Biomechanics of UCL Tears and Tommy John surgery in MLB pitchers

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Introduction

Major League Baseball pitchers have been becoming bigger and stronger with the average height and weight of MLB pitchers increasing from 6'1" 189 pounds in 1955 to 6'3" 205 pounds in 2014 (12). Since Major League Baseball has begun recording velocities of pitches with their Statcast data tracker, the average fastball velocity of pitchers has increased from 90.9 MPH in 2006 to 93.5 in 2016 with a record high of 106 MPH being clocked in during the 2010 season by Aroldis Chapman (13,17). For a pitcher to be able to throw a pitch of this velocity they must be able to transfer momentum up through their body using a process called the kinetic chain. The kinetic chain is a coordinated effort of muscle units from the entire body culminating with an explosive motion with the upper extremity to achieve the overhead throw. The kinetic chain consists of six phases, the windup, early cocking, late cocking, acceleration, deceleration and the follow through (16). The late cocking and acceleration phase are what are going to be looked into the most during this paper because the greatest amount of valgus torque is placed upon the medial elbow during these phases (3,5,6,10,16). Valgus stress in this sense is defined as a force that wants to displace the arm distal to the elbow joint laterally and away from the midline in the frontal plane. The humero-ulnar joint of the elbow joint complex is a hinge joint and does not allow for frontal plane motion. Any valgus stress experienced around the elbow joint would be resisted by the ligament complex around the medial elbow. This valgus torque on the medial elbow puts a high amount of stress upon the valgus stabilizers, specifically the Ulnar Collateral Ligament (UCL). When too much valgus torque is placed upon the Ulnar Collateral Ligament, more precisely the anterior bundle of the Ulnar collateral ligament, it can tear and significantly impact an individual's ability for overhead throwing. Once torn, the thrower undergoes a procedure called 'Tommy John' surgery to reconstruct the torn ligament. First performed by renowned surgeon Dr. Frank Jobe on pitcher Tommy John, Dr. Jobe was able to harvest his palmaris longus tendon and anchor it in place of the torn UCL through small tunnels bored into the medial epicondyle of the humerus and the proximal end of the ulna, located inferiorly and medially to the coronoid process. The number of pitchers who have received this procedure has grown immensely from the first surgery in 1974 to 2003 when approximately 1 in 9 MLB pitchers had received Tommy John to today when officially 26.2% of MLB pitchers, or a little more than 1 in 4 have had their UCL reconstructed (15). These trends pose the question, what about pitching puts players at such high risk for UCL tears and does the reconstruction surgery enhance the pitchers elbow from a biomechanical perspective?

Applicable Anatomy

Soft tissue of the elbow account for about 50% of elbow stability and can be classified as dynamic muscular stabilizers and static ligamentous restraints (5,7,9,14). For the medial elbow, the flexor/pronator mass are the main dynamic muscular stabilizers and the UCL and the medial side of the joint capsule are the main static ligamentous restraints to help resist valgus instability. The UCL is composed of three separate bundles: anterior (the primary restraint to valgus stress), posterior and transverse (Figure 1). The anterior bundle is the most commonly injured during pitching. The anterior bundle itself is composed of an anterior band, which is taut and serves as the primary ligamentous valgus stabilizer from 30-90 degrees of flexion, and the posterior band, which is taut and serves as the primary ligamentous valgus stabilizer from 90-120 degrees of flexion (5).

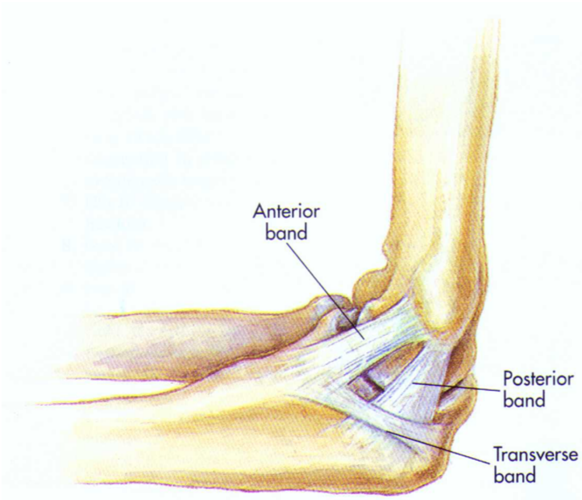

Figure 1

Biomechanics of UCL tears

As stated above, the most commonly torn part of the UCL complex is the anterior bundle. This bundle of the ulnar collateral ligament provides 31% of total resistance to valgus stress (9). However, with increased elbow flexion the UCL provides a larger percentage of overall resistance to valgus stress, increasing to 55% of total resistance to valgus stress at 90 degrees of flexion (9). This is very important because the arm is between 90 and 100 degrees of flexion during the late cocking and early acceleration phase of the kinetic chain (i.e. the phases with most valgus torque on the medial elbow). This would mean that specifically the posterior band of the anterior bundle of the UCL is the most important ligamentous structure in the medial elbow for overhead athletes such as pitchers.

The mean valgus stress per pitch in an adult is 64 N.m. which occurs during the late cocking and early acceleration phases of the kinetic chain (3,5,6,7,9,14). This stress would be the equivalent of valgusly loading 150 baseballs or about 5 bowling balls on the elbow joint. At the elbow joint, eccentric contraction of the muscles within the flexor/pronator mass serve to resist valgus force but still >50% of the valgus stress is transmitted through the UCL. This means stresses greater than 32 N.m. are experienced directly on the anterior bundle of the UCL (3,5,9). In cadaver studies, the mean load to failure of a native UCL has been reported to be 34.29 N.m. for the anterior bundle of the UCL (3,5,9). This means that the peak mean stress placed on the UCL is nearly sufficient enough to cause a tear.

How valgus stress is created during the kinetic chain

It is easy to understand how a valgus stress can be applied to the elbow joint in a two-dimensional diagram, but home does a dynamic complex movement such as pitching generate so much valgus torque on the elbow? The valgus torque is produced during the pitching motion because of the combination of the creation of scapular retraction, horizontal abduction and external rotation quickly followed by horizontal adduction, scapular protraction and internal rotation. This puts the arm distal to the elbow joint into external rotation motion and when the humerus begins to internally rotate the elbow joint is put under serious stress especially the tensile stress across the medial elbow.

Figure 2

This process begins with the activation of the supraspinatus, infraspinatus and teres minor externally rotate the shoulder and position of the humeral head in the glenoid fossa. The serratus anterior and the scapular retractors (middle trapezius, rhomboid and levator scapulae) position the scapula in upward rotation and retraction providing a stable base in which the humeral head can rotate. The elbow also begins to flex (Figure 2). This process begins during the early cocking phase and reaches the peak shoulder external rotation and abduction as well as scapular retraction during the late cocking phase (16).

The muscles described above are able to produce enough of an external rotation, abduction and upward rotational torque to overcome the arms angular moment of inertia and put it in motion to a peak positon of about 165-175 degree external rotation, 90-95 degree abduction (16). From Newton's first law a body in motion will stay in motion unless acted on by an outside force, in this case to throw the ball forward the pitcher needs to produce a force to counteract the external rotation, scapular retraction and horizontal adduction. During the late cocking phase, the torso will begin to rotate and the anterior deltoid and pectoralis major contract to bring the throwing arm into horizontal adduction. During the horizontal adduction, the humerus is still externally rotating (Figuree 4). Near the end of the late cocking phase the peak external rotation is reached, right before this point, maximum shoulder internal rotation torque occurs. This is important because as I described above, the humerus' moment of inertia would continue to take it into external rotation unless acted on by an outside source. This outside source is the internal rotators, after being pre-stretched during the external rotation they are able to eccentrically contract to decelerate the

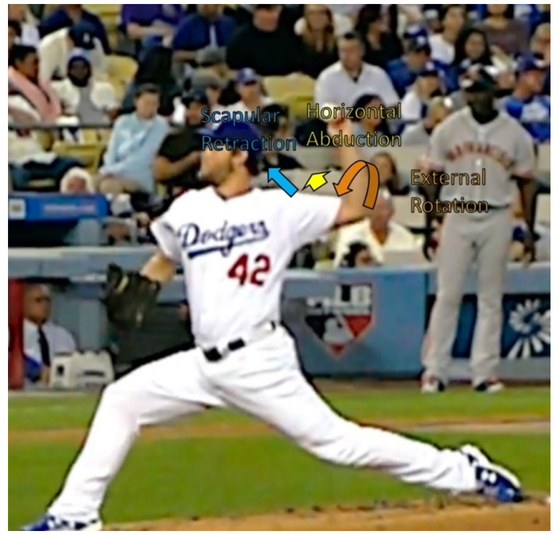

Figure 3

Figure 4

Figure 5

humerus and reach maximum external rotation (Figure 5). Immediately following the eccentric contraction, the internal rotators contract concentrically and produce an increased amount of force due to the stretch shorten cycle and the release of stored elastic energy. This terminates the late cocking phase and begins the acceleration phase.

The acceleration phase is defined as the time between maximum external rotation and the release of the ball. During this phase, the energy created during the kinetic chain is transmitted through the upper extremity and through the ball. The increased force produced by the internal rotators causes the humerus to internally rotate at velocities as high as 7000-9000 degrees per second (16). As the torso continues to rotate and flex, the scapula protracts, humerus horizontally adducts and the elbow extends (Figure 6). During this phase of acceleration, the valgus stress on the UCL decreases compared to the transition between late cocking and acceleration.

Figure 6

As the force created by the kinetic chain is transmitted through the upper extremity, stress is placed on the medial elbow because of the forearm, hand and ball want to continue to externally rotate while the humerus internally rotates as described above (Figure 7). This means the medial side of the elbow is put in tension and the lateral side of the elbow is put under compression. This tension on the medial elbow specifically on the posterior band of the anterior bundle, is what causes tears. Looking at the stress strain properties of the UCL, we see that for every single pitch thrown the tensile stress applied to the UCL stretches out the ligament through the toe region and the elastic region and often surpassing the yield point (Figure 8).

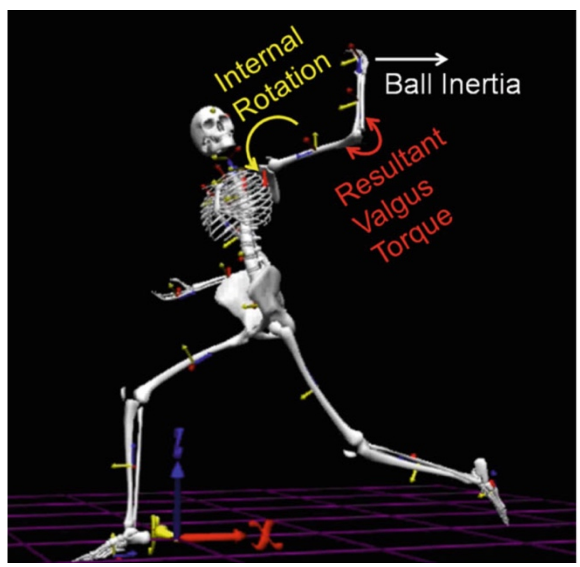

Figure 7

Types of UCL Tears

The UCL is a dynamic structure that does undergo hypertrophy, the mean thickness of a UCL in throwing arms was 6.2 ±1.6 mm compared to only 4.8 ± 1.3mm on non-throwing arms (5,9). This means that the UCL is strained past the yield point consistently during the throwing motion because for hypertrophy to occur there needs to be an overload applied to the structure, in this case the UCL, and micro damage to occur. An adequate amount of rest is also needed for the ligament to recovery and repair itself. Because MLB pitchers have such a strenuous schedule with relief pitchers throwing on average 17 pitches almost every day (1) and starting pitchers throwing on average 92 pitches per game they pitch which is about every five games of the MLB season (2), their elbows are not given adequate time to fully recover. These statistics also do not take into account the numerous pitches thrown when these pitchers warm up. This is how an overuse injury could occur in the UCL, the yield point is passed and micro tears occur consistently over time. This lowers the stress-strain properties of the remaining healthy tissue compared to that of the intact ligament. The yield point and the ultimate failure point are lower for the UCL with micro damage build up and require less stress applied to fully tear because less ligamentous fibers of the UCL are healthy and present to help resist a load. This type of tear is associated with chronic elbow pain and decrease in velocity and performance because the damaged ligament can no longer sustain the same amount of force transmitting through the upper extremity (9,18,19). The other type of tear is an acute tear in which the ultimate failure point is passed entirely by the valgus load placed on the UCL. With an acute tear, there is often a pop heard as the ligament fully tears. After the ligament has fully torn there is valgus instability present in the humero-ulnar joint (9,18,19) Valgus instability is defined as the movement laterally along the elbow joint in the sagittal plane in anatomical position. Movement can occur here because the UCL that is usually present on the medial elbow to resist valgus movement is torn and can no longer resist

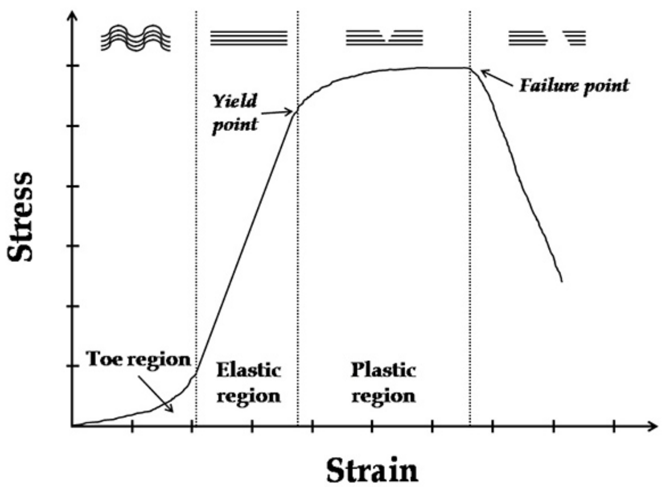

Figure 8

this movement. Pitchers who have suffered this damage to their medial elbow can no longer throw due to severe pain and instability in their elbow. For these pitchers, 'Tommy John' Surgery is needed to reconstruct the medial elbow and replace the torn UCL to be able to pitch again.

Biomechanics of UCL Reconstruction

The goal of the UCL reconstruction surgery is to create a replacement for the torn UCL and to replicate the stability and support that the native ligament did. Many believe that UCL reconstruction surgery can biomechanically augment performance due to some pitchers returning to play throwing harder and having statistically greater seasons than before surgery, all biomechanical research and evaluations have provided this narrative to be false.

The palmaris tendon used as the graft to replace the anterior bundle of the UCL had actually a greater load till failure than the native ligament in cadaveric studies (357N vs 260N) (5). Although this study shows the palmaris longus tendon is stronger than native ligament, reconstruction techniques have not been able to create failure strength greater than the native ligament. Looking at the biomechanical properties of the reconstructed elbow the average ultimate failure point was 30.55 ± 19.24 N.m. while the ultimate failure point of intact elbows was 34.29 ± 6.9 N.m. (5,9). A pairwise comparison of the two were also conducted that determined that the ultimate failure point of the reconstructed elbow was 95% of that of the intact elbow. The ultimate failure points have been almost replicated by the reconstruction surgery, the stiffness of the reconstructed UCL has not been replicated. The average stiffness of the intact elbow was 42.81 ± 11.6 N/mm compared to 20.28 ± 12.5 N/mm (5). Stiffness is the slope of the elastic region of the stress-strain graph means the native ligament requires twice as much force to be lengthened the same amount as the replicated ligament (Figure 9). Because the native ligament has a greater slope and higher ultimate failure point than the reconstructed ligament it can contain and

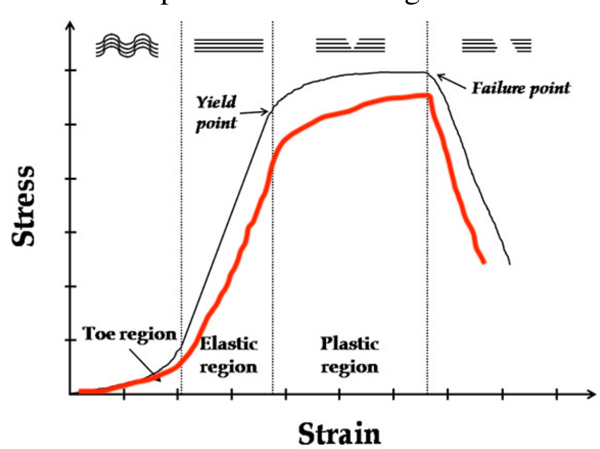

Figure 9

release more energy through the upper extremity without tearing. This is strong evidence that a native ligament is still hands down superior to that of a reconstructed ligament.

Conclusion

As pitchers across all baseball levels are becoming bigger and stronger, they are able to produce more force through the kinetic chain and into the baseball. To be able to transmit this force through the upper extremity, the anatomical structures of the medial elbow need to be fully functioning because without them sever valgus instability would be present and pitching/throwing would not be able to occur. The posterior band of the anterior bundle of the UCL is the most important ligamentous structure of the medial elbow and is key for any overhead athletes to be able to resist the valgus stress produced during the throwing motion. The valgus force produced by the inertia of the forearm, hand and ball moving in the opposite direction as the internal rotation and horizontal adduction of the arm in late cocking/early acceleration phases. This peak mean valgus force produced on the UCL on every throw is within 93% of the ultimate failure point of the ligament. Meaning for a pitcher that with every pitch thrown, their UCL nears a full tear and most likely crosses into the plastic region of the stress-strain graph which would induce micro tears as evidenced by the hypertrophy of the UCL in throwing elbows. Now that the surgery has become so common in today's baseball culture we have to be cognizant that no matter what the rumors tell us that UCL reconstruction surgery enhances performance and makes you throw harder, biomechanical studies hands down tell us that reconstructed ligament is inferior to that of the native ligament.

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