A Collaborative Approach to Prevent Medial Elbow Injuries in Baseball Pitchers

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SUMMARY

BASEBALL PITCHERS ARE HIGHLY SUSCEPTIBLE TO MEDIAL ELBOW INJURIES. PITCHING FREQUENCY, PITCH ACCUMULATION, PATHOMECHANICS, EXERCISE PHYSIOLOGY STATUS, AND INJURY HISTORY MUST BE EVALUATED IN ALL ATHLETES TO REDUCE RISKS. PLAYER DEVELOPMENT COMBINES EFFORTS OF BOTH HUMAN PERFORMANCE AND PITCHING COACHES. THE MECHANISMS ASSOCIATED WITH MEDIAL ELBOW INJURIES WILL BE DESCRIBED THROUGH FUNCTIONAL ANATOMY, INJURY DATA, AND BIOMECHANICS. CONCURRENT TRAINING (COMBINED STRENGTH, CONDITIONING, AND PITCHING TRAINING) WILL BE SUGGESTED IN MANAGING REPETITIVE STRAIN INJURY RISKS. THE INFORMATION FORMS A PREVENTATIVE APPROACH IN REDUCING MEDIAL ELBOW INJURY RISKS, WHILE MAXIMIZING PHYSIOLOGIC AND MECHANICAL PERFORMANCE IN ELITE-LEVEL HIGH SCHOOL, COLLEGIATE, AND PROFESSIONAL PITCHERS.

MEDIAL ELBOW INJURY RISKS ON THE RISE IN COMPETITIVE BASEBALL

Despite widespread improvement in medical technology, rehabilitation, therapeutic modalities, and training, elbow injuries are on the rise in competitive baseball. The escalation of pitching injuries forms a current orthopedic concern pertaining to all competitive baseball ranks. Data collected on professional baseball players from 1999 indicated a 54% increase in the number of pitchers disabled and a 58% increase in the number of days pitchers had missed because of throwing arm injuries from 1998 (8,9). Similarly, among all professional baseball players in 1999, pitchers had shown the highest susceptibility for arm injuries, accounting for 56.9% of the total days that players spend on the disabled list (9). In 2010, elbow injuries and elbow torques were correlated, reflecting an estimation that 50% of the active pitchers in professional baseball may endure a shoulder or elbow injury requiring throwing cessation within their careers (3). At the youth level, 47% of the baseball players are predicted to experience arm pain of varying injury severity during their participation (21). Medial elbow injury reports from the American Sports Medicine Institute has indicated that from 1995 to 1998, 119 pitchers had undergone ulnar collateral ligament (UCL) reconstruction, whereas during 2003–2006, 619 pitchers had undergone the same procedure (12). A near 5-fold increase in UCL reconstruction at the same orthopedic clinic was recorded for high school pitchers, which may have been attributed to an increase in popularity concerning medical services (12).

More than 4.8 million children and adolescents participate annually in organized baseball (8). Injury data for elbow pain has been documented to afflict 26% of youth participants and 58% of high school–aged athletes (12). In the youth population, pitching injuries have been approximated to be most prevalent at 12 years of age (8). This age-related vulnerability may be indicative of many aspects, such as ineffective coaching, overuse, orthopedic adaptations, and growth.

In youth participants, "Little Leaguer's elbow" syndrome, affecting both medial and lateral compartments of the

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elbow joint, appears to be the most commonly reported throwing pathology (8). Skeletal immaturity, joint laxity, and reduced muscle mass are the main orthopedic factors associated with ineffective force production and force absorbance for the throwing arm (21,37). For "Little Leaguer's Elbow", the mechanism of injury is frequent, high velocity lateral and posteriolateral compression, combined with medial traction forces applied to skeletally immature elbow joints (21,37). During peak height velocity, coaches must continually monitor pitching status (mechanics, accuracy, pitch accumulation, and pitch type) because rapid bone growth and tendon remodeling increase the risk of acute injury with repetitive throwing efforts (21,36,37). In addition, year round resistance training should be emphasized for the throwing musculature.

The following article has been written for strength and conditioning professionals working with competitive pitchers from adolescence to the professional level. Strength and conditioning specialists must be aware of athletes' orthopedic histories, chronicity of throwing arm injuries, injury risks related to poor static stabilizers (joint structures), poor dynamic joint stability (muscular interactions), and individual differences in pitching biomechanics. A detailed record and sound understanding of the previous factors will assist successful programming for pitchers who engage in concurrent strength and pitching training programs. Information within this article is presented within 3 important entities concerning prevention training for medial elbow injuries in pitchers: (a) functional anatomy, injury causation, and treatment of medial elbow injuries, (b) mechanical flaws associated to medial elbow injuries, and (c) management of concurrent training practices. These elements are important facets to be acknowledged by strength and conditioning professionals who are currently working with or wish to expand their training populations to involve competitive pitchers.

FUNCTIONAL ANATOMY, INJURY CAUSATION, AND TREATMENT OF MEDIAL ELBOW INJURIES

The elbow joint comprises 3 bone interactions between the radius, ulna, and humerus (6). Articulation for joint stability is offered by ligamentous and capsular tissues, cartilage, and muscle tendons. These soft tissues originate and insert medially, laterally, anteriorly, and posteriorly across the elbow joint for movement functionality and stability (2). Three separate joint interactions include the radiohumeral, ulnohumeral, and radioulnar articulations (1,6). The predominance of injuries about the elbow arises between 20 and 120° of elbow flexion, where connective tissues and muscles act as static and dynamic stabilizers of the elbow joint (6). The primary ligamentous structure about the medial elbow is the UCL (1–3,6,18). The UCL is a static stabilizer of the medial elbow consisting of 3 branches: the anterior, intermediate, and posterior bundles (Figure 1) (6,38). The anterior branch is the UCL's greatest tensile restraint to the medial opening of the elbow in baseball pitching (6). Consequently, this structure is most susceptible to ligamentous microinjuries, which may in time develop into partial- and full-thickness ruptures (2,3,6). The primary dynamic stabilizers about the medial elbow joint are the flexor-pronator mass groups, which offer tensile stability throughout changing joint angles (6). The common flexor-pronator group originates from the medial epicondyle of the humerus and includes the pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and flexor digitorum superficialis (Figure 2) (6,16). Collectively, these muscles provide tensile compression of the medial elbow joint, while reducing the stabilization efforts of the UCL (2). The action of flexor-pronator mass in rotating the forearm to close the medial elbow joint is considered an act of tensile muscle compression. As closure of the medial compartment occurs, a simultaneous opening of the lateral compartment is experienced, and this rotational torque is known as a varus moment (1–3,6). Essentially, the varus moment is a protective countermoment (rotational force about a frontal axis of rotation) to resist medial joint space opening. The moment, or torque, causing medial space opening is known as the valgus moment and is associated with medial elbow stress and strain (Figure 3) (1–3,6,18). The varus moment not only protects the medial elbow structures from traction strain but also protects the lateral elbow compartment from high compression stress between the radial head and capitellum (1,6). Peak lateral compression forces applied at the maximum opening of the medial elbow during the baseball pitch have been recorded at as high as 500 N about the radiocapitellar joint (6,18). Repetitive compression of this magnitude has the capacity to cause chondral defects, loose body formations, and other radiographic changes (2,16). Essentially, poor regulation of the valgus moment is considered to be the principle mechanism causing tensile injuries to the medial elbow's soft tissue structures (2,16). Over time, an inability to dissipate valgus stress may parallel with the degree of injury severity (exceeding tensile stress limits to inner elbow structures). Likewise, compression stress will also amplify within the lateral compartment (18). Improvements in reducing valgus loading rates, magnitudes, and frequencies can occur by using three-dimensional (3D) motion evaluations of pitching biomechanics combined with appropriate strength and conditioning practices. Ultimately, it is in all coaches' best interest to improve valgus-varus loading responses about pitchers' throwing arms from stride foot contact to ball release (BR) (1–3,6,18).

Elbow flexion has been documented at 85–110° at the maximal cocking position of the arm while approximately 10° elbow flexion occurs at the point of BR (1,6,18–20). The forearm's angular velocity in elbow extension, occurring from peak elbow flexion at maximal external rotation (MER) to BR, contributes to a medial elbow injury

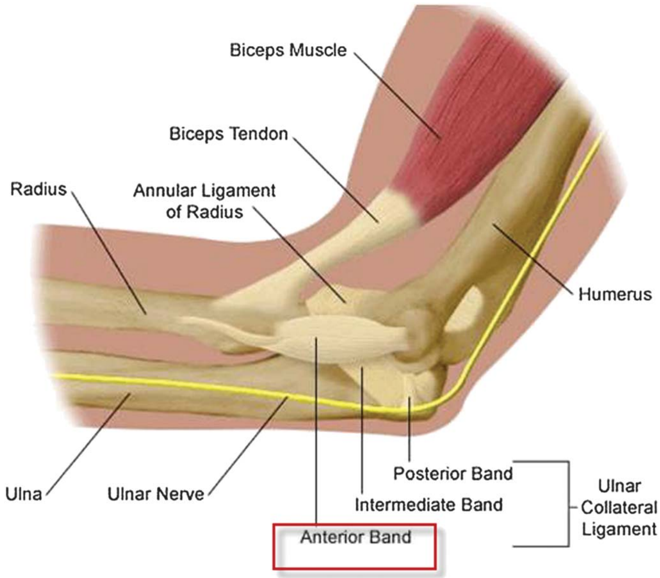

Figure 1. The anterior band of the ulnar collateral ligament. Reprinted with permission (38).

mechanism known as valgus extension overload (VEO). Valgus extension overload is a force-coupled interaction that involves the combination of repetitive medial tension caused by valgus moments, coinciding with rapid and simultaneous elbow extension torques in the delivery of a baseball pitch (2,6). The use of 3D biomechanical evaluations of pitching kinematics (descriptors of motion) and kinetics (pitching forces) have indicated that

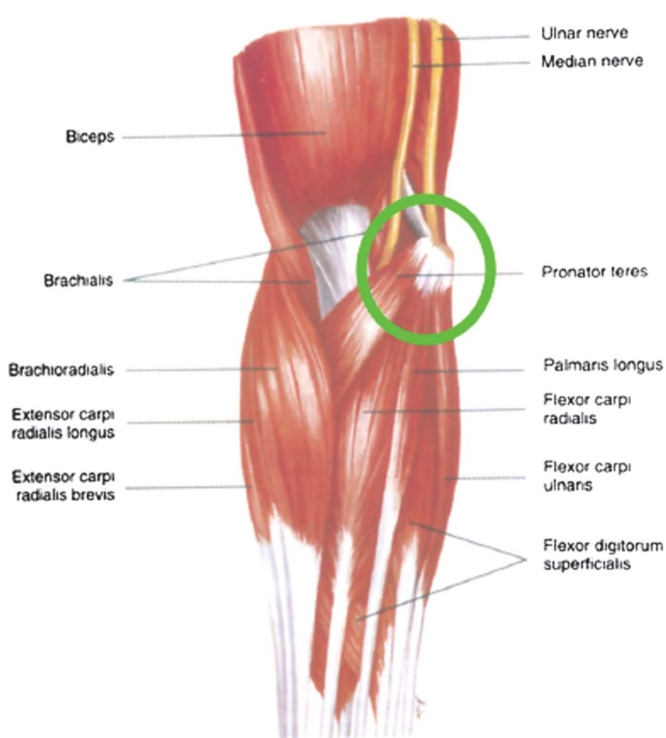

Figure 2. The origin of the common flexor-pronator mass. Reprinted with permission (38).

elbow extension velocity can occur at more than 2,700° per second from MER to BR (1,6,18–20). Valgus extension overload enacted under a state of muscular fatigue increases tensile stress to the UCL's anterior and intermediate bands (6). Articular damage, osteophyte formation, and microfractures about the posteriomedial trochlea have also been documented as a result of VEO (6). Eccentric actions enacted by the biceps tendon regulate the extension velocity (6). As a result of an improved deceleration in elbow extension, degenerative changes about the posteriomedial trochlea and coronoid process of the ulna may be attenuated (6). Severe forms of VEO are responsible for articular microfractures, which cause displacement of loose body formations (bone chips) within intra-articular spaces about the elbow joint (2). Bone and cartilage fragmentation will affect the range of motion and functionality about the elbow joint (2). In both youth and adult populations, VEO demonstrates a disruption of the balance between mechanical damage and physiologic repair of soft tissues (1–3,6,18).

Physiologically, microtraumatic imbalance precedes the development of flexor-pronator tendonitis, medial epicondyle apophysitis (inflammation of medial epicondylar growth plates), ulnar neuritis (inflammation of the ulnar nerve), and UCL sprains (1–3,6,18). Ulnar collateral ligament injuries and forearm muscle tendonitis are more commonly seen conditions in older adolescents and adults (6). Medial epicondylitis and apophysitis are considered the main conditions associated with, Little Leaguer's elbow syndrome (2). Medial elbow apophysitis is an inflammatory condition about the medial epicondyle apophysis affecting the natural growth and development of the medial epicondyle (16,21). The medial epicondyle (inner bump of the elbow) is characterized as swollen and painful to the touch. In some instances, powerful tensile contractions from muscles and ligaments attached to the medial epicondyle can cause avulsion fractures in skeletally

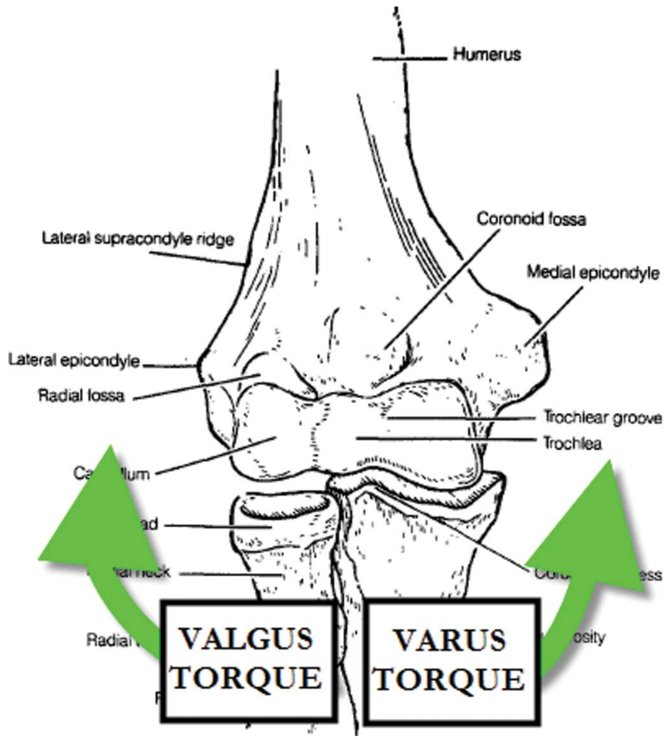

Figure 3. Elbow varus torque (opens lateral compartment) and elbow valgus torque (opens medial compartment). Reprinted with permission (38).

immature athletes (6,36,37). The avulsion fractures are associated with relative weakness in tissue strength between the developing bone (low mineralization) and the tensile restraint enacted by attached ligaments and tendons (1–3,6,18).

Operative treatment of the UCL is prescribed for incomplete and complete tears of the anterior bundle (6,37). Surgery is also performed on athletes who are not responding positively to conservative treatment forms (6,37). Reconstruction of the anterior bundle known as "Tommy John" surgery is generally performed by placing a free-tendon graft from the palmaris longus, plantaris, or Achilles (6,16). The autograft is sutured in a figure 8 fashion, via bone tunnels through the ulna and medial epicondyle of the humerus (6,16). For most operative outcomes, a near 90% success rate in return to play and return of preinjury performance has been established (30). However, in older pitching populations (older than 30 years), the combination of both UCL and flexor-pronator mass surgeries have shown a negative impact on competitive returns (30). Physical therapy is initiated within 6 weeks after operative bracing conditions (30). Athletes generally initiate an interval throwing program 4 months after reconstruction (30). The minimum amount of time required to ensure a healthy return to competition is 9 months after operation (30).

Nonoperative treatment is generally acceptable for nonthrowing athletes. It has been established that high-demand throwing populations do not respond well to conservative treatments (6). Traditionally, for a period of 2–6 weeks, throwing is ceased, allowing the focus to involve inflammatory management via cryotherapy, range of motion improvements, and improvement in internal and external rotator cuff strength (6). Scapular stabilization and serratus anterior training should also occur simultaneously to avoid detraining of auxillary throwing arm muscles (6). As soreness resolves, medial flexor-pronator training should be initiated (6). Functionality training (throwing-specific training with plyometrics and bands) and interval throwing are the last aspects prescribed in the treatment model (6). Pain-free pitching during interval segments indicates an athlete's status for return to competition, where innings pitched and pitch accumulations must be modified and meticulously monitored (6). Because of the low compliance in nonoperative treatments and the length of time required for rehabilitation from invasive surgery, the strength and conditioning professional has an integral role in preventing injuries about the medial elbow in potentially saving pitchers' careers.

MECHANICAL FLAWS ASSOCIATED TO MEDIAL ELBOW INJURIES

Chronic injuries require greater interpretation of pitching biomechanics to adjust mechanics. Video analyses using appropriate software for visualization of joint angles would be suffice. The use of 3D motion analyses provides the most accurate real-time biomechanical analyses in 3 planes of movement (Figure 4). In Figure 4, a pitcher is analyzed using 3D motion capture technology synched to video. Both aspects allow for quantification of joint angles, joint velocities, and accelerations. Force plate data can infer how pitchers accelerate and decelerate the center of mass, transitioning from positive to negative momentum about the kinetic chain. Through newtonian physics applications, joint forces and moments can be identified in 6 degrees of freedom (3 segment translations and 3 segment rotations).

The management of pitching performance and injury risk requires interpretations of optimal energy generation and bracing from lower-body drive, timing of mechanical actions about the upper body, and optimal joint positions for efficient transfer of joint forces. Research has indicated that valgus moments are caused by a combination effect of centrifugal forces (a hypothetical force

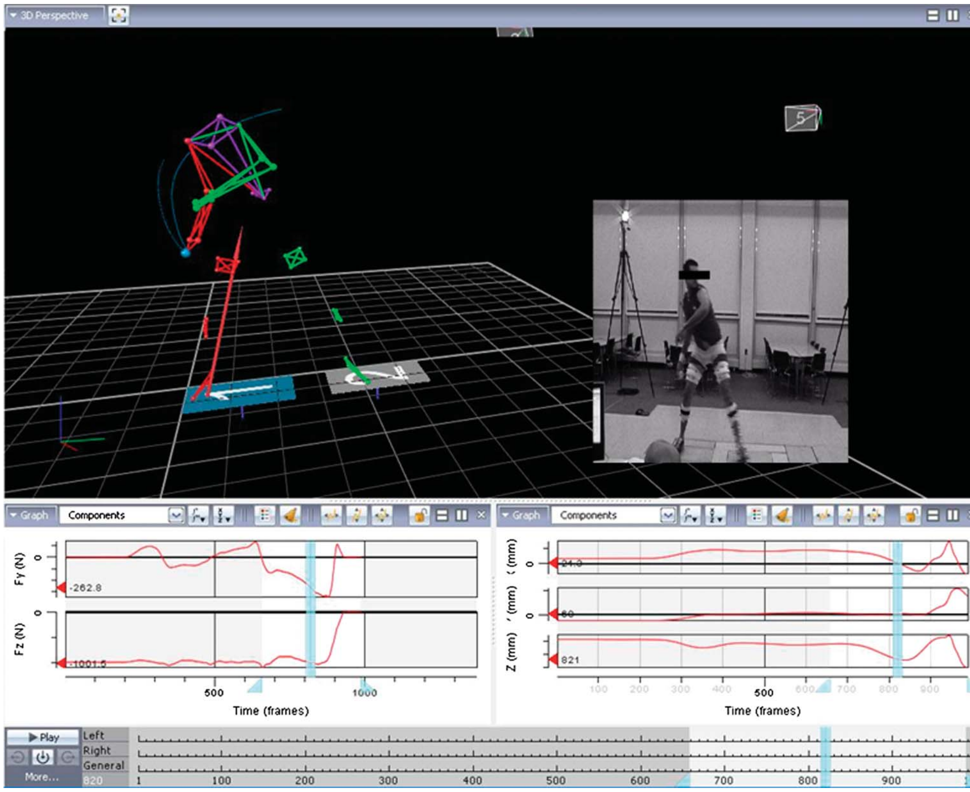

Figure 4. 3-Dimensional motion capture of a pitcher synched to video for biomechanical analyses.

causing the forearm mass to rotate laterally away from the elbow joint center) (1,3,16,18). Centrifugal forces acting upon the elbow joint are considered to be the result of rotary energy sources provided by high velocity pelvic, torso, and shoulder external rotation (1,3,16,18). Upper arm stabilizers impart forces upon the forearm to resist forearm translations and joint distraction (separation of joint surfaces) throughout the pitching sequence (1,3,16,18). Joint reaction forces have been quantified as 240–360 N medial (resists lateral forearm translation), 240 N anterior (resists posterior forearm translation), and 1000 N of compressive forces (resists distraction of the elbow joint) (18).

The kinetic properties (force properties) vary with developmental age, mass, height, and pitch type. Intuitively, fastball pitching has published higher values than the changeup, offering an importance in teaching the changeup concomitantly with the fastball to unload tissue stress (16,18). Kinetics quantification indicated that the adult pitching elbow must withstand an average valgus torque (rotational force opening the medial elbow) of 64 Nm, while youth pitchers are to resist valgus loading of 28 Nm, as reflected by varus moments (13,15,19). The quantitative increase in valgus stress by the adult population is greatly attributed to larger muscle mass causing greater anatomical segment accelerations (19,37). Furthermore, greater anthropometric mass and muscular strength, increased moment arm lengths, and mass moments of inertia collectively combine to produce the highest valgus torque outputs (19,37). This information may warrant greater attention to larger and taller pitchers in their expression of varus torque outputs (resistance to medial elbow tension). In the adult population (primarily pitchers older than 16 years), UCL components are less capable of handling tensile stress versus their bony attachment points (1,36,37). As mentioned, there is an opposing relationship in youth participants regarding the strength of bone, tendon, and ligamentous tissue. In youth pitchers, medial elbow apophysitis and growth plate fractures are the outcomes of having greater ligament and tendon strength with respect to bone (1,36,37).

LATE-COCKING STAGE IN PITCHING: MAXIMAL EXTERNAL ROTATION CONCERNS

The most stressful elements about the pitching delivery occur at maximal external shoulder rotation (MER) through acceleration of the throwing hand (18). It has been noted that increased external rotation torques about the throwing shoulder highly correlate with increases in medial elbow injury severity (3). Valgus stress loading at MER can be further exacerbated by segmental asynchronicity, fatigue-related parameters such as changes in external rotation velocities about the shoulder, lateral flexion of the spine toward the pitching arm side,

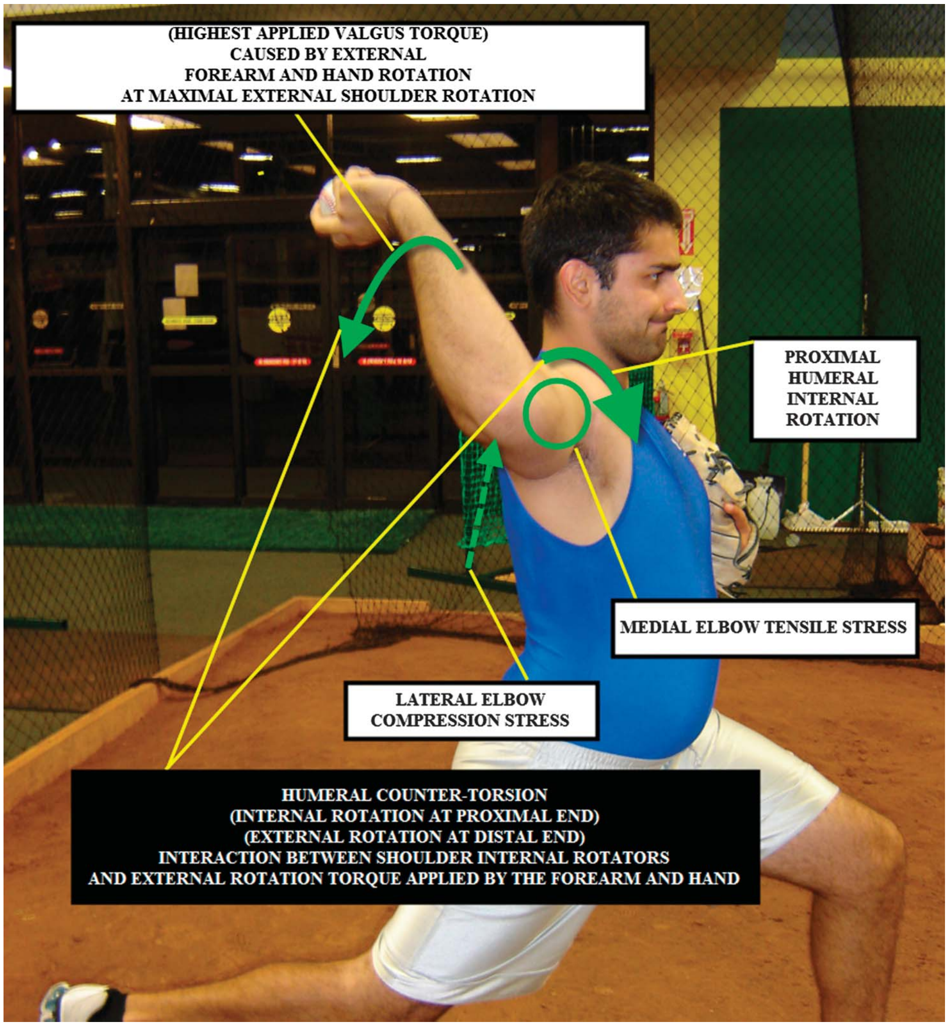

Figure 5. Axial countertorsion about the humerus at maximal external rotation and valgus stress implications.

reduced shoulder abduction, increased horizontal abduction velocity, wrist supination at maximum horizontal abduction, and increased elbow extension at MER (1,14,29,37). During the pitching cycle, MER occurs in the late-cocking phase, where the throwing hand is in a catapult-like position. At the MER position, elastic potential energy is generated through eccentric loading of the internal rotator cuff, accompanied by internal rotation muscles and their connective tissues (18). The prestretch, or eccentric stretch that transitions to a concentric, muscular contraction, known as a "stretch-shortening couple", causes powerful, internal rotation of the humerus (18). Acceleration of the throwing arm from MER is produced by an internal rotation moment about the shoulder joint. The internal rotation moment is produced by a coordinated muscular interaction that involves the pectoralis major, latissimus dorsi, subscapularis, and teres major (1,3,18). Greater rates of force development are achieved through maximal stretch-shortening couples, as increased tissue elasticity combines with the myotatic reflex (proprioceptive response in the muscle), creating maximal throwing arm acceleration (23). In comparison with low-velocity pitchers, high-velocity throwing athletes reveal greater MER ranges of motion for enhancement of the eccentric preload (3,19).

Insidious danger to the medial elbow occurs if the stretch-shortening response lacks optimization between external and internal rotation torques about the shoulder (1–3,18,30). The "countertorsion" effect about the humeral axis signifies a critical relationship between the internal rotation at the point of acceleration, directed at the proximal aspect of the humerus, and the simultaneous distal humeral external rotation. The axial countertorsion about the humerus greatly amplifies valgus loading about the elbow (1–3,18,30). Specifically, the external rotation of the forearm and hand, asynchronously coupled with internal shoulder rotation, shifts the joint center and axis of rotation medioanterior, causing an increase in the external rotation velocity of the forearm and hand segments (1–3,6,37). The increase in external rotation velocity enhances the forearm/hand segments' inertial effects (resistance to change in acceleration or velocity) (1–3,6,37). As such, an increase in varus (valgus-opposing) torques must be enacted (1–3,6,37). As a result of increased valgus stress loading and reduced restraint capacities by varus torque providers (soft tissue restraints), an increased risk of medial tensile and lateral compression injuries arises about the elbow joint (Figure 5) (1–3,6,37).

The injury mechanism associated with humeral "countertorsion" indicates the importance of tensile strength maintenance in the anatomical structures that produce internal shoulder rotation (eccentrically and concentrically), as well as varus torque agonists about the elbow (1–3,6,16,37). If deficits arise in varus and internal shoulder rotation torque components, which can occur because of fatigue or microdamage, one will experience an increased tensile loading about the UCL (1–3,6,13,32). Similarly, greater compression stress about the radiocapitellar joint will also occur because of less than optimal regulation of valgus stress (1–3,6,16,37). Management of repetitive pitching stress combined with implementing pitching-specific resistance training can both reduce neuromuscular fatigue and disturbances to tissue remodeling (1–3,6,16,37). Effective dynamic and static stability to withstand medial elbow joint opening caused by valgus torques will ultimately reduce the severity and frequency of acute and chronic strains to the flexor-pronator mass, UCL, and degeneration of both cartilage and subchondral bone (2,18).

THE "M-POSITION" PITCHER

"M-Position" or "inverted-W" mechanics have been examined anecdotally concerning their predisposition to cause medial elbow injuries. In the author's professional and collegiate experience concerning baseball coaching, biomechanics research reviews, and playing experience, pitchers revealing a greater internal rotation at stride foot contact are at a higher risk for shoulder impingement and medial elbow injuries. Internal rotation displacement about the forearm vector from the anterior reference vector of the trunk (considered 0° neutral axis) is considered the degree of internal rotation about the shoulder. Pitching coaches should evaluate the forearm position at stride foot contact to determine whether the athlete is above or below the neutral axis (Figure 6). The M-Position is speculated to cause high external rotation velocities initiated by the external rotator cuff musculature (3). The increase in external rotation velocity is coordinated to synchronize throwing hand acceleration with the anterior drive of the center of mass upon stride foot landing (3). Theoretically, large external rotation velocities have been shown to increase the inertial properties of the throwing forearm at MER (3). Greater forearm acceleration into external rotation will increase medial elbow stabilization requirements as a result of amplified valgus torques. Conceptually, the strength and conditioning professional and pitching coach would indicate the critical importance of varus moment training to reduce medial elbow tension and lateral elbow compression injuries (1–3,6). It is also possible that the anterior capsule of the shoulder shows greater laxity as a result of the deceleration actions to control high-velocity external rotation. As in all pitchers, the M-Position pitcher should be evaluated for external rotation range of motion, which may indicate the degree of corrective exercise to improve range of motion arcs about the shoulder (34). The ability to regulate external rotation velocity can reduce valgus loading in the late-cocking stage of pitching (1–3,6). This

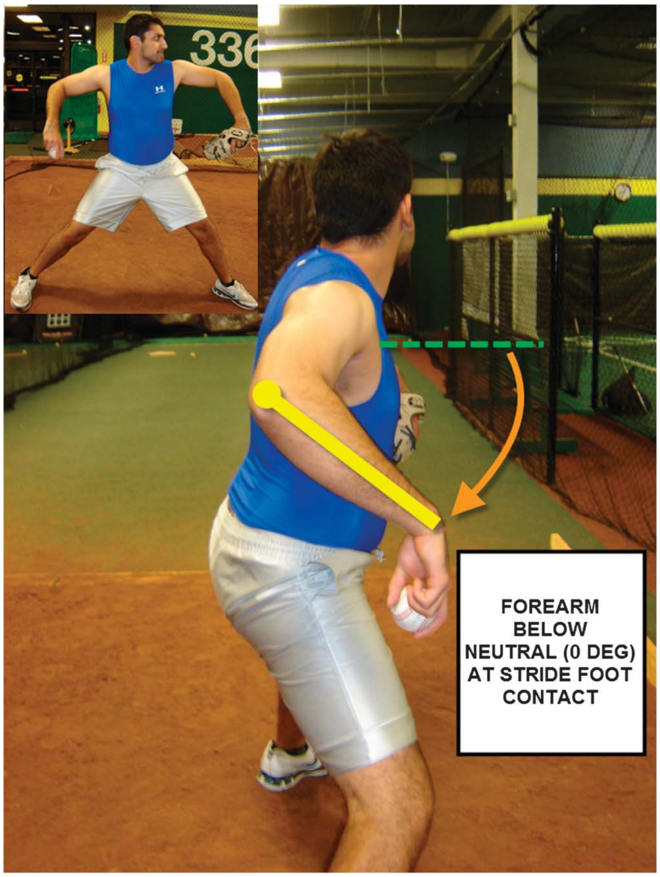

Figure 6. The M-Position at stride foot contact.

corrective notion has been supported by previous studies that investigated exceedingly high external rotation torques (1,3,37). It was determined that high external rotation torques about the shoulder had a positive association with greater elbow valgus torques at the professional level (1,3,37). The improvement of internal rotation eccentrics combined with improved mechanics to allow for passive external shoulder rotation may reduce loading rates and magnitudes of the applied varus torques (counterbalancing moments to resist valgus stress) (1,3,37).

THE SIDEARM DELIVERY

A deficit in sport medicine research exists concerning potentially injurious effects of sidearm throwing mechanics. Traditionally, sidearm deliveries have been attributed to pitchers lacking overhand velocity (41). A change in arm slot (combination of lateral trunk flexion, shoulder abduction, and elbow extension) at BR provides greater cutting movement on each pitch (41). Although effective, there are inherent injury risks concerning valgus stress applications to the elbow for this subgroup of pitchers (1). Lateral trunk tilt and shoulder abduction regressions have been examined in association with applied elbow varus torque (1,24). Current science has identified that the optimal arm slot orientation in minimizing elbow varus torque is 100° of shoulder abduction and 10° of lateral trunk flexion to the nonthrowing arm side (contralateral side) (24). In contrast, sidearm biomechanics generally have reduced shoulder abduction and ipsilateral trunk tilt in the frontal plane, which has been indicated to increase varus loads at the elbow (24). Theoretically, centrifugal forces about the throwing forearm (acceleration of the forearm into valgus positioning away from an axis of rotation) amplify the counteraction of the varus moment (1,2,6,16). In comparison with traditional overhand pitchers, "sidearmers" are notorious for early trunk rotation with respect to stride foot contact (1,41) (Figures 7, 8). Pitching studies in biomechanics research are time normalized for kinetic and kinematic evaluations, as well as sequential actions about the pitching delivery. As such, stride foot contact has been considered 0% time where BR is interpreted as 100% of the pitching cycle (1,15,18,37). It is believed that early onset of trunk rotation amplifies centrifugal force properties because early trunk rotation had been positively correlated with elbow valgus torque (1). In relation, it has been determined that reduced shoulder rotation torques occur in pitchers who use late-onset trunk rotation (1). A reduction in proximal torques from the shoulder musculature about the humerus may reduce kinetic energy effects about distal segments in the upper extremity (1,41). Consequently, reduced elastic and kinetic energy transfers can improve valgus loading rates, thereby reducing stabilization needs (1). Sidearm pitchers who are able to achieve greater elbow flexion at the point of peak elbow valgus stress, that being the late-cocking stage and the beginning of acceleration, will experience reduced centrifugal effects as well (1,6,16). Arm lag (increased horizontal abduction of the shoulder combined with elbow extension) has been considered a key mechanical factor involved in elbow injury. In sidearm pitching, trunk rotation onset greatly exceeds throwing arm acceleration (1,41). It has been theorized that an extended elbow at 90° shoulder abduction (extended sidearm delivery) increases the bending moment in valgus about the throwing elbow (1,6,16). Ultimately, the positioning of segment masses further from the principle axis of rotation, that being the rotary elements of the torso, will contribute to greater inertia, or centrifugal effects (acceleration in the direction of the valgus bending moment) (1,6,16).

CURRENT SCIENCE ON CURVEBALLS AND ELBOW INJURY RISKS

The frequency of curveballs thrown per game has been investigated as an injury mechanism for elbow injuries in youth pitchers (1,16,17,21,22,27,41). In contrast to current beliefs, baseball biomechanists are fully convinced that curveballs do not cause greater stress to the medial elbow than what is experienced by traditional fastballs (1,16,17,21,22,27,41). Epidemiologic

Figure 7. Trunk mechanics and increased valgus stress in side-arm pitchers.

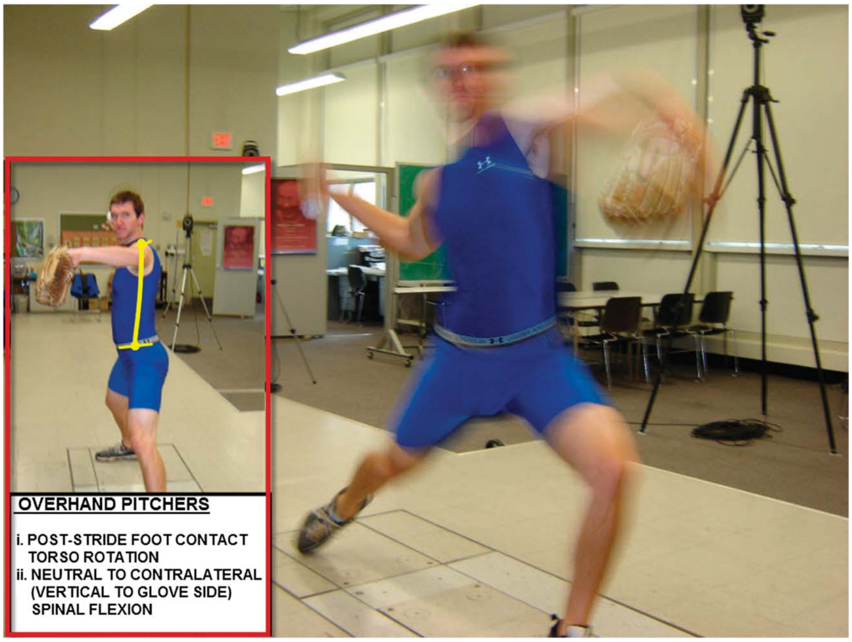

Figure 8. Trunk mechanics and reduced valgus stress in overhand pitchers.

research has indicated nonsignificance between curveball pitch frequency and the age of curveball introduction. Orthopedically, healthy and nonhealthy questionnaire respondents were used to determine curveball use in competitive and practice participation (28). Quantitative comparisons in 3D biomechanical studies have indicated 20 N differences (290 N fastball and 270 N curve ball) for peak medial forces and identical elbow extension velocities, which average 2,400°/s (16). Fastball and curveball pitching indicated a marginal difference in average compression forces because the fastball was recorded at 790 N, whereas the curveball was recorded at 730 N (16). Ultimately, the curveball had less elbow varus torque, shoulder internal rotation torque, elbow flexion torque, and compression force in comparison with the fastball (12,16, 20,27). Ironically, all previously mentioned variables concerning deceleration kinetics indicate that the curveball may be a favorable pitch to reduce loading of the youth throwing arm (12). The curveball offers lowered valgus stress, external shoulder rotation torques, elbow extension velocity, and elbow distraction in youth participants (12). Other comparisons that may indicate greater causation of injury with frequent curveball deliveries include differences in MER and the degree of supination of the forearm at MER (20). Fastball pitching achieves an average MER of 170–178° with a pronated baseball grip, whereas the curveball pitch experiences a MER range of 172–180° with a supinated baseball grip (16). The combination of increased MER and forearm supination for curveball pitching may amplify valgus stress overload risks (16). It is possible that the supinated grip reduces the pronator teres' force capacities in resisting valgus loading (varus contribution deficit) at the medial elbow (16). Pitching coaches may wish to maintain a pronated grip at the point of MER while instructing the athlete to rotate the forearm to a neutral position through acceleration to ulnar deviation at BR. The pronated grip at MER may improve varus resistance at the hallmark arm position known for the highest applied valgus stress to the medial elbow (1,3,16,20).

MANAGEMENT OF CONCURRENT TRAINING PRACTICES

Pitchers, strength and conditioning professionals, and pitching coaches must collectively work together on a year-round basis to assess elements that can exacerbate or potentially increase throwing arm injury risks. The off-season and preseason considers correction of mechanical flaws and the maximization of human performance factors (muscular strength, muscular power, aerobic endurance, flexibility, speed, agility, and quickness). Competitive stress is removed during baseball off-seasons, whereas strength and conditioning intensity, duration, and frequency are systematically increased to challenge the athlete. Modified pitching sessions are initiated in addition to training for the improvement of delivery mechanics and to build arm strength. All affiliated coaches must be aware of their athletes' pitching and training routines to avoid overtraining symptoms and promote an improved training status.

To manage training performance and throwing progression, training variables (resistance, exercise choice, exercise order, volume, rest, frequency, and tempo) must systematically meet the macrocycle (several months to years), mesocycle (several weeks to months), and microcycle (weekly) objectives. For instance, a high-intensity upper-body lift (>80% 1 repetition maximum [RM]) at moderate volumes should not be followed consecutively by a pitching session. Intuitively, the prescribed training demands would cause substantial neuromuscular and metabolic fatigue (reduction in fuel sources, recruitment, and activation of muscle fibers) in close proximity to pitching practices (4,40). On days where pitcher-fielding plays are planned, or light flat ground throwing is to be prescribed, one may organize a high-intensity training session to be followed by pitching skills practice, as the throwing stress is reduced. As a general rule of safety, pitching practices should occur before strength and conditioning to reduce the onset of injury caused by prepitching fatigue.

The suggested training format reflects an undulated or nonlinear periodized program. Undulation entails variation in loading and volume where training prescriptions alternate between dynamic and maximal strength. Maximal strength training (described in the tables as "effort training") refers to multijoint exercises that exceed 85% 1RM. Intensity prescriptions (%RM values) are to be applied to *Primary Exercises*. Primary exercises are generally considered multijoint exercises in developing linked system power. Dynamic training entails high acceleration of the resistance implement. Again, multijoint exercises are prescribed by which the athlete develops high rates of force development (newtons/second). Essentially, the enhancement of force capacity and contractile velocity provide a means to improve muscle power, an attribute that is pivotal for pitching performance. As the athlete progresses through the off-season and preseason training cycles, a suggested reduction in training volume and intensity (<90% 1RM) should be prescribed. This adjustment coordinates with increased throwing obligations and orthopedic stress. This adjustment reduces the magnitude of loading and allows for high-velocity repetition (high volume, light resistance, and high velocity). Although not scientifically confirmed, high-velocity repetition days have been suggested by the author to promote localized anaerobic recovery and improve Creatine Phosphate energetics about the throwing arm musculature. Core and lower back musculature should be routinely trained to promote movement synergy between upper-body and lower-body extremities. Many resources are available concerning core and lower back training aspects. Tables 1 and 2

Table 1
Mesocycle 1 (November 1 to December 31) 4-day concurrent off-season training schedule for professional and collegiate pitchers

Day	Pitching instruction	Strength and conditioning
M	Long toss 60–90 ft (50 throws)	Effort lower body (82.5–90% RM)
		Bulgarian split squats 6 × 3–4 reps*
		Romanian deadlifts 3 × 6 reps*
		Lateral lunge 3 × 12 reps
	70 ft changeups (20 throws)	Walking calf raises 3 × 20 reps
		Core training 4–5 × 20 reps
		Interval cycle ergometer (15 min)
		2 min (70–80 RPM) LEVEL 8
	Postthrowing exercises	30 s (80–90 RPM) LEVEL 10
		30 s (max RPM) LEVEL 10
		2 min (60–70 RPM) LEVEL 8
		3 sets
Tu	Off	Dynamic upper body (50–80% RM)
		Single arm floor press 3 × 8 reps*
		1-arm lateral pull-down 3 × 8 reps*
		Lateral raise 3 × 12–15 reps
		Y-T-I scapular training 3 × 15 reps each
		Alternating hammer curls 3 × 12 reps
		Overhead triceps extension 3 × 12 reps
		Flexibility training
W	Long toss 90–120 ft (40 throws)	Off
	Postthrowing exercises	

Table 1
(continued)

Th	Off	Dynamic lower body (50–80% RM)
		Bench pistol squats 6 × 6 reps*
		Single leg deadlift 3× 12 reps*
		Banded hip abduction 3 × 20 reps
		Banded hip adduction 3 × 20 reps
		Cable hip flexion 3 × 10–12 reps
		Floor hyperextensions 3 × 15 reps
		Front, side planks 3 × 10 reps, 10-s hold
		Interval training (30 min)
		2 min (60–70% MHR)
		1 min (80–90% MHR)
		30-s walking
		30-s sprint
		6 sets
F	Off	Effort upper body (80–87.5% RM)
		Flat bench dumbell press 3 × 4–6 reps*
		Single arm row 3 × 8 reps*
		Banded D2 patterns 3 × 25 reps
		Pronation/supination 3 × 40 reps
		Dumbell wrist curls 3 × 40 reps
		Core training 4–5 × 20 reps
Sa	30 pitch video captured bullpen	Athletic development training†
		Interval cycle ergometer (15 min)
	Pitch ratio	2 min (70–80 RPM) LEVEL 8
	3 fastballs	15 s (max RPM) LEVEL 15
	2 changeup	30 s (60–70) LEVEL 8
	6 sets	15 s (max RPM) LEVEL 15
	Postthrowing exercises	5 sets
Su	Off	Off

MHR = maximum heart rate estimate (% age-predicted max); RM = repetition maximum (1 RM = 100% effort); RPM = revolutions per minute.

*Suggested %RM prescription applied to primary exercises.

†Athletic development training, speed, power, agility, reaction, quickness.

provide concurrent training schedules for off-season and preseason workouts for collegiate and professional pitchers; Tables 3–5 provide concurrent training schedules for off-season and preseason for adolescent pitchers; and Table 6 provide in-season concurrent training schedule for starting pitchers.

FATIGUE MANAGEMENT

Strength and conditioning and pitching programming must account for fatigue management. Prefatiguing the pitcher

Table 2
Mesocycle 2 (January 1 to February 15) 3-day concurrent preseason training schedule for professional and collegiate pitchers

Day	Pitching instruction	Strength and conditioning
M	45 pitch video captured bullpen	Effort lower body (82.5–87.5% RM)
		Bulgarian split squats 8 × 2–3 reps*
		Romanian deadlifts 8 × 4 reps*
		Lateral lunge 3 × 8 reps
		Walking calf raises 4 × 12 reps
		Core training 4–5 × 30 reps
	Pitch ratio	Dynamic upper body (50–75% RM)
	3 fastballs	Single arm floor press 8 × 3 reps*
	1 changeup	1-arm lateral pull-down 8 × 3 reps*
		Lateral raise 3 × 20 reps
	1 alternate	Y-T-I scapular training 3 × 30 reps each
		Alternating hammer curls 3 × 8 reps
	9 sets	Overhead triceps extension 3 × 8 reps
		Interval cycle ergometer (15 min)
	Postthrowing exercises	2 min (60–70 RPM) LEVEL 10
		15 s (max RPM) LEVEL 12
		2 min (70–80 RPM) LEVEL 10
		15 s (max RPM) LEVEL 12
		30-s full rest
		3 sets
Tu	Long toss 90–120 ft (40 throws)	Athletic development training†
	80 ft changeups (20 throws)	Low back and core 3–4 × 20 reps
	Postthrowing exercises	Flexibility

Table 2 (continued)		
W	Off	Dynamic lower body (50–70% RM)
		Bench pistol squats 20 × 3 reps*
		Single leg deadlift 3 × 8 reps*
		Banded hip abduction 3 × 20 reps
		Banded hip adduction 3 × 20 reps
		Cable hip flexion 3 × 10–12 reps
		Floor hyperextensions 3 × 15 reps
		Front side planks 3 × 10 reps, 10-s hold
		Dynamic upper body (40–50% RM)
		Single arm floor press 3 × 25 reps fast*
		1-arm lateral pull-down 3 × 25 reps fast*
		Lateral raise 3 × 25 reps fast
		Y-T-I scapular training 3 × 25 reps fast
		Alternating hammer curls 3 × 25 reps fast
		Floor triceps extension 3 × 25 reps fast
		Interval cycle program (15 min)
		2 min (60–70 RPM) LEVEL 8
		15 s (max RPM) LEVEL 15
		2 min (70–80 RPM) LEVEL 8
		15 s (max RPM) LEVEL 15
		30-s rest
		3 sets
Th	Long toss 90–120 ft (60 throws)	Athletic development training†
	70 ft changeups (30 throws)	Low back and core 3–4 × 20 reps
	Postthrowing exercises	Flexibility

(*continued on next page*)

Table 2 (continued)

F	Off	Dynamic lower body (40–60% RM)
		Bulgarian split squats 6 × 25 reps fast*
		Romanian deadlifts 3 × 20 reps fast*
		Lateral lunges 3 × 15 reps
		Walking calf raises 3 × 25 reps fast
		Core training 4–5 × 20 reps
		Effort upper body (75–85% RM)
		Flat bench dumbell press 6 × 3–4 reps*
		Single arm row 4 × 8 reps*
		Banded D2 patterns 3 × 30 reps
		Pronation/supination 3 × 1 min max reps
		Dumbell wrist curls 3 × 1 min max reps
		Core training 4–5 × 30 reps
		Medicine ball training circuit
Sa	30–40 hitter simulated bullpen	Postpitching interval training (25 min)
		1 min (60–70% MHR)
		10-s sprint
		1 min (60–70% MHR)
	Replicate game conditions	10-s sprint
		1min (60–70% MHR)
		10-s sprint
	Postthrowing exercises	1 min (60–70% MHR)
		10-s sprint
		1-min full rest
		4 sets
Su	Off	Off

MHR = maximum heart rate estimate (% age-predicted max); RM = repetition maximum (1 RM = 100% effort); RPM = revolutions per minute.

*Suggested %RM prescription applied to primary exercises.

†Athletic development training, speed, power, agility, reaction, quickness.

before throwing efforts will impact mechanical efficiency in one's ability to accelerate and decelerate the body and extremities (15,21,25). Fatigue management has been a topic of debate in professional baseball because the sport has evolved from a 4-man rotation to a pitching schedule that features 5 starting pitchers. Professional pitching schedules for starting pitchers are built upon 5 days of competitive rest to accommodate recovery from the physiologic stress placed upon pitchers' nervous systems, musculature, immune systems, and metabolic states (32,33). Anecdotally, when pitching and training sessions are organized at different times in the same 24-hour period (an occurrence in professional baseball and summer league baseball), the author suggests a minimum of 6 hours of rest between training and pitching practices to allow for short-term energy recovery (replenishment of creatine phosphate and lactate removal).

Because of evening games, pitchers should attempt to train in the morning and early afternoon. Training before competitive efforts may introduce

Table 3
Mesocycle 1 (November 1 to December 31) 3-day concurrent off-season training schedule for adolescent pitchers

Day	Pitching instruction	Strength and conditioning
M	Off	Effort lower body (77.5–82.5% RM)
		Bulgarian split squats 3 × 8–10 reps*
		Romanian deadlifts 3 × 8–10 reps*
		Lateral lunge 3 × 12 reps
		Walking calf raises 3 × 20 reps
		Core training 4–5 × 20 reps
		Interval cycle ergometer (15 min)
		2 min (70–80 RPM) LEVEL 5
		1 min (80–90 RPM) LEVEL 8
		30 s (max RPM) LEVEL 10
		90 s (60–70 RPM) LEVEL 5
		3 sets
Tu	Long toss 60–90 ft (40 throws)	Off
	50 ft changeups (20 throws)	
	Postthrowing exercises	
W	OFF	Total body dynamic (50–70% RM)
		Standing cable punch 3 × 10*
		Standing cable row 3 × 10*
		Bench pistol squats 4 × 8–10 reps
		Single leg deadlift 3 × 12–15 reps
		Banded hip abduction 3 × 20 reps
		Banded hip adduction 3 × 20 reps
		Cable hip flexion 3 × 12–15 reps
		Floor hyperextensions 3 × 15 reps
		Front side planks 3 × 10 reps, 3-s hold
		Flexibility training
Th	Long toss 90–120 ft (40 throws)	Off
	Postthrowing exercises	

(*continued on next page*)

Table 3 (continued)

F	Off	Effort upper body (77.5–82.5% RM)
		Flat bench dumbell press 3 × 4–6 reps*
		Single arm row 3 × 8 reps*
		Banded D2 patterns 3 × 25 reps
		Hammer curls 3 × 8 reps
		Triceps extensions 3 × 8 reps
		Pronation/supination 3 × 40 reps
		Dumbell wrist curls 3 × 40 reps
		Core training 4–5 × 20 reps
		Athletic development training†
Sa	30 pitch video captured bullpen	Postpitching interval training (30 min)
	3 fastballs	2 min (65–70% MHR)
	2 changeups	30-s sprint
	6 sets	1 min (65–70% MHR)
		15-s sprint
	Postthrowing exercises	1-min walk
		30-s sprint
		6 sets
Su	Off	Off

MHR = maximum heart rate estimate (% age-predicted max); RM = repetition maximum (1 RM = 100% effort); RPM = revolutions per minute.

*Suggested %RM prescription applied to primary exercises.

†Athletic development training, speed, power, agility, reaction, quickness.

pregame fatigue. Thus, understanding training status, progression, undulation, and athletes' recoverability will collectively enhance pitching performance. Survey data featuring adolescent pitchers, their workloads, and physiologic statuses presented an association with shoulder and elbow injury risks (21,22,28). Epidemiologic evidence supports this notion and states that youth pitchers averaging greater than 80 pitches per game per season were approximately 4 times more likely to have surgery (21). Respondents who pitched more than 8 months in the year were 5 times more likely to require surgical intervention (28). Pitchers who described their physical statuses as "occasionally fatigued" when pitching were 4 times more likely to experience surgery, whereas those who regularly pitched under a state of fatigue had a 36-fold increase in invasive surgery injury risks (28). Pitching volume was also classified as respondents who threw fewer than 300 pitches (undertraining the throwing arm) and more than 600 pitches (overtraining the throwing arm) per season, and both were more susceptible to severe upper extremity injuries (28).

Muscles are dynamic stabilizers that enact high tensile forces and torques over multiple joint angles. Muscles respond to high velocity, segment rotations, and linear translations (16). The dynamic stabilizers assist static stabilizers, tissues that have less stress reactivity and tensile strength (2,18). The static stabilization tissues are primarily connective tissues (ligaments, capsule, bone, and cartilage) (16). Because static stabilizers are less capable of handling high rates of loading during pitching, prefatigue about the shoulder and elbow musculature greatly increases the injury risk to static stabilizers (2,18). Essentially, dynamic muscle fatigue, or micro-injury, compromises one's ability to resist and regulate joint distraction, joint moments, and joint forces (18,21,22,26,28). For example, if the muscles producing varus moments about the elbow fatigue, greater varus torque efforts must be provided by the principle static stabilizer, the UCL, in maintaining joint integrity (2,6,18). The

Table 4
Mesocycle 2 (January 1 to February 28) 3-day concurrent off-season training schedule for adolescent pitchers

Day	Pitching instruction	Strength and conditioning
M	Off	Effort lower body (70–75% RM)
		Bulgarian split squats 8–10 × 3 reps*
		Romanian deadlifts 6 × 6 reps*
		Lateral lunge 3 × 10 reps
		Walking calf raises 3 × 30 reps
		Core training 4–5 × 25 reps
		Interval cycle ergometer (15 min)
		2 min (70–80 RPM) LEVEL 8
		2 min (80–90 RPM) LEVEL 10
		1 min (max RPM) LEVEL 8
		3 sets
Tu	Long toss 60–90 ft (60 throws)	Off
	50 ft changeups (30 throws)	
	Postthrowing exercises	
W	Off	Total body dynamic (50–60% RM)
		Standing cable punch 3 × 12–15*
		Standing cable row 3 × 12–15*
		Bench pistol squats 4 × 12–15 reps
		Single leg deadlift 3 × 20 reps
		Banded hip abduction 3 × 15 reps
		Banded hip adduction 3 × 15 reps
		Cable hip flexion 3 × 12–15 reps
		Floor hyperextensions 3 × 20 reps
		Front side planks 3 × 10 reps, 5-s hold
		Flexibility training
		Medicine ball circuit
Th	Long toss 90–120 ft (45 throws)	Off
	50 ft Changeups (40 throws)	
	Postthrowing exercises	

(*continued on next page*)

Table 4 (continued)

F	Off	Effort upper body (70–75% RM)
		Flat bench dumbell press 8 × 3 reps*
		Single arm row 3 × 10 reps*
		Banded D2 patterns 3 × 30 reps
		Hammer curls 3 × 15 reps
		Triceps extensions 3 × 15 reps
		Pronation/supination 3 × 1 min max reps
		Dumbell wrist curls 3 × 1 min max reps
		Core training 4–5 × 20 reps
		Athletic development training†
Sa	50 pitch video captured bullpen	Postpitching interval training (15 min)
	3 fastball	15-s sprint
	2 changeups	90 s (60–70% MHR)
	10 sets	5-s sprint
	Postthrowing exercises	30 s (60%-70% MHR)
		7 sets
Su	Off	Off

MHR = maximum heart rate estimate (% age-predicted max); RM = repetition maximum (1 RM = 100% effort); RPM = revolutions per minute.

*Suggested %RM prescription applied to primary exercises.

†Athletic development training, speed, power, agility, reaction, quickness.

principle dynamic stabilizers about the throwing arm are the following muscles and muscle groups: the rotator cuff, wrist flexors, pronator teres, biceps brachii, triceps, scapular stabilizers, deltoids, pectorals, latissimus dorsi, wrist extensors, and anconeus (2,6,18).

Cadaver research has indicated that the UCL can withstand approximately 54% of the valgus torque applied to the forearm when the elbow is flexed at 90° (18). It has been noted that the average failure point of a healthy UCL specimen was 32 Nm in the same anatomical position (18). Kinetic evaluations of valgus torques during adult pitching reveal average valgus moments between 55 and 70 Nm (1,3,15,18). The quantified valgus torques further validates the importance of efficient musculature assistance because the kinetic presentation of the valgus moment during pitching is more than twice the capacity that could be restrained by the UCL alone (1,3,15,18). From current biomechanics literature, it is imperative that flexor-pronator strength is maintained year round to improve the capacity to compress the medial elbow compartment by applying a varus torque (1,3,15,18). Ultimately, repetitive valgus stress and inefficiency in the dynamic stabilization of the medial elbow will cause greater engagement of the UCL (1,3,15,18). With overuse, chronic medial epicondylar injuries and poor remodeling capacities ensue, both of which will cause the UCL to be extremely vulnerable to tensile failure (1,3,15,18).

UNDERSTANDING RECOVERY

Recovery time between training and pitching segments is greatly individual. Recoverability relates to the mode of exercise, its intensity, duration, and volume that has been prescribed to the athlete (4,40). Aspects, such as energy sources used, resistance to microinjury, neural recruitment, training status, and nutrition will collectively dictate the time course required for metabolic and neuromuscular restoration (4). Research conducted by Potteiger et al (29) has indicated that the primary energy systems used for pitching are the alactic and lactic systems. Both anaerobic systems are also used in strength training and contain metabolites that are replenished by oxidative metabolism (4,31). As such, one can infer that improved aerobic restoration of fuel sources and clearance of lactate can enhance recoverability in pitchers (4,40).

At some point in all pitchers' careers, anecdotal beliefs relating arm fatigue to lactate accumulation may have ingrained a degree of noncompatibility

Table 5
Mesocycle 3 (March 1 to April 30) 3-day concurrent preseason training schedule for adolescent pitchers

Day	Pitching instruction	Strength and conditioning
M	Light toss 60 ft (50 throws)	Effort lower body (70–80% RM)
		Bulgarian split squats 12 × 2 reps*
		Romanian deadlifts 6 × 3 reps*
	Bunt coverage	Lateral lunge 3 × 8 reps
		Walking calf raises 3 × 12 reps
		Core training 4–5 × 25 reps
	First-third plays	Interval cycle ergometer (15 min)
		2 min (70–80 RPM) LEVEL 6
		10 s (max RPM) LEVEL 12
	Pitcher fielding plays	30 s (60–70 RPM) LEVEL 6
		10 s (max RPM) LEVEL 12
		5 sets
Tu	Long toss 60–90 ft (50 throws)	Off
	70 ft changeups (30 throws)	
	30 pitch video captured bullpen	
	3 fastballs	
	2 changeups	
	1 curveballs	
	5 sets	
	Postthrowing exercises	
W	Off	Total body dynamic (50–60% RM)
		Standing cable punch 3 × 20 reps fast*
		Standing cable row 3 × 20 reps fast*
		Bench pistol squats 10 × 5 reps
		Single leg deadlift 8 × 5 reps
		Banded hip abduction 3 × 10 reps
		Banded hip adduction 3 × 10 reps
		Cable hip flexion 3 × 10 reps
		Floor hyperextensions 3 × 15 reps
		Front side planks 3 × 10 reps, 5-s hold
		Flexibility training
		Medicine ball circuit

(*continued on next page*)

Table 5 (continued)

Th	Long toss 120–200 ft (45 throws)	Off
	50 ft changeups (40 throws)	
	Postthrowing exercises	
F	Off	Effort upper body (70–75% RM)
		Flat bench dumbell press 10 × 2 reps*
		Single arm row 3 × 10 reps*
		Banded D2 patterns 4 × 20 reps
		Hammer curls 3 × 10 reps
		Triceps extensions 3 × 10 reps
		Pronation/supination 3 × 90 s max reps
		Dumbell wrist curls 3 × 90 s max reps
		Core training 4–5 × 20 reps
		Athletic development training†
Sa	60 pitch video captured bullpen	Postpitching interval training (15 min)
	3 fastballs	10-s sprint
	2 changeups	60 s (60–70% MHR)
	1 curveball	10-s sprint
	10 sets	60 s (60–70% MHR)
	Postthrowing exercises	10 s
		60 s (60–70% MHR)
		5 sets
Su	Off	Off

MHR = maximum heart rate estimate (% age-predicted max); RM = repetition maximum (1 RM = 100% effort); RPM = revolutions per minute.

*Suggested %RM prescription applied to primary exercises.

†Athletic development training, speed, power, agility, reaction, quickness.

training (training inappropriate metabolic, muscular, and neurologic pathways). Current literature has not supported aerobic training as a mainstay in the conditioning of power athletes, such as baseball pitchers (10,31,35). Previous studies involving noncompatibility training arising from an overemphasis in aerobic training in pitchers have illustrated negative effects concerning fast twitch fiber morphology, biochemistry, force production, and neuromuscular recruitment (13,31,33,35,39). To avoid noncompatibility effects on muscular power, it is suggested for the athlete to perform interval training (28,29,35). Interval training frequency should be greatest at the beginning stages of the off-season, with a tapering of frequency and duration during Spring Training. During the in-season, the athlete should maintain aerobic conditioning through high-intensity interval training methods, having greater emphasis on cyclic max effort, speed, and power (7,11,13,31,33,39). The ability to improve aerobic capacity through interval training may improve pitchers' aerobic capacities for between-inning rest and recovery periods during the competitive season (5,40). The strength and conditioning coach should collaborate with the pitching instructors to identify periods in the training season where aerobic conditioning is to be maximized and when to ingrain aerobic maintenance training (lower volume, frequency, and variance in interval training) (4,35). Ideally, aerobic conditioning should be the emphasis at the beginning of the training platform to maximize cellular recovery, where muscular power is to be the principle training focus as the athlete approaches

Table 6
An example of an in-season concurrent training schedule for starting pitchers (professional baseball and collegiate summer league)

Day	Pitching instruction	Strength and conditioning
Pitch	Pregame bullpen mechanics	Assisted stretching if requested
	Game (80+ pitches)	
	Postpitching exercises	
1	Light toss (if desired)	Lower body resistance training
	Review previous game	In place lunge 12, 8, 6, 4, 2 reps (50, 60, 70, 80, 85% RM)
		Lateral lunge 12, 8, 8 reps (50, 70, 70% RM)
		Db Single leg deadlift 12 × 3 reps (70–80% RM)
		Cable hip abduction 2 × 15 reps
		Cable hip adduction 2 × 15 reps
		Cable hip flexion 2 × 15 reps
		Stability reverse hyperextensions 3 × 12 reps
		Cable woodchops 3 × 15 reps
		Interval poles 20 minutes
		Jog warning track 2×
		Sprint half warning track
		Jog half warning track
		Sprint warning track
		Walk warning track
		3–4 sets
2	30–40 video-based side bullpen	Athletic development training*
	Postpitching exercises	
	Mechanics discussion	Rotational medicine ball circuits

(*continued on next page*)

Table 6 (continued)		
3	Long toss to max distance (40–50 throws)	Upper body resistance training
		Standing cable punch 25, 15, 10, 8, 4 reps (50, 60, 70, 77, 82.5% RM)
		Standing cable pull 25, 15, 10, 8, 4 reps (50, 60, 70, 77, 82.5% RM)
		Hammer curl to dumbell press 3 × 8–10 reps
		Triceps kickbacks 3 × 12 reps
		Supination/pronation 2 × 1 min max reps
		Radial/ulnar deviation 2 × 1 min max reps
		Wrist curls 2 × 1 min max reps
		Core training 4–5 × 20 reps
		Repetitive sprint training
		5 yards
		15–20 reps
		3–5 sets; 15–20 s rest per rep
		Attempts to replicate activity to rest times
		Creatine Phosphate recovery maintenance
4	Light toss (if desired)	Extended dynamic warm-up
	Review game plan	
Pitch	Pregame bullpen mechanics	Assisted stretching if requested
	Game (80+ pitches)	
	Postpitching exercises	

*Athletic development training, speed, power, agility, reaction, quickness.

preseason (4,35). Szymanski (39) indicated that heart rate intensities during bullpen sessions provide a foundation to establish interval conditioning demands. Strength and conditioning coaches should be aware that mean pitching heart rates (151.6–171.8 beats per minute) could be elevated during actual competition with increased emotional and psychologic stress (33,39).

Excess postexercise oxygen consumption (EPOC) research has illustrated 2 recovery mechanisms concerning rapid and slow rates in baseline return of elevations in oxygen consumption (4). Postexercise oxygen consumption reflects fuel sources used according to the energy demand in previous activity and infers one's ability to recover from exercise (4,40). Excess postexercise oxygen consumption values also indicate the extent of physiologic repair (structural protein integration, collagen formation, immunologic function) required after activity (4). Generally, repetitive high-intensity eccentric exercise inspires a greater amount of muscular microdamage for repair and greater absorbance of glycogen stores (4). Blood lactate has not significantly accumulated in response to pitching, as the intermittence and short duration of the pitching delivery permits its clearance (29,35). With greater recovery costs, EPOC values may extend the time for one to reach baseline in comparison with lighter activity of less physiologic and metabolic consequence (4). In the author's opinion, it is best to incorporate an undulated program (varying training workloads rather than progressive overload), especially in-season, to allow for greater recovery capacity by limiting microdamage, fuel source depletion, and lactate levels. Examples of interval training prescriptions are listed in the concurrent training templates (Tables 1–6). Current information concerning interval training for pitchers can also be found in Szymanski (39).

Baseball strength and conditioning coaches must have a conceptual idea in qualifying their pitching populations. An understanding of performance capabilities, pitching role, and orthopedic history will provide the frameworks as to how one organizes training, reinforces mechanical aspects, and competitive objectives. Pitchers are separated by roles, which are generally determined by the variety of pitches they can throw, the frequency they can tolerate, and the velocity by which they can deliver each pitch. Generally, starting pitchers have command of 4–5 pitches or pitch variations (arm slot, grip changes and tempo) to offer a deceptive approach to hitters throughout the majority of a competitive game (5–7 innings). Mid relievers throw 2–3 pitches with control and offer short-term relief for 2–3 innings. The closer is a position held by a pitcher who throws 1–2 pitches that are traditionally thrown at high velocities. The closer may come in to only face a series of batters or to record an out. For the relief staff, high-intensity training is a principle focus, as endurance work must be managed in not exceeding strength and power training. In contrast, starting pitchers, being the extended inning performers in baseball, require a higher degree of baseline aerobic fitness. Again, appropriate aerobic training formats can be used through the use of interval training to condition both aerobic and anaerobic metabolism (33,35,39). Collectively, the enhancement of aerobic and anaerobic conditioning can facilitate an improved recoverability during competition and between innings.

SUMMARY

A well-managed concurrent training program should be organized to involve pitching and physiologic training, both aimed to reduce prepitching fatigue and the risk of injury. The guidelines set forth from Tables 1–6 suggest intensities that systematically load and unload the musculoskeletal system over the course of each training cycle. Greater percentages of a single repetition maximum (1RM) entitled "effort" offers improvement of force production. Lower percentages condition contractile velocity, which is considered "dynamic" training to accelerate resistance loads. The delicate combination of both muscular force and contractile velocity equates to total body power, essential for optimizing the pitching delivery. Interval training intensities from exercise machine settings, such as the cycle ergometer, are attributed to time, revolutions per minute, and resistance settings (LEVEL). Typically, the LEVEL setting on exercise equipment corresponds to the resistance applied. Interval training intensities can be easily monitored by heart rate values, as greater percentages of age-predicted maximum heart rates correspond to greater physiologic effort and anaerobic involvement (31,32,38).

Continuous observation will afford strength and conditioning officials and affiliated coaches a means to protect pitchers from overtraining risks. Human performance gains, especially the improvement of total body power, a product of both muscular force and contractile velocity, has to be maximized and trained for repetition. Special attention to injury prevention exercises entitled *Post-Throwing Exercises* must be ingrained for all athletes to maintain competitive prowess and longevity about the throwing arm.

Pitching performance observation should be performed by a qualified person with knowledge of biomechanics and mechanisms of throwing arm pathologies. The most basic form of mechanical observation entails 2-dimensional video review to denote kinematic changes. Kinematic changes concern joint position and timing of motion sequences. It is best to configure multiple cameras to be synchronized and assess motion about 3 orthogonal planes (sagittal, coronal, and transverse). Pitching coaches should carry a pitch count tracker so that pitch volume is recorded. Similarly, radar feedback concerning pitch type and accuracy estimation will provide sound methods to determine progress and fatigue-related aspects.

Performance records will offer insight into where strength coaches and pitching coaches are to make adjustments in training variables (frequencies, intensities, exercise selection, etc). It is important that strength coaches and pitching coaches collaborate for program modification. As such, analyses of individual needs will be more efficacious, as both the strength and skill assessment will consistently reinforce one's desired kinesiology within his/her pitching delivery. Examples of shared communications will entail (a) descriptions of mechanical flaws in pitching and the prescribed physical adjustments to allow for remediation, (b) range of motion deficits, (c) laxity impacts, (d) acute and chronic injury histories, (e) human performance baselines, and (f) clearly stated competitive goals for the approaching season.

If working with youths, one must acknowledge risks associated to Little Leaguer's elbow syndrome. Current research has not quantified the impact of strength and conditioning, nor qualified appropriate exercises for youth pitchers concerning medial elbow injuries. It would be in the best interest of youth baseball leagues to hire strength and conditioning consultants to educate skill coaches in the implementation of training activities to better improve the physical strength, coordination, and recovery capacity of the developing pitcher. It is speculated by the author that a youth baseball initiative to address injury prevention practices regarding pitching management, biomechanics, and physiologic training will greatly reduce injury vulnerability and statistics.

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