motion have been consistent with 372 professional pitchers.⁹⁰ Furthermore, this shift may reduce the risk of injury as collegiate baseball players with shoulder pain demonstrated a 9.6° difference in total arc of motion bilaterally, while players with no history of shoulder pain displayed 0.9° difference.⁷

Multiple studies have reported increased glenohumeral external rotation and decreased internal rotation ROM among baseball players.^{4,6,7,12,14,16,89,92-97} Thomas *et al.*⁹⁵ reported that collegiate baseball players had more GIRD, less external rotation gain, and more total rotation arc difference when compared with high school baseball players. Freehil *et al.*⁴ reported not only the similar pattern of total arc of motion shift, but also different patterns between starting pitchers and relievers from the beginning to end of one season. The starting pitchers displayed gains of 6.5° in internal rotation and 7.9° in total arc of motion, while relievers had more GIRD with 5.3° decreased internal rotation at the end of one season.⁴ Additionally, Wilk *et al.*⁹² reported that pitchers with GIRD are 1.9 times more likely to get injured and pitchers with total arc of motion greater than 5° bilaterally are 2.5 times more likely to be injured. According to Shanley *et al.*,⁹⁶ there was a 25% prevalence rate of GIRD among a sample of 72 professional baseball pitchers over a two year period.

Soft Tissue Adaptations

A study by Reinold *et al.*⁹⁸ reported that shoulder internal rotation, total arc of motion, and elbow extension in the dominant arm decreased after pitching, but there was no change in the non-dominant arm. After 24 hours, these deficits were still present, even

though there was a pattern of returning to baseline.⁹⁸ This most likely occurs from the significant eccentric contraction during pitching and chronically contributes to ROM changes in addition to bony or capsular adaptations.⁹⁸ Kibler *et al.*⁹⁹ also reported decreased shoulder internal rotation after pitching that was maintained for at least 72 hours. Long-term ROM changes develop when baseline levels are not reached within a 5-day pitching cycle.⁹⁹ In addition to acute reduction of shoulder internal rotation, Ruotolo *et al.*⁷ has concluded that soft tissue contractures of the posterior shoulder cause loss of shoulder total arc of motion and internal rotation.

Along with decreased shoulder internal rotation, decreased horizontal adduction of the dominant arm of baseball players compared to the non-dominant arm has been reported.^{8,12,16,93,96,97} This may be due to posterior shoulder tightness.^{8,12,16,100} Posterior shoulder tightness is soft tissue tightness of the posterior aspect of the glenohumeral joint that is caused by tight musculatures of that region and the posterior glenohumeral joint capsule.¹⁰¹ This posterior shoulder tightness is associated with anterior glenohumeral laxity¹⁰² and forward scapular posture,¹⁶ and can be the start of a pathological cascade for the throwing shoulder pathologies, such as superior labral anterior posterior (SLAP) lesion.⁵ Six professional baseball pitchers who presented with GIRD, rotator cuff tear, and labral pathology all displayed an appearance of increased PIGHL thickness on magnetic resonance arthrographic imagings.¹⁰³

Posterior shoulder tightness can be a direct result of increased posterior capsule thickness of the dominant arm which is often caused by repetitive loading during the throwing motion.^{13,104} More specifically, the increased posterior capsule thickness is hypertrophy of the PIGHL.^{18,103} This hypertrophy has been correlated with increased

glenohumeral external rotation and decreased internal rotation ROM.¹⁰⁴ A common mechanism for this thickening is due to the large forces repeatedly placed on the PIGHL, while the glenohumeral joint is internally rotating during the deceleration phase.^{13,104}

Anterior Glenohumeral Laxity

Previous studies have reported the existence of anterior glenohumeral laxity as a result of repetitive baseball throwing or pitching.^{8,9,105} Specifically, excessive shoulder external rotation elongates the AIGHL resulting in increased anterior glenohumeral laxity.⁹ The shoulder is more stable to anterior displacement when positioned at 90° of shoulder abduction and 90° of shoulder external rotation compared to 90° of abduction with neutral rotation.¹⁰⁵ This is because the capsuloligamentous structures are in a better position to resist force, but they can experience more strain during throwing.¹⁰⁵ A cadaveric study demonstrated that anterior and inferior humeral translation and shoulder external rotation ROM were increased when the AIGHL was elongated.⁹ However, healthy high school baseball pitchers did not display bilateral or directional differences in shoulder laxity or stiffness, which suggested that they may have not yet developed chronic capsuloligamentous adaptations, including anterior capsule attenuation and posterior capsular contracture.¹⁰⁵ Among professional baseball players, a negative relationship between anterior glenohumeral laxity and horizontal adduction and shoulder internal rotation ROM has been reported.⁸ This study suggested that decreased horizontal adduction and internal rotation ROM may be a partial predictor for increased anterior glenohumeral laxity.⁸

Forward Scapular Posture

Forward scapular posture is defined as protraction and anterior tilt of the scapula on the thorax.¹⁰⁶ It can be measured with the double square technique.¹⁰⁷ This technique uses a 12-inch combination square with a second square added in an inverted position. In order to take this measurement, the subjects are asked to stand against wall with their heels and back touching the wall.¹⁰⁷ The tool is then used to measure the distance from the wall to the anterior tip of the acromion process in millimeters.¹⁰⁷ Reliability testing for the double square technique has revealed an ICC = 0.84 and SEM = 4.6 mm.¹⁶ Another study demonstrated excellent intrarater reliability with an ICC = 0.99 and SEM = 0.1 mm.¹⁰⁸ Also, there was a moderate correlation between the double square technique and radiograph for patients with forward scapular posture ($r = 0.55$, $r^2 = 0.30$, $SEE = 1.38$).¹⁰⁷ Therefore, the double square technique is a reliable and valid test to measure forward scapular posture.

Both pitchers and position players display greater forward scapular posture in the dominant arm compared to the non-dominant arm.¹⁶ More specifically, twenty asymptomatic professional baseball pitchers demonstrated a forward scapular posture of 170.7 ± 9.1 mm in the dominant arm and 163.1 ± 10.5 mm in the non-dominant arm.¹⁶ Twenty asymptomatic positional players displayed a forward scapular posture of 165.4 ± 8.3 mm in the dominant arm and 157.7 ± 11.0 mm in the non-dominant arm.¹⁶

Excessive forward scapular posture has been negatively correlated with GH horizontal adduction ROM.¹⁶ This may be due to the posterior shoulder tightness, caused by contracture and increased capsular thickness, pulling the scapula into a more protracted position during the follow through phase of the throwing motion.¹⁶ Tightness

of the pectoralis minor, serratus anterior, and upper trapezius and weakness of the middle and lower trapezius muscles may also cause forward displacement of the scapula.⁴⁵ This posture results in the inability to properly retract the scapula during the cocking phase, which therefore could decrease performance and increase the risk for shoulder pathologies.¹⁶ Unfortunately, current literature does not describe how much forward scapular posture is necessary to increase a baseball player risk of developing a shoulder injury.

Other Static and Dynamic Scapular Alternations

Several studies have been done on scapular alternations observed among throwing athletes.^{15,104,109,110} Statically, throwing athletes display asymmetrical resting scapular posture, with the dominant side of the scapula more anteriorly tilted and internally rotated.¹⁰⁹ Dynamically, Myers *et al.*¹⁵ found that throwers had increased upward rotation, scapular internal rotation, and retraction during humeral elevation. This may be a chronic adaptation to clear the acromion during a baseball throw.¹⁵ Similarly, a study on healthy professional pitchers showed more upward rotation and anterior tilt and less scapular internal rotation than non-throwers throughout shoulder flexion.¹¹⁰ In addition, Thomas *et al.*¹⁰⁴ found that increased scapular upward rotation during the mid-range of shoulder abduction is correlated with increased posterior capsule thickness among collegiate baseball players.

Thomas *et al.*⁹⁵ reported that collegiate baseball players displayed less scapular upward rotation in both the dominant and non-dominant arms and more scapular protraction than high school baseball players. Collegiate baseball players also had greater GIRD and total rotation arc differences. This suggests that more GIRD and total rotation

arc differences may change scapular positions greatly at higher levels of competition.⁹⁵ In addition, subjects with GIRD have shown increased anterior tilt at the end range of shoulder internal rotation at 90° of shoulder abduction compared to a control group. Those with increased GIRD have increased anterior tilt and decreased upward rotation with glenohumeral internal rotation at 90° of abduction.¹¹¹

Throwers with internal impingement have demonstrated greater clavicular elevation and scapular posterior tilt compared to throwers with no history of internal impingement.¹¹² Patients with subacromial impingement have demonstrated greater clavicular elevation and scapular upward rotation with humeral elevation and slightly greater clavicular retraction and scapular posterior tilt with humeral scaption compared to people without subacromial impingement.¹¹³ Furthermore, patients with multidirectional instability have shown decreased upward rotation and increased scapular internal rotation throughout humeral scaption compared to an asymptomatic control group.¹⁹

Comparing asymptomatic athletes to those with scapular dyskinesis showed that those with dyskinesis had 9° less upward rotation from resting to 60° of humeral flexion, but eventually, as the arm elevates, the scapula caught up to the same angle of upward rotation as the asymptomatic athletes.¹¹⁴ This decreased upward rotation during the early phases of humeral elevation may lead to subacromial impingement.¹¹⁴ Also, the dyskinesis group showed less clavicular elevation, less posterior tilt, and more protraction, which may result in subacromial impingement and other pathologies related to scapular dyskinesis.¹¹⁴

Muscular fatigue also affects scapular kinematics. After a fatiguing protocol of the shoulder external rotators, the scapula assumes a more anterior tilted, internal rotated,

and downward rotated position during humeral elevation.¹¹⁵ This may result in subacromial impingement and decreased dynamic glenohumeral stability.¹¹⁵ Since baseball players may experience fatigue of the glenohumeral external rotators during a single game and over competitive seasons, these altered scapular kinematics may occur among competitive baseball players.^{116,117} Over the course of a season, pitchers have been shown to develop less upward rotation compared to position players, which supports these previous findings and theories.¹¹⁷ However, chronic fatigue in the upward rotators, such as the upper and lower trapezius and serratus anterior, and chronic tightness in the pectoralis minor, rhomboids, and levator scapulae may also limit scapular upward rotation.^{116,117}

Bony Adaptations

Glenoid retroversion. Glenoid version is a measured angle that is created by following two lines.^{10,97,118} From an inferior to superior view, one line connects the posterolateral angle of the acromion and the anterior tip of the coracoid process while another line connects the anterior and posterior edges of the glenoid articular surface.^{10,97,118} On average, the dominant shoulder of baseball pitchers have displayed increased glenoid retroversion compared to the non-dominant shoulder.^{10,14,97} The glenoid version of the dominant arm were $8.7^{\circ} \pm 5.6^{\circ}$ ⁹⁷ and $8.6^{\circ} \pm 6.0^{\circ}$,¹⁰ whereas the glenoid version of the non-dominant arm were $5.5^{\circ} \pm 5.2^{\circ}$ ⁹⁷ and $4.9^{\circ} \pm 4.8^{\circ}$.¹⁰ This adaptation is currently believed to be a result of repetitive torsional forces that have acted on the open growth plate of the glenoid from throwing during a young, skeletally immature, age.⁹⁷ In terms of a risk of injury related to glenoid retroversion, pitchers with no history of SLAP lesions showed a 4.4° increase in glenoid retroversion of the dominant arm compared

with the non-dominant side while pitchers with a history of SLAP lesions had no increase in glenoid retroversion compared with the non-dominant side.⁹⁷ Sweitzer *et al.*⁹⁷ has suggested that the long head of the biceps tendon attachment experiences less strain during the cocking phase if both the glenoid and humerus undergo adaptive retroversion.

Humeral retroversion. Humeral retroversion is the amount of rotation within the distal humerus in the direction of external rotation relative to the proximal humerus,¹¹⁹ and is measured as the angle between the humeral head axis and the elbow epicondylar axis.¹²⁰ In other words, the greater humeral retroversion, the more posterior the humeral head faces relative to the distal humerus.¹²¹ Currently, computed tomography (CT) scan technique is the gold standard, and has shown humeral retroversion to be approximately 16.1°, which was found in 65 fresh cadavers.¹²⁰

Since CT scans are not always feasible, an indirect technique using diagnostic ultrasound has been proposed.^{119,121} This technique requires the subject to lie supine with the test arm abducted to 90°, the elbow flexed to 90°, and the palm of the hand facing caudally.¹²¹ The ultrasound head is modified with the attachment of a bubble level.¹²¹ The first examiner applies the ultrasound head to the anterior humeral head to visualize the proximal bicipital groove and rotates the shoulder to where the bicipital groove is located in the uppermost portion of the ultrasound image.¹²¹ With vertical alignment of the ultrasound head to the shaft of the humerus, determined by the level, the uppermost bicipital groove is achieved when the floor of the bicipital groove is horizontal and the greater and lesser tuberosities are at equal heights.¹²¹ A second examiner then applies a digital inclinometer to the shaft of the ulna to measure the angle created between the ulna and a vertical reference.¹²¹ For digital inclinometer placement, one edge of the

inclinometer is aligned with the distal ulna styloid process and the other is aligned with the shaft of the ulna.¹²¹ The ultrasound technique is comparable with the CT scan technique ($r = .797$ and $r^2 = .68$); therefore, US is a valid alternative to measure humeral torsion.¹¹⁹ Also, reliability of US for humeral torsion measurement has been presented, including intrarater reliability = 0.997 with a SEM of 0.8°,¹¹⁹ interrater reliability = 0.99 with a SEM of 1.5°,¹¹⁹ and an ICC of 0.98 for the right shoulder and an ICC of 0.94 for left the shoulder.¹²¹

Humans have high humeral retroversion at birth and move into more humeral anteversion as they age.¹²² At age 8, humeral anteversion is close to maturation, with complete development around 16 to 19 years old.¹²² Using a variation of the standard anthropologic measuring technique, the average amount of humeral retroversion for adults has been found to be $32.8^\circ \pm 10.5^\circ$ for the right shoulder and $26.9^\circ \pm 13.2^\circ$ for the left shoulder.¹²³ However, youth baseball players between 11 to 14 years old actually display increased humeral retroversion in the dominant arm than the non-dominant arm.⁸⁹ This occurs due to a large and repetitive compressive and tensile stresses on the proximal humerus from throwing that may fuse the open epiphyseal plate earlier, resulting in greater retroversion.^{13,89} Whiteley *et al.*¹²⁴ reported a positive relationship between humeral retroversion and throwing experience prior to age 16. In another study by Whiteley *et al.*,¹²⁵ both adult and adolescent baseball players displayed similar increases in humeral retroversion (adult: dominant $12.0^\circ \pm 12.4^\circ$ and non-dominant $24^\circ \pm 12.7^\circ$, adolescent: dominant $13.8^\circ \pm 8.6^\circ$ and non-dominant $25.0^\circ \pm 9.2^\circ$). Crockett *et al.*¹⁴ found that there was no significant difference in humeral retroversion between the non-dominant shoulder of a throwing group ($23^\circ \pm 10.4^\circ$) and the non-dominant shoulder of a

non-throwing group ($19^\circ \pm 13.5^\circ$). This suggests that increased humeral retroversion in the dominant shoulder is an adaptive change due to overhead throwing. This increase is beneficial because the shoulder can gain more external rotation, which can assist in generating more velocity without stressing the anterior structures.⁹¹ Increases in retroversion may also affect glenohumeral ROM, such as increasing external rotation with a concomitant decrease in internal rotation ROM.^{10,12-14,91,126,127} Further, a trend has been found that elite adolescent baseball players with an increased humeral retroversion in both arms, may have more proprioceptive acuity in the anterior glenohumeral joint. This may be due to more input coming from muscle spindles rather than joint capsule proprioceptors when compared to arms with increased anteversion.¹²⁷ Active proprioceptive acuity was tested around 80° of glenohumeral external rotation, suggesting that the humerus with increased retroversion was in mid-range whereas the humerus with increased anteversion was at the end range.¹²⁷ Also, humeral retroversion was negatively correlated with horizontal adduction and internal rotation ROM, suggesting that there is less horizontal adduction and internal rotation ROM with increased humeral retroversion.⁹⁶

Throwing Related Injuries

Burkhart *et al.*⁴⁶ first described the SICK scapula, which stands for Scapular malposition, Inferior medial border prominence, Coracoid pain and malposition, and dysKinesis of scapular movement. This condition is associated with several throwing shoulder pathologies.¹⁸ The SICK scapula displays protraction and an upper scapular anteroinferior tilt.¹⁸ Excessive protraction of the SICK scapula results in patterns of increased tensile load on the anterior glenohumeral joint and compressive load on the

posterior glenohumeral joint, increased peel-back labral stress due to increased external rotation, decreased scapular retraction that causes posterior compression on the labrum and rotator cuff, decreased scapular stability for muscular origin that decreases muscular strength, and decreased acromial elevation that causes subacromial impingement.^{18,78} Also, excessive scapular protraction during a pitch potentially causes tensile injury to the suprascapular nerve as it courses around the scapular notch and a strain to the medial scapular muscles.¹²⁸

When muscular fatigue, weakness, and/or capsular laxity at the shoulder exist, the GH joint can become unstable during overhead throwing, which may result in subacromial impingement.³ When there is inability to inferiorly translate the humeral head during an overhead throw, superior migration of the humeral head may occur.³ This would cause impingement of the rotator cuff or biceps tendon between the greater tubercle and the acromion or coracoacromial ligament.^{3,78} Patients with subacromial impingement compared with asymptomatic individuals during arm elevation showed a decrease in upward rotation, increase in anterior tilt and IR, decreased activity of the serratus anterior and increased activity of the upper and lower trapezius muscles.²⁰

Walch *et al.*¹²⁹ first described internal impingement as pain between the posterosuperior aspect of the glenoid and the greater tubercle of the humerus during shoulder external rotation with abduction between 90° and 150°. Internal impingement may be caused by a contracture to the PIGHL rather than anterior capsule laxity.¹³⁰ This is due to less inferior humeral migration during maximum external rotation with simulated PIGHL contracture compared with anterior capsule laxity on cadaveric specimens.¹³⁰ Similarly, Myers *et al.*⁶ reported that throwing athletes with internal

impingement have greater GIRD and posterior shoulder tightness with no difference in external rotation gain compared to a control group of throwing athletes.

Type 2 SLAP lesions have been reported to occur at the posterosuperior quadrant or both posterosuperior and anterosuperior regions of the glenoid.⁵ Of 124 baseball pitchers with a type 2 SLAP lesions, GIRD ranged from 25 to 80°, with a mean of 53°. ⁵ Another mechanism for SLAP lesions is peel-back mechanism.⁵ With the shoulder abducted and in ER during the cocking phase, the long head of the biceps is shifted to a posterosuperior position in a vertical and posterior angle.⁵ This dynamic movement changes the biceps tendon vector posteriorly and a torsional force is applied to the posterosuperior labrum through the twisted biceps tendon at its base.^{5,130} This peel-back mechanism is worsened by a tight PIGHL that is a common cause of GIRD.^{5,130} Also, this peel-back force is magnified by increased protraction of the scapula, which anteriorly tilts the glenoid.⁵

As a shoulder with a tight PIGHL abducts and external rotates, the center of rotation of the humeral head on the glenoid shifts posterosuperiorly creating slack in the anterior capsule.⁵ This shift in position allows for greater external rotation ROM. This increase in external rotation can create additional torsional stress to the superior labrum and the long head of biceps ultimately resulting in SLAP lesions.⁵ Increased protraction of the scapula, which has also been associated with posterior shoulder tightness,¹⁶ may also increase the risk of anterior capsule damage.^{5,17} This is because the static restraints of the anterior glenohumeral joint may experience increased stresses when the scapula is protracted and the humerus is in maximal external rotation.¹⁷

Conclusion

In summary, the current literature of the overhead throwing shoulder has been well documented, but it requires extensive further investigations to improve our understanding of the cause and effects and subsequent relationships among the numerous soft tissue and bony alterations experienced by baseball players.

CHAPTER III

METHODS

Participants

A total of 48 asymptomatic NCAA Division I collegiate baseball players participated in this study, which consisted of 27 pitchers and 21 position players (Table 1). All testing was conducted during the off-season. Participants were excluded from the study if they had a recent shoulder or elbow injury (past 6 months) or a history of shoulder surgery. Due to these criteria, one participant was excluded because of shoulder or elbow injury in the past six months. No testing was completed following any throwing activities or resistance training. Each participant was briefed on the study, signed an informed consent form, and completed a medical history form that were approved by the university institutional review board.

Table 1: Participant Characteristics (means \pm standard deviations)

Player position	Number of participants	Age (yrs)	Height (cm)	Mass (kg)
Pitchers	27	20.3 \pm 1.2	187.30 \pm 6.52	90.79 \pm 8.52
Position players	21	20.1 \pm 1.1	183.49 \pm 6.42	89.88 \pm 9.60
Total	48	20.2 \pm 1.2	185.63 \pm 6.69	90.39 \pm 8.92

Instrumentation

A Terason t3000 M-series diagnostic ultrasound unit (Teratech, Burlington, MA) and digital inclinometer (SPI-Tronic, Garden Grove, CA) were used to measure humeral retroversion. A bubble level was attached to the ultrasound head (5-12 MHz linear array) to aid in proper positioning and a clear gridded ruler was attached to the screen to ensure the greater and lesser tuberosities were aligned horizontally. The LigMaster arthrometer (Sport Tech Inc, Charlottesville, VA) was used to measure anterior glenohumeral laxity. This arthrometer uses a modified Telos GA-II/E stress system (Austin & Associates Inc, Fallston, MD) with specialized software to calculate laxity of soft tissue restraints. Two 12” combination squares (Johnson Level & Tool Manufacturing Co, Inc, Mequon, WI) were used to measure forward scapular posture.

Humeral Retroversion Measurement

Humeral retroversion was measured using a technique described by Whiteley *et al.*¹²⁵ Participants were positioned supine, with the test shoulder abducted at 90°, elbow flexed at 90°, and the wrist in a neutral position. A split level was attached to the ultrasound head so vertical alignment on the anterior glenohumeral joint was achieved. One examiner applied the ultrasound head over the anterior glenohumeral joint to visualize the bicipital groove, while a second examiner rotated the humerus until the greater and lesser tuberosities were at equal height parallel to the floor. The horizontal alignment of both tuberosities were ensured with attachment of a clear gridded ruler on the image screen. Once this position was determined, the second examiner aligned the digital inclinometer with the shaft of the ulna, between the styloid and the olecranon processes. The angle of torsion relative to the vertical reference line calculated by the

digital inclinometer was recorded. Degrees of internal rotation were recorded as negative and degrees in external rotation were recorded as positive. *A priori* reliability of this technique was measured on the dominant shoulder of 7 volunteers with no history of humeral fracture or shoulder surgery. Each participant was measured twice within a 24 hour period by the same investigator. Intrarater reliability was found to be excellent with an intraclass correlation (ICC) of .96 (95% Confident Interval = .787 - .994, $p = .001$) and a standard error of measurement (SEM) of 1.95°.

Anterior Glenohumeral Laxity Measurement

To measure anterior glenohumeral laxity, each participant was in a seated position with the test shoulder abducted to 90°, the elbow flexed to 90°, and the palm of the hand facing forward. The arm was placed within the LigMaster, which was placed on a firm table with padded stabilizations at the coracoid process and elbow. Twelve daN (120N) of anterior force were applied to the posterior humeral head at a rate of 1 daN/s.⁸ To determine anterior GH laxity, the difference between the inflection point and the terminal displacement recorded at 12 daN of anterior force was used.¹⁰⁵ The inflection point was calculated by the LigMaster software using values at the end of posterior soft tissue compression that was caused by the pressure of the anterior force and at the initiation of humeral head translation. *A priori* reliability of this technique was measured on the dominant shoulder of 7 volunteers with no history of humeral fracture or shoulder surgery. Each participant was measured twice within a 24 hour period by the same investigator. Our intrarater reliability was ICC = .52 (95% Confident Interval = -.299 - .922, $p = .217$) with a SEM of 1.04mm.

Forward Scapular Posture Measurement

To measure forward scapular posture, the double square method presented by Peterson *et al.*¹⁰⁷ was used. Each participant was asked to stand in a relaxed position with their back and heels against the wall. The participant marched in place for 10 steps to ensure relaxation of the shoulders. One side of the square was placed against the wall over the test shoulder, and the other square was placed against the anterior aspect of the acromion process. The amount of forward displacement by the scapula was measured using the 12-in ruler between the two squares. Difference between the two shoulders was recorded. *A priori* reliability of this technique was measured on the dominant shoulder of 7 volunteers with no history of humeral fracture or shoulder surgery. Each participant was measured twice within a 24 hour period by the same investigator. Our intrarater reliability was ICC=.89 (95% Confident Interval = .332 - .982, $p = .003$) with an SEM of 2.6mm.

Procedures

Participants reported to an athletic training facility and were briefed about the study and signed an informed consent form. Measurements of humeral torsion and anterior glenohumeral laxity were taken on the dominant shoulder and measurements of forward scapula posture were taken on both shoulders to calculate the bilateral difference. The order of measurements was randomized and each variable was tested twice and averaged for data analysis. The participants were asked to not engage in any throwing or conditioning activity prior to our measurement on that day.

Data Analysis

Multiple regression analyses were run using IBM SPSS Statistics 20.0 (Chicago, IL) to determine the effect of variable combinations on an individual variable. Alpha was set *a priori* at .05.

CHAPTER IV

RESULTS

There were no significant multiple regression correlations ($p > .68$) for any of the variable comparisons. The result of multiple regression between humeral torsion and a combination of anterior glenohumeral laxity and forward scapular posture was $R = .02$ ($p = .99$), between anterior glenohumeral laxity and a combination of humeral torsion and forward scapular posture was $R = .13$ ($p = .69$), and between forward scapular posture and a combination of humeral torsion and anterior glenohumeral laxity was $R = .13$ ($p = .68$). The mean and standard deviation for humeral torsion was $-16.0 \pm 9.8^\circ$, anterior glenohumeral laxity was 13.4 ± 1.5 mm, and the bilateral difference in forward scapular posture was 6.5 ± 7.9 mm.

CHAPTER V
DISCUSSION AND CONCLUSION

Discussion

Adaptations in humeral torsion, anterior glenohumeral laxity, and forward scapular posture involve different structures that occur over various stages in human development. Although, we hypothesized that relationships would exist between these variables, no significant correlations were found.

Clinicians have hypothesized that increased humeral retroversion, which is common in the dominant arm of baseball players,^{10,12-14,89,91,124-127} is beneficial for such athletes so the arm can achieve maximal external rotation during the cocking phase without stressing the anterior capsuloligamentous structure; therefore, decreasing the risk of developing excessive anterior laxity.⁹¹ This is because for athletes with increased retroversion, the distal shaft of the humerus is more externally rotated relative to the humeral head; therefore, allowing for greater external rotation with less stress on the anterior glenohumeral joint. However, the results of our study did not support this relationship. Crawford and Sauers¹⁰⁵ reported that high school baseball pitchers did not have increased anterior glenohumeral laxity in the throwing shoulder compared to the non-throwing side, suggesting that chronic capsuloligamentous adaptations have not developed at this stage of human development.¹⁰⁵ However, at the age of high school

baseball pitchers, their adaptations of humeral torsion should be close to completion.¹²² Youth baseball players, 11 to 14 years old, have displayed increased humeral retroversion,⁸⁹ and adolescent and adult baseball players have also shown similar values of increased humeral retroversion.¹²⁵ Further, humeral retroversion will be completed during adolescent around age 16 to 19 years old.¹²² This may be a reason why humeral retroversion and anterior glenohumeral laxity occur independently. Therefore, regardless of the amount of humeral retroversion present, other factors such as internal rotation torque accumulated during excessive throwing can cause microtrauma to the anterior capsuloligamentous

Forward scapular posture is a muscular adaptation resulting in protraction and anterior tilting of the scapula on the thorax.¹³² Although humeral torsion adaptations are typically completed in adolescence,¹²² adaptations of scapula position may continue throughout the baseball career.¹¹⁷ The anterior inferior glenohumeral ligament adaptations typically occur chronically, but adaptations of the scapula is influenced by short-term and long-term muscular activities. Therefore, forward scapular posture can occur independently regardless of the amount of humeral retroversion or anterior glenohumeral laxity. While no correlation was found and the results did not support our hypotheses, different structures and timing that are involved with these adaptations may explain our results.

As with any investigation, there were limitations to our study. Measurements were taken prior to throwing or conditioning activities; therefore, this study controlled for possible short-term tightness of the shoulder musculature. However, we did not control for any throwing or conditioning activities in the days leading up to our measurements

although baseball teams were off from practices or strength and conditioning programs. If participants engaged those activities individually, values of forward scapular posture may have been affected. Since this study was a cross-sectional study, the measurements were only taken during the off-season. A previous prospective study has found a decrease in scapular upward rotation at the end of a season among pitchers.¹¹⁷ Therefore, future research should assess these measurements throughout a season, as the degree of adaptations may change, especially with anterior glenohumeral laxity and forward scapular posture. Also, years of overhead throwing experience and age that the participants started playing baseball were not asked in this study. Other variables such as these may have an effect on humeral retroversion, anterior glenohumeral laxity, or forward scapular posture. More throwing experience prior to the age of 16 has demonstrated greater humeral retroversion¹²⁴ and healthy high school baseball players have not shown an increase in anterior glenohumeral laxity in the throwing shoulder compared to non-throwing shoulder.¹⁰⁵ Therefore, in collegiate baseball players, years of overhead throwing experience and age that the participants started playing may correlate to humeral torsion, forward shoulder posture and anterior glenohumeral laxity. Future research with a prospective or retrospective study is warranted to improve our understanding of throwing adaptations among baseball players.

Conclusion

In conclusion, this was the first study to investigate if relationships exist between humeral retroversion, anterior glenohumeral laxity, and forward scapular posture in collegiate baseball players. The results of the study did not support our hypotheses, showing there are no relationships among these three variables.

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