Biomechanical Estimation of Elbow Valgus Loading in Throwing Athletes as a Means to Reduce Injury Risk

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Introduction

Throwing athletes competing in sports such as baseball, javelin, cricket and handball are exposed to greater ulnar collateral ligament (UCL) injury risks due to accumulated overhand repetitions and elevated arm accelerations.[1-3] Repetitive loads fatigue and damage the elbow's dynamic stabilizers placing greater stress demand on the UCL as a tensile restraint to valgus opening.[4]

Medial elbow instability and chronic pain typically ended careers of competitive athletes prior to 1974; when Dr. Frank Jobe and his surgical team performed the first UCL reconstruction on a professional pitcher, Tommy John, coining the name "Tommy John surgery." Surgical repair has become quite successful with 83% of patients demonstrating excellent results with highest efficacies associated with the muscle-splitting approach.[5] Both primary and UCL revision surgeries have been increasing over the past several decades.[6] Despite the public's perception, primary reconstruction does not enhance performance and tends to decrease quality of play.[7] Furthermore, revision surgeries report longer recovery periods, lower rates of return to play, decreased competitive durability and shortened career length.[6] This abstract outlines how biomechanical assessments of overhand throwing can approximate joint loads for the medial elbow—a surrogate for UCL loading—and how modifying other aspects of the pitching motion may mitigate medial elbow loading. Further understanding of biomechanical influences on the elbow joint in throwers has the potential to reduce primary and revision UCL surgery rates.

Background

Elbow pain is one of the most common injuries associated with overhand throwing—nearly 50% of all baseball players report elbow pain[2, 8] and similar trends are expected in other throwing sports.[8] While managing throwing frequency and intensity is vital for protecting athletes from overuse injuries,[2,3,8] biomechanical analyses of joint and ligament loading during the delivery may identify risk factors for elbow pain and injury.

Question

How are biomechanical screenings established for coaches, parents and athletes to estimate medial elbow loads and how can mechanics be modified to lessen UCL stress?

Discussion

Elbow loading mechanics are estimated using throwing arm kinematics acquired using high-speed motion capture systems (Figure 1A). Throwing arm kinematics are tracked via retroreflective markers adhered to the skin to determine joint centers of rotation, body segment orientations, velocities, and accelerations.[9, 10] These kinematic data are then used to solve Newton's equations[10] to approximate the reaction loads at each joint of the throwing arm. While these joint reaction loads do not account for internal factors, like muscle force or ligament engagement, it does provide insight into the external demands placed on the joint. Computational modeling can then be employed to approximate how muscles and ligaments stabilize the joint.[11]

Ulnar collateral ligament tension stabilizes the elbow when the joint is exposed to valgus loads.[5, 10,12] Valgus torque has been reported as high as 100 Nm during maximal external shoulder rotation,[5, 10, 13] which would overload and cause UCL failure without contributions from active stabilizers.[4, 10, 14] Elbow loading can be exacerbated with increases in throwing velocity, competitive level, and physical size.[15] Elbow valgus moments are continued through acceleration as the humerus internally rotates toward home plate following the late cocking stage, or maximal external shoulder rotation. Forearm inertia resists forward acceleration where it continues to lay back causing flexor-pronator mass stabilizers and the UCL to counteract with varus moments (Figure 1B).[10] Internally generated elbow varus moments compress the medial elbow compartment thereby accelerating the forearm and hand forward in the direction of the throw. Repetitive loading and inadequate rest can impair valgus resistance offered by the flexor-pronator mass muscles causing the UCL to assume a greater role in stabilization.[4]

Modifying other aspects of pitching biomechanics can mitigate elbow loading while simultaneously improving performance.[12, 13, 16] Youth throwing athletes throw with greater variability and gross mechanical flaws—characterized by less elbow flexion at peak

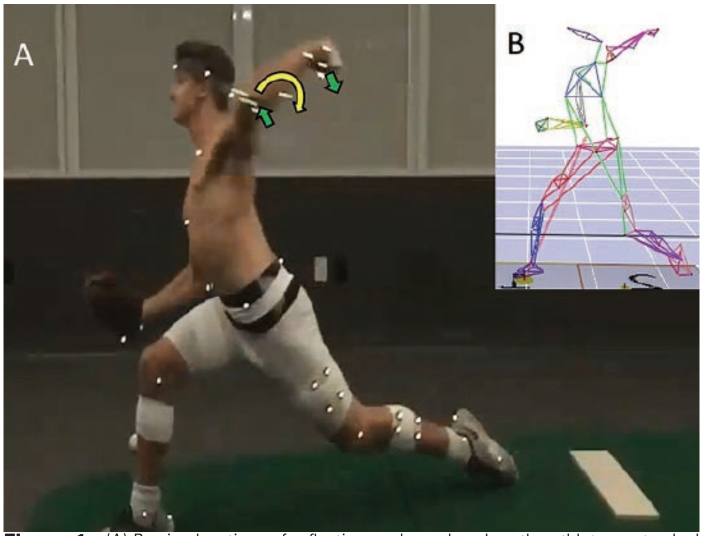

Figure 1. (A) Precise locations of reflective markers placed on the athlete are tracked to quantify throwing kinematics. These data are used to approximate throwing-arm elbow loading (B, yellow arrow), along with modifiable biomechanical variables like stride-length and trunk-tilt.

shoulder external rotation and increased lateral trunk tilt at releasemaking them susceptible to medial epicondylitis and UCL strains.[17] Adult pitchers are more biomechanically consistent, deliver with higher velocities, and are at greater risk of overuse injuries that lead to ruptures of the UCL. Professional pitchers monitored over the course of three seasons showed that elbow injuries were directly related to higher elbow valgus loads.[15] Mechanical consequences owing to greater valgus loading among the injured pitcher group were attributed to higher shoulder external rotation torques and ball velocities.[15] Throwing at high velocities with deeply engrained injurious mechanics from youth development may be the strongest contributors to adult elbow injuries.[15,17]

Lower body and trunk mechanics impact medial elbow loading.[12,13,18] Stride length, the basis of generating, bracing and transferring energy in the throwing delivery[16] is perhaps the most important modifiable behavior that affects elbow loading. Short strides relative to body height may elicit aggressive external rotation moments for the shoulder in preparation of arm acceleration.[16,18] Stride length must regulate the degree of rotational opening of the pelvis and trunk relative to foot contact.[12,13,16] Early opening of the pelvis decreases elbow valgus loading,[13] while the early initiation of trunk rotation in the transverse plane has been linked to increasing elbow valgus rates of loading.[12] Excessive trunk tilt to the non-throwing arm side tends to increase elbow valgus loading.[19,20] Quantified changes of every 10 degrees of contralateral lean increases elbow valgus by 3.7 Nm in baseball pitcher.[20]

Closing Remarks

Biomechanical analysis has the potential to decrease injury susceptibility while increasing throwing performance, as pathomechanic risks can be communicated to coaches, parents, and athletes. Motion capture techniques offer measurable means to reduce elbow loading by monitoring linked segment motion; for example, optimizing stride length, stride orientation (stride foot placement), decreasing axial and lateral trunk orientation relative to stride foot contact can decrease elbow valgus loading[12,16]. Ultimately, identified increases in elbow valgus loads during throwing warrant mechanical changes to minimize demands placed on the dynamic stabilizers and UCL while maximizing ball velocity. The Human Motion Lab at Penn offers a biomechanical and evidence-based approach to identify and correct maladaptive pitching mechanics and should be considered an important tool in the prevention of throwing injuries.

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