THE BIOMECHANICS OF THROWING

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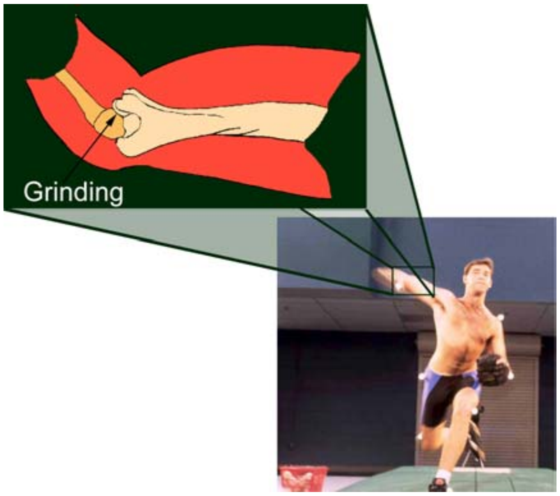
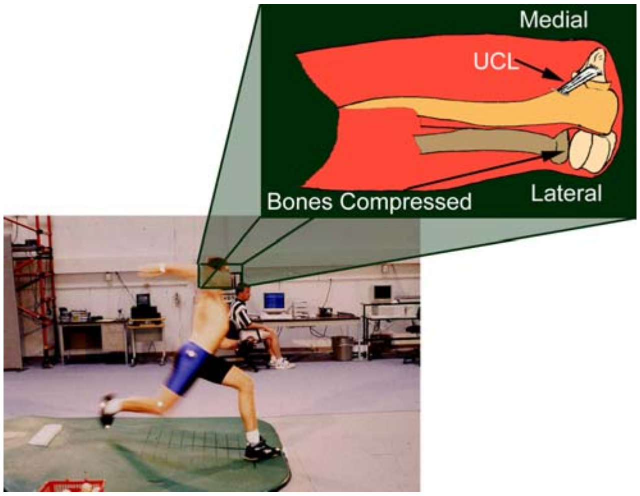
Overuse injury in baseball result most often from pitching. To investigate this problem, the American Sports Medicine Institute (ASMI) has focused on pitching biomechanics. Kinematics (motions) and kinetics (forces and torques) are computed with a four-camera 200 Hz automated motion analysis system. Since 1989, ASMI has conducted 600 throwing tests. Because of its high risk of injury, baseball pitching has been the focus of much of the research. Kinematic and kinetic data from the 26 fastest healthy pitchers were analyzed to determine a model for proper pitching mechanics.

KEY WORDS: baseball, softball, pitching, football, shoulder, elbow

The Six Phases of Pitching: To make the biomechanics easier to understand, the pitching motion can be divided into six phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. The windup phase begins when the pitcher stepped back with his front foot and positions his back foot against the rubber. The windup phase ends when the front leg is at its maximum height and the two hands begin to separate. During the stride phase, a pitcher moves his front foot toward home plate as the two arms swing down and apart from each other. The stride phase ends when the front foot touches the mound. During the arm cocking phase, the pelvis and then upper trunk rotate to face home plate as the throwing arm externally rotates at the shoulder. The arm cocking phase ends when the shoulder reaches its maximum external rotation. The arm acceleration phase was from the instant of maximum shoulder external rotation until ball release. From ball release until the arm stops internally rotating is defined as the arm deceleration. Follow-through begins with maximum shoulder internal rotation and ends when the pitcher regains a balanced position. The greatest kinetic and kinematic values occurred during the arm cocking, acceleration, and deceleration phases, implying that these are the phases where overuse injuries are likely to happen.

Elbow Injury Mechanisms: Elbow injuries occur at the posterior (grinding of the ulna against the humerus), medial (ulnar collateral ligament tear), and lateral (compression wear between the radius and humerus) aspects of the elbow. All three types of elbow injuries are related to the large torques needed to slow down the cocking of the arm and accelerate the forearm, hand, and ball forward. Elbow torque is greatest when the arm is in its maximum cocked position.





Shoulder Injury Mechanisms: Most shoulder injuries occur when the arm is cocked into maximum external rotation, or during arm deceleration. When the arm is cocked, the posterior supraspinatus muscle may become pinched in the posterior shoulder. Another potential injury is a tensile tear to the anterior capsule surrounding the glenohumeral (shoulder) joint. As the arm rapidly rotates to throw the ball, the soft tissue structures must maintain shoulder stability. If there is an imbalance, the humeral head may rub against and damage the anterior labrum (lip) of the glenoid fossa (shoulder socket). The rotator cuff muscles and other soft tissue must continue to maintain shoulder stability after the ball is released as the arm moves towards the target and then across the body.

Factors related to ball speed: It is generally believed that pitchers with good mechanics throw harder than pitchers with poor mechanics. To test this hypothesis, the kinematics of 134 healthy adult subjects were studied. This study showed that approximately 50% of difference in ball speed between pitchers can be explained by looking at pitching mechanics. The most important mechanical factor was the timing of maximum arm velocity. In other words, when a pitcher extends his elbow and internally rotates his shoulder is very important. How much the trunk stretches and moves during pitching is also important. Non-mechanical factors, such as how big a pitcher is, also effect the ability to generate ball speed.

Relationship between poor mechanics and chance of injury: Improper mechanics are believed to increase the stress on the throwing shoulder and elbow, resulting in increased chance of injury. In a study by ASMI, eight mechanisms of improper kinematics that lead to increased loads were proposed. To investigate these hypotheses, 72 pitchers were studied. Four kinematic parameters correlated with increased shoulder force: placement of the lead foot toward the open side, pointing of the lead toe toward the open side, and increased or decreased shoulder rotation at the instant of front foot contact. Two kinematic parameters correlated with increased elbow force: increased shoulder rotation at the instant of front foot contact, and increased shoulder horizontal adduction. Although these correlations were statistically significant, the loading increase from any individual mechanism was minimal. The presence of multiple improper mechanisms may increase loading further. Cumulative effect of increased loads from repetitive pitching may result in increased injury risk.

Differences between fastball, changeup, curveball, and slider biomechanics: Fastball, changeup, curveball, and slider mechanics were measured and compared for 16 college pitchers. Both the curveball and the changeup had slow trunk rotation. Elbow extension and shoulder internal rotation were relatively slow in the curveball and changeup. Even though these motions were slowest in the changeup, the curveball had the lowest ball speed. A couple of factors in the curveball's low ball speed were that there was more forearm supination and radioulnar wrist motion during the curveball than during the other pitches. Shoulder and elbow kinetics were lowest in the changeup. Kinematics and kinetics during the slider were very similar to those of the fastball. Based upon these results, ASMI recommends that the changeup should be the first off-speed pitch learned by a pitcher, since the kinematics are similar to fastball kinematics (making it easy to learn) and the kinetics are significantly lower (making it safe). On the other hand, a young pitcher may want to avoid the curveball since kinematic differences from the fastball make the curveball difficult to master, and kinetics during the curveball are similar to those during the fastball or slider.

Flat-ground throwing: While pitchers throw from a mound, all other players throw from flat ground. To identify differences between these throws, 27 college pitchers were tested throwing from flat ground (60, 120, 180 ft) and pitching from a mound (60.5 ft). The crow-hop technique (similar to an outfielder's throwing motion) was used for all flat ground throws. At the instant of foot contact, a shorter stride and less shoulder external rotation were present when throwing from flat ground. At ball release, the trunk was most upright during long-distance (120 and 180 ft) throws. Deceleration forces in the shoulder and elbow after ball release were lowest during long-distance throws. This may help explain why non-pitchers experience less overuse throwing injuries than pitchers. However, elbow varus torque was greatest during 180' throwing, implying that the lower incidence of elbow injury in non-pitchers is probably due to other factors, such as number of throws, intensity of throws, and type of throws (e.g., fastball, curveball).

The Interval Throwing Program: Flat ground throwing and partial effort pitching are often used in rehabilitation programs like the "Interval Throwing Program." The purpose of these programs is to reinforce proper mechanics while systematically increasing joint loads. To investigate this claim, 27 healthy pitchers were tested performing six different types of throws: full-, ¾-, and half-effort pitching from a mound; and 60-ft, 120-ft, and 180-ft full-effort throwing from flat ground. Compared to full-effort pitching, throwing from flat ground produced a shorter stride and less shoulder external rotation at foot contact, more elbow varus torque during arm cocking, a more upright trunk at ball release, and less shoulder and elbow compressive forces during deceleration. Compared to full-effort pitching, ¾-effort pitching produced slower ball and joint speed (approximately 91%), and decreased kinetics (85%). Half-effort pitching produced 85% ball and joint speed, and 77% kinetics. Partial effort throwing also correlated with reduced arm rotation and a more upright trunk.

Benefits/risks of increasing mound height: In order to reduce offense and speed up the game, Major League Baseball is considering raising the pitching mound from 10 inches to 13 inches. To help make the decision, Major League Baseball commissioned ASMI to compare biomechanics for the two mounds. This study found insignificant differences between the two mounds, implying that raising the mound would not increase the risk of injuries to pitchers.

Youth Pitchers: Pitching biomechanics were compared for 23 youth (age range: 10-15 yrs), 33 high school (15-20), 115 college (17-23), and 60 professional (20-29) level athletes. Even when normalized by bodyweight and height, all joint forces and torques increased with competition level. Ball and joint velocities also increased. However, ten of eleven position parameters (shoulder angle, elbow angle, trunk position, etc.) showed no differences between levels. These results support the philosophy that a child should be taught "proper" pitching mechanics that could be used throughout a career. Use of a smaller, lighter baseball might allow youth league pitchers to generate arm velocities more similar to those produced by adult pitchers, and might help the young pitcher learn proper grips.

Football throwing: The biomechanics of football passing and baseball pitcher were compared. In general, football passing looked similar to baseball pitching, but without a high leg lift in the windup. Quarterbacks had less ball speed, arm angular velocity, and trunk angular velocity. These maximum angular velocities occurred later for quarterbacks, although maximum shoulder external rotation occurred earlier. Quarterbacks had shorter strides and stood more erect at ball release. During arm cocking quarterbacks demonstrated greater elbow flexion, and shoulder horizontal adduction. Even though a football is three times heavier than a baseball, football passing did not produce greater forces or torques. In fact, during the arm deceleration phase greater forces and torque in the shoulder and elbow were produced by pitchers. These results may help explain differences in performance and injury rates between the two sports.

Windmill softball pitching: Eight active and former collegiate softball pitchers were studied with ASMI's motion analysis system and force plates. To simplify the interpretation of data, the pitching motion was separated into four phases: windup, stride, delivery and follow-through. The wind up phase was defined as the time of initial movement until lead foot toe off. During the windup phase, the arm was hyperextended at the shoulder. The stride phase was defined as the time from toe off to complete contact of the lead foot with the ground. During this phase forward momentum was generated and the trunk (pelvis, upper torso) was rotated away from home plate to position the body for delivery. The delivery phase was defined as the time from lead foot contact to release of the ball. During this phase the ball was accelerated forward with a combination of trunk (pelvis and upper torso) rotation and arm (flexion and internal) rotation. The final phase was the follow-through which occurred from the instant of ball release until forward motion of the throwing arm stopped. During follow-through, the elbow continued to flex as the arm and forearm were decelerated. Compared to baseball pitching, softball pitching had a significantly longer stride from the rubber (110 %height vs. 84 %height) since the softball pitchers (illegally) jump forward from the rubber before throwing. While softball pitchers generated less internal rotation speed that baseball pitchers (4600°/s vs. 7600°/s), softball pitchers also generated great shoulder flexion (5300°/s). Large magnitudes of superior force (98 %weight) and extension torque (9.8 %weight*height) were produced during the delivery phase to stabilize the shoulder. These magnitudes are considerable and imply that underhand pitching is stressful on the arm.

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