Mechanisms and Treatments for Shoulder Injuries in Overhead Throwing Athletes

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Abstract
Shoulder injuries in overhead throwing athletes are very common. Throwing volume and mechanical forces that are placed on the glenohumeral joint and associated soft tissue structures are contributors. Poor biomechanics and weak links in the kinetic chain place this athletic population at increased risk for shoulder injuries. Common biomechanical deficiencies in overhead throwing athletes typically involve poor sequential timing of muscle activity and insufficient coordination also presented in shoulder elevation and other functional tasks. Kinetic chain deficits will lead to injury due to poor transference of energy from the lower extremities to the dominant upper extremity. Correction of these deficits involves effective treatment and prevention strategies. These include core and hip strengthening, balance training, optimize timing of biomechanical phases and events for each throwing movement, and following recommended rest guidelines. This article will synopsize current evidence of sport-specific injury mechanisms, injury treatment, and prevention of the shoulder in overhead throwing athletes.

Epidemiology

Shoulder injury is commonly managed in musculoskeletal and sports medicine clinical settings. The shoulder is the most common location for the throwing-related injury (21). In the United States, there are more than 2.1 million participants in high school American football, baseball, softball, and volleyball who are at risk for sport-related shoulder injury (83). During 2005 to 2012, there was a shoulder injury rate in high school athletics of 2.15 per 10,000 athlete exposures (110). At the NCAA level, there are currently over 140,000 men and women that participate in overhead throwing sports at the division I, II, and III levels, including baseball, softball, and volleyball. In collegiate baseball, a 16-yr study revealed 1623 shoulder injuries of which 59.5% were associated with throwing and 73% were attributed to pitching (26). Interestingly, if comparing pitchers versus position players in high school baseball and softball, one study revealed that the incidence of injury for pitchers was 37.3% versus 15.3% for position players (116). A subset of track and field athletes participate in four throwing sports: javelin, discuss, hammer, and shot put (84). Cricket is enjoyed by nearly two million participants in England, Wales, and Australia and is the most popular sport in India (22,25,42). Based on the chosen sport, stresses placed on the glenohumeral joint with repeated overhead motion contribute to shoulder injury. Please see Table 1 for a summary of the available epidemiological data for the proportion of throwing sport-related injuries occurring in the shoulder.

Baseball has emerged as the activity with the highest shoulder injury rates among overhead throwing sports. During 2005 to 2007, shoulder injuries in high school baseball players comprised more than 17% of the 130,000 high school baseball-related injuries. A majority of shoulder injuries occur from pitching (74,98) and 58% to 69% of all reported injuries in baseball occur in the dominant upper extremity with rotator cuff tendonitis as the most frequent shoulder injury diagnosis (74,99,128,143). In other sports, like American football, more than 15% of all injuries to National Football League (NFL) quarterbacks affect the shoulder. Fourteen percent of those injuries are related to overuse (2.1% of total NFL injuries) (58). Cricket and handball induce a relatively high injury rate. A total of 23% to 36% of high-level cricketers have suffered shoulder pain during one season of play (43,104). The incidence of shoulder pain and injury in elite handballers ranges from 7% to 28% (4,82,114). Table 1 summarizes the evidence of the proportion of sport injuries that occur in the shoulder. For consistency of kinematic and biomechanical comparison in the following sections, we are focusing on sports that do not use an external extension of a lever arm, such as lacrosse or tennis.

Identification of common kinetic chain deficits and biomechanical mechanisms underlying shoulder stress and pain

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Table 1.
Summary of the evidence relating to the proportion of sport injuries occurring in the shoulder.

Sport	Injuries Related to Shoulder (% of Total Injuries)
Baseball (pitchers and position players)	58%–69% (74,99,128,143)
Softball (pitchers and position players)	14%–25% (49,73)
Cricket (bowlers)	12.5%–41% (25,104,119)
Handball	7%–40% (4,82,114)
Volleyball	8%–60% (11,38,107,124), 33–53% due to overuse (106)
Football (quarterbacks)	15% (58), 2.1% due to overuse throwing (58)

is clearly needed. Injury prevention strategies and treatment plans for the overhead throwing athlete can help athletes stay active as long as possible in a competition. Through an understanding of the mechanics and pathomechanics of overhead throwing in various overhead throwing sports, health care providers can better assess and screen for potential kinetic chain deficits in the overhead throwing athlete and prevent injury (17). This article will address these points.

Weak Links in the Kinetic Chain

The kinetic chain connects body segments and transfers energy from one body segment to the next during motion such as throwing (17,61). More than 50% of kinetic energy is transferred to the upper extremity via the legs and core in overhead throwers (17,61,113). The typical sequence of events during a general throwing motion includes the stride, pelvis rotation, upper torso rotation, elbow extension, shoulder internal rotation, and wrist flexion (35). Deficits in the kinetic chain, otherwise known as deficiencies or "weak links," such as in the core, spine, hip, and glenohumeral range of motion (ROM), and scapular kinetics, may lead to shoulder injury in overhead throwers (4,17,61,68). One recent study found that professional pitchers who had less than 5° greater external rotation in the throwing shoulder compared with the nondominant shoulder were four times more likely to require shoulder surgery (136). A second example, the core, is important in providing stabilization to the spine and trunk of the body, which allows transference of energy to the extremities (50). Proper glenohumeral ROM and scapular kinetics will lead to decrease stress on shoulder during the cocking phase of throwing in baseball (113,135). For maximum efficiency of movement and injury prevention, coordinated motions between the lower and upper body are required.

Biomechanical Deficiencies

Proper sequential timing of muscle activity and coordination is required to safely transfer energy from the lower extremities to the projectile release. An efficient kinetic chain involves all segments of the body that must work in unison (17,61). When specific aspects of the segmental coordination are compromised, loading stresses develop at unaccustomed areas of the musculoskeletal tissues (17,51,61). Poor muscular flexibility, muscle endurance, low shoulder and hip ROM, poor spinal mobility, and muscular weakness (particularly in the rotator cuff) are all factors that increase shift mechanical loading to tissues along the kinetic chain. This increases the risk of injury (53,93,127,144). A breakdown of the motion of the proximal segments (hips, core, legs, and spine) leads to increased demands placed on the distal segments of the body (*e.g.*, the shoulder, elbow, and wrist) (17,51,61). This concept, also known as the "catch-up" phenomenon, was previously described by van der Hoeven and Kibler (51). For example, muscular fatigue in baseball pitchers contributes to reduction of shoulder external rotation angle and increase in the leading leg knee flexion angle (80).

Biomechanical Components of the Overhead Throwing Motion

Throwing motions from different sports have common phases and events as depicted in Figure. Sport-specific nuances, such as projectile type objects or required positioning of the throwing arm, may predispose an athlete to higher risk of injury. Each throwing motion involves an initiation of the throw, a transfer of linear energy from the lower body to rotational energy in the upper body, and projectile release. Sequential timing of muscle activity in the lower extremities, trunk, and the dominant upper extremity is required for optimal energy transfer. Table 2 provides a summary of the common phases and events in each of the sport throwing motions. Additional sport detail is described in the following sections. For example, javelin throwers are not able to throw as far if using inconsistent upper extremity motion patterns (69,129).

Baseball

In baseball, there are several well-defined and researched phases and events that comprise a pitch. As such, the baseball pitch will serve as the motion reference for the other sports. The phases include the wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. The events include initial position, balance point, foot contact, maximum shoulder external rotation, ball release, maximum shoulder internal rotation, and fielding position (36). When the arm is in the early stages of cocking, the shoulder extends, abducts, and externally rotates. This event may lead to glenoid internal impingement, a significant cause of posterior shoulder pain in the overhead athlete (7,23). During the late stages of cocking, the humerus is at its most extreme ROM, which creates significant anterior shear force on the shoulder exceeding 1200N (64). At this time, the scapula begins to retract and elevate while the humerus elevates and externally rotates at a velocity upward of 7000° per second (28). This position (abduction and external rotation, otherwise known as the 'peel-back' mechanism) may cause injury due to the twisting of the long head of the biceps (LHB) tendon along the superior glenoid rim. This also may lead to a superior labral anterior to posterior (SLAP) injury (12,97). A SLAP lesion occurs in a thrower's shoulder when the LHB brachii tears the biceps labrum complex from the glenoid rim (5). In skeletally

Figure: Still comparative panels of key serial phases of the throwing motions in baseball (A), cricket (B), volleyball (C), football (D), and javelin (E).

immature athletes, typically between 11 and 16 yr old, repetitive external rotation can create physeal damage and lead to proximal humeral epiphysiolysis, or "Little League Shoulder" (123). Once acceleration begins, there may be labral and/or rotator cuff fraying if the glenohumeral stabilizers are deficient. This cuff fraying is in part due to the combination of humeral translation, compression, and internal rotation (34,36). During the deceleration stage, the arm dissipates high velocities over a very short period (92). These distractive forces at the shoulder may be equal to the thrower's body weight (64). The scapula continues to tilt anteriorly while internally and downwardly rotating while the humerus horizontally adducts and internally rotates leading to maximum humeral head superior shear forces.

Injuries that may occur in the deceleration phase include a SLAP tear and a LHB tendon injury. This is due to the traction forces imparted on the biceps-labral complex with the shoulder in abduction and maximum external rotation orientation (64). The biceps also is most active during this phase (27). The rotator cuff may be injured due to the large eccentric forces with potentially weak rotator cuff muscles. Compressive forces can approximate 1100 N (which is nearly equal to 250 lb), and posterior shear forces can reach 400 N (approximately 90 lb) (34,36,64). Higher-level pitchers can produce very high force and torque and have higher risk of rotator cuff injury than lower-level pitchers (36). Finally, posterior shoulder capsular tightness and thickening is a consequence of repeated large torques on the posterior rotator cuff and joint capsule as muscles attempt to slow horizontal adduction and internal rotation of the humerus during the deceleration phase (10,64). This is clinically significant as thickened and stiffer posterior shoulder capsules in baseball players are associated with decreased glenohumeral internal rotation deficit (GIRD), a risk factor for throwing injury (121).

Football

While similar to the baseball pitch, a football throw does involve some differences in shoulder motion. Quarterbacks will rotate their shoulders earlier during arm cocking. Greater cocking increases the energy stored and increases the distance in which the shoulder can accelerate forward and internally rotate (76). While the football itself is heavier than a baseball, the velocity of shoulder movement is slower. Shoulder internal rotation velocities throwing a football are more than 2000° per second slower than throwing a baseball (76). Furthermore, quarterbacks have increased shoulder horizontal adduction, increased elbow flexion, and shorter lever arm to offset the effect of a heavier football (76). There is variability of the segmental velocities of an overhead throw based on the age of the participant. For example, younger players throw with slower upper body segmental velocities than older players (36). Compared with baseball, relatively fewer shoulder injuries in football than baseball may be a consequence of: 1) slower angular velocities at the shoulder (76) and 2) lower throwing volume per athletic exposure than in baseball. On average, we estimate that a starting baseball pitcher will pitch in a game approximately every five days, sometimes more frequently if the pitcher is a reliever. This same pitcher may throw more than 100 pitches in a game. It is rare in a football game to for a quarterback to throw more than 30 to 40 times per game. Moreover, there is only one

Table 2.
Common phases and events in overhead throwing sport motions.

Sport Motion	Phase	Event	Phase	Event	Phase	Event	Phase	Phase
Baseball pitch (36)	Wind-up and stride	Balance point	Arm cocking	Max shoulder ER	Arm acceleration	Max shoulder IR and ball release	Arm deceleration	Follow through
Cricket (54)	Run-up and lead leg stride	Max elbow extension	Arm late cocking	Max shoulder *abduction*	Arm acceleration	Hands free and ball release	Arm deceleration	Follow through
Handball (95,122)	Two-hand contact	Stride foot contact	Arm cocking	Max shoulder ER	Arm acceleration	Max shoulder IR	Arm deceleration	Follow through
Volleyball serve (107)	Approach	Take-off	Arm cocking	Maximum shoulder ER	Arm Acceleration	Ball contact	Arm deceleration	Follow through
Football throw (76)	Front foot step	Stride	Arm cocking	Max shoulder ER	Arm acceleration	Max shoulder IR	Ball release and arm deceleration	Follow through
Javelin throw (69)	Approach run and cross-over	Acceleration	Acyclic	Javelin release	1 Leg support to 2 leg support	Braking	Arm deceleration	Follow through

ER, external rotation; IR, internal rotation.

game per week during the season. Common throwing shoulder injuries in quarterbacks were overuse type injuries, specifically rotator cuff tendonitis and biceps tendonitis (57,58). One final point is that full shoulder pads may change the throwing mechanics in American football quarterbacks. While we can surmise that padding may restrict shoulder abduction and external rotation, additional study is needed to confirm this.

Volleyball

The phases and events of a volleyball serve or spike are similar to those of baseball with one main exception. The first event involves an approach and "take-off" where the athlete jumps vertically in preparation to make contact with the ball. During a volleyball serve, shoulder angular velocity will range from approximately 1800° to 2500° per second in female collegiate volleyball players, nearly 5000° per second slower than a high level baseball pitcher (36,105). The peak shoulder forces are significantly less in volleyball players compared with baseball players (330–358 N versus more than 1000 N, respectively). Similarly, the peak shoulder internal toques are less in female volleyball players compared with professional baseball players (32–40 Nm versus 68 Nm, respectively) (36,105). These torques and shoulder forces increase the risk for development of subacromial impingement or labral injury (105). Common shoulder injuries in volleyball players include rotator cuff tendinosis, musculotendinous strain, and glenohumeral subluxation/dislocation (106).

Javelin

In javelin, the initial phase of movement involves an approach run to generate momentum before the throw. This initial phase is paramount to success as the throw. Fine coordination of the steps of the approach and the foot strike enables maximal transfer of momentum from the lower body to the upper body (79). There is a significant drive off of the back leg preceding the javelin throw, similar to what occurs in a baseball pitch. Evidence shows that the mean maximum shoulder joint resultant force may be as high as 1740 N due to the transfer of momentum (67). To increase the distance range over which force may be applied to the javelin, throwers strive to achieve high shoulder external rotation values while limiting shoulder internal rotation during the approach run and crossover (48). The result is a large eccentric load during the acyclic phase. The repetitive emphasis of limiting internal rotation of the glenohumeral joint will lead to tightening of the rotator cuff in the posterior capsule (60,81). Repeated eccentric stresses on the rotator cuff with eccentric loading and excessive external rotation can cause microtrauma of the rotator cuff tendons, potentially leading to overuse injuries (60,62,77).

Cricket

Compared with baseball, cricket is characterized by a couple key motion differences. Cricket has a similar first phase to that of Javelin (called a "run-up") where running is involved. Due to rules of play, players must throw with an extended arm with no more than a 15° elbow flexion during the act of delivering, or bowling, the ball. From a biomechanical perspective, this is important because this arm extension increases the valgus torque on the elbow and increases distractive forces on the shoulder to nearly 600 N, which is nearly 100 N more than in baseball pitchers (19,32,120). As in baseball, different throws exist in cricket, including fast and spin bowls. Fast throwers have increased rates of overall injury compared to spin throwers likely due to poor technique, improper training, and overuse (119). Spin bowlers typically have higher shoulder bowling injury rates compared with throwers who throw at faster speeds, in some cases more than 10% greater (47). This may be due to spin bowlers rotating the shoulder internally while circumducting the arm, potentially leading to impingement (47). Interestingly, this pattern is reversed in the baseball literature. Baseball players who throw harder have increased shoulder distraction forces which could potentially put them at increased risk for shoulder injuries, whereas fast bowlers typically have increased rates of low back injury by a factor of more than 2.6 (instead of shoulder injuries) compared with spin bowlers (100). This may be because fast bowlers have increased muscle activation in the paraspinal and gluteal muscles in the lumbopelvic region due to increased compressive and shear forces with increased bowling speeds (37). Common shoulder injuries in fast-throwing cricketers include rotator cuff tendonitis and biceps tendonitis, the same as American football quarterbacks (90).

Other Sports

We are aware that other overhead throwing sports, such as handball, have similar throwing motions to that of the other sports described, particularly baseball. However, the specific biomechanics of handball are not yet known. Injuries experienced by handballers include scapular dyskinesis, total glenohumeral rotation deficit, and decreased rotator cuff strength (3,18).

Injury Risk Exacerbation: Overuse

Overuse can increase shoulder injury risk in overhead throwers. Strong evidence shows that overuse injuries occurred in baseball with greater frequency when pitching more months per year, games per year, innings per game, pitches per game, and pitches per year (89). Injuries occur more frequently in pitchers due to year-round baseball training, concurrent participation in multiple teams, and participation in showcase events than those who intersperse rest (14,59,89,140). Most alarming is that pitchers who continue to pitch with arm pain symptoms despite fatigue have a 36 times the increased risk of injury compared to players who stop with onset of pain (89). Other risk factors for shoulder injury in baseball include pitching on consecutive days, pitching with higher velocity, pitching with rotator cuff weakness, and pitching with a GIRD (29,30,56,71,94,134). One additional factor may be geography. Warm weather-based pitchers are able to pitch year round which may result in an increase in cumulative wear and tear on the throwing arm, leading to an increase in overuse pitching injuries compared with their cold weather counterparts (141,143).

Overuse contributes to shoulder injuries in other sports, such as volleyball, cricket, and handball. Volleyball injuries are proposed to be due to a history of prior shoulder pain and the volume of activity to which the athlete's shoulder is exposed are considered key in risk assessment (107). Limited evidence shows that team handball players perform more than 48,000 throws per season (114). Factors included shoulder internal rotation strength deficit, downward facing scapula, and bowling workload (46,88).

Treatment and Rehabilitation

Treatment and rehabilitation goals for a shoulder injury are to restore full ROM, strength, static and dynamic stability,

Table 3.
Phases and content of rehabilitation programs for the overhead throwing athlete.

Phase	Aims	Treatment
I: Acute	• Reduce pain and inflammation	• Ice, iontophoresis, ultrasound, electrical stimulation
	• Normalize ROM	• Flexibility and stretching
	• Reestablish muscular balance and delay muscular atrophy	• Rotator cuff and scapular strengthening
		• Balance training
II: Intermediate	• Progress strengthening program	• Continue stretching and flexibility
	• Restore muscular balance and augment dynamic stability	• Progress isotonic strengthening
	• Control flexibility and stretches	• Rhythmic stabilization drills
III: Advanced Strengthening	• Progress neuromuscular control	• Continue stretching, flexibility, rhythmic stabilization drills
	• Improve strength, power, and endurance	• Begin Advanced Thrower's Ten program
IV: Return to Activity	• Begin return to throw program	• Strength and flexibility drills
	• Return to sport	• Thrower's Ten program
	• Maintain strength and flexibility drills	• Plyometric program
		• Progress to competitive throwing

(133) Modified from: Wilk KE, Arrigo CA, Hooks TR, Andrews JR. Rehabilitation of the overhead throwing athlete: there is more to it than just external rotation/internal rotation strengthening. *PMR*. 2016 Mar;8(3 Suppl):S78-90.

and neuromuscular control (16). Kibler et al. (61) break down treatment interventions into five main areas: shoulder flexibility, pelvic and core strengthening, scapular control, and RC activation. To accomplish these goals, four main phases of rehabilitation need to be completed including acute, intermediate, advanced strengthening, and return to throwing (133,137). Table 3 provides an overview of the treatment and rehabilitation plan and Table 4 refers to the clinical recommendations with level of evidence.

At the end of a clinical encounter, a physician may consider various treatment modalities in the acute setting. Depending on the diagnosis, medical history, and age of the patient, oral and/or topical anti-inflammatory medications, and various injections (such as corticosteroid) may be considered to reduce any pain and inflammation. Education on rest from sport and exertion to the shoulder is advised. Typically, a referral to a licensed physical therapist and/or certified athletic trainer is indicated. If there is a concern of an injury requiring surgery, referral to an orthopedic shoulder and/or sports medicine surgeon is warranted.

During the acute phase of rehabilitation, the main aim is to restore function. Treatment goals include protection from further injury, restoration of ROM, reduction of pain and inflammation, and possible initiation of closed kinetic chain exercises. The main aim of the intermediate phase is to restore functional strength, increase sport specific strength and endurance, continue full pain-free ROM, and optimize neuromuscular control. Data from collegiate baseball players showed that a posterior capsule stretching program helps to increase passive internal rotation ROM at the glenohumeral joint (2). The aim of the advanced strengthening phase is to increase sport-specific strength and endurance, and its treatment goals are to begin open kinetic chain exercises. Finally, the main aim of the return-to-throwing (RTT) phase is to progress through a sport-specific program at full strength, pain-free, emphasizing neuromuscular and proprioceptive control, flexibility, and strength (133,137). Age and level of competition are two factors that could dictate if a player returns to competition sooner based upon position; younger players who throw with less volume may return earlier to competitive play. Other overhead sports, such as volleyball, have published data recording the frequency of hits per match and by position. These data provide the frequency of overhead activity that is required to safely return to competition (52).

Specific rehabilitative programs designed for overhead throwing athletes include the *Thrower's Ten Exercise Program* and the *Advanced Thrower's Ten Exercise Program* (130,132,138). The Thrower's Ten is a set of strength training and stretching exercises specifically designed for overhead throwing athletes. The Advanced Thrower's Ten exercise program transitions an athlete from rehabilitation to training and emphasizes neuromuscular control, strength, coordination, endurance, and muscular balance (138). For a list of the exercises please refer to Supplemental Tables 1a and 1b, http://links.lww.com/CSMR/A12 and http://links.lww.com/CSMR/A14. Core weakness also may be a risk factor for shoulder pain. Inadequate core strength interferes with the transference of energy from the lower to the upper body during a throw. As a consequence, the muscles of the shoulder girdle must generate greater joint torques and moments to compensate for core weakness (12,13).

An RTT program in baseball requires slowly progressing through increasing throwing distances while minimizing the risk of reinjury (16,117). RTT programs include balance, coordination, flexibility, strength, and conditioning, gradual progression to minimize risk of reinjury, proper warm-up, and proper throwing mechanics (108). Age, skill set, and severity of injury all influence progression during rehabilitation. Progression is dependent on each phase being pain-free and without complications (108).

Once an overhead throwing athlete is asymptomatic a biomechanical throwing analysis is useful. Electromyographic (EMG) and high speed video analysis can provide visual and objective details regarding the timing and coordination of the involved muscles, joints, and kinetic and kinematic variables (115). It also should be noted that the age of the athlete and type of pitch (such as a fast versus spin bowler in cricket) can affect muscle recruitment patterns and change usage of different segments of the kinetic chain (45,47,115). Sport performance also may improve due to correction of kinetic chain and biomechanical defects. This is as a result of the coordination of proximal and distal segments of the kinetic chain resulting in improved transfer of energy to the upper extremity, which in turn leads to increased ball speed velocity and efficient force generation (17,115).

Table 4.
Clinical recommendations.

Clinical Recommendation	SORT Evidence Rating
Kinetic chain deficiencies place overhead throwing athletes at increased risk for shoulder injuries.	C (17,31,61,68,80)
Not following pitch volume restrictions can lead to overuse throwing injuries.	A (62,75,89,119)
Rehabilitations programs should focus on restoration of ROM, strength, static and dynamic stability, and neuromuscular control.	C (6,9,131,133,138)
A return to throw program after injury is recommended to reduce and prevent throwing injury.	A (16,108,117)

SORT, Strength of Recommendation Taxonomy.

A: Consistent, good-quality patient oriented evidence.

B: Inconsistent or limited-quality patient oriented evidence.

C: Consensus, disease-oriented evidence, usual practice, expert opinion, case series.

Prevention of Injury

Prevention of injury in the overhead throwing athlete begins with early recognition of pain and dysfunction. Injury prevention in overhead throwers is challenging due to a concept known as the "thrower's paradox" (137). This concept refers to the role of the RC complex on maintaining the humeral head centered in the glenoid fossa—athletes must have enough shoulder flexibility to throw, but maintain enough stability to prevent instability events from occurring (15,131). The thrower's paradox concept should be leveraged during regular training. Prevention programs that are aimed at increasing glenohumeral internal rotation, rotator cuff and scapular muscle strength, improving kinetic chain and thoracic mobility, and medicine ball training has been shown to reduce the prevalence of shoulder injuries and improve performance in handballers and javelin throwers (4,55,62,102).

Following Recommendations for Volume of Throwing

Overhead throwing injuries can be minimized in baseball by following expert recommendations for pitch counts, rest days, and proper mechanics (78). With the gradual onset of pain, early intervention and evaluation may help prevent development of injury. Similar patterns regarding overuse have been observed in cricket (24,75), softball (66), and handball (4).

Core and Hip Strength

Low hip and core strength can be addressed with rehabilitation or training programs. Testing of hip extension strength, hip abduction strength, and assessment of a Trendelenburg sign are key initial steps. Other dynamic tests may include single-legged squats, in-line lunges, hip drops, and alternating quadruped tests (86,125). Hip and trunk ROM should be evaluated to identify any asymmetry in internal or external rotation, because changes in hip ROM are associated with shoulder injury in overhead throwing athletes (33,72,112,126,142,144). Improving core strength can enhance shoulder strength and throwing velocity in female handballers (55,102) and in collegiate softball players (101). Core strengthening programs can improve velocity in throwing in handballers, and throwing accuracy in baseball players (70,111). Research has shown that activating and maintaining gluteal strength in softball catchers increases strength to the lumbopelvic-hip complex, thereby improving core stability across the entire kinetic chain which in turn prevents upper extremity injury (96). Trunk flexibility and ROM should be assessed due to the involvement of these parts of the kinetic chain during phases of throwing (126). In cricket, there is a term known as the "crunch factor" (44). This occurs when there is lateral flexion and axial rotational velocity of the lumbar spine during a throw. There is concern that the crunch factor may be partly responsible for lower back injuries and for affecting spatial orientation of the arm at release during a throw (44). Thus, throwers should consider training programs to improve core and hip muscle strength and activation to optimize the functional throwing motion.

Lower Extremity Balance

Balance is crucial for dynamic stability. Balance on the back leg during the wind-up phase of a baseball pitch or with the plant leg after the approach run and cross-over in the javelin are important because balance can maintain appropriate body position (17). A majority of overhead throwing sports require stability and strength from a plant/back leg (refer to Table 2). Thus, gluteal strength and timely activation of the gluteal muscular complex are necessary to provide increased stability of the lower extremity. A stable base can efficiently transfer energy from the lower to the upper body and control the forces that develop at the shoulder. Emerging evidence supports this concept (37,87,96).

Timing of Biomechanical Phases and Events

The timing of phases and key events during repetitive throwing is critical for prevention of throwing injury. For example, baseball pitchers who have improper timing of trunk rotation (too early or too late) and anterior trunk lean experience increased maximal shoulder external rotation angle and proximal shoulder force. This results in increased upper extremity loading and increased shoulder injury risk (91,118). Improper stride length might lead to throwing arm injuries in baseball pitchers because shorter strides generate less lower forward momentum before stride foot contact leading to insufficient total body momentum (103).

Practical Applications on Injury Prevention

Implementation of an injury prevention program is not an easy task. Clinicians who care for overhead throwing athletes, particularly at the adolescent and high school levels, need to develop relationships in their communities with athletic trainers, sports physical therapists, coaches, parents/caregivers, and athletes. This can be performed through volunteer coverage of competition, outreach lectures aimed at educating the community on overuse throwing injuries, as well as implementation of kinetic chain assessments. Development of an injury prevention program will, in turn, benefit athletes by decreasing injuries, potentially increase sports performance, and lead to development of relationships with medical professionals who can care and be resources to athletes in a timely manner. As has been noted in the previous literature, prevention of throwing injuries can be reduced with education regarding following recommended pitch count and rest rules, and common sense (33). Furthermore, an injury prevention program fits into the concept of patient-centered care (PCC). PCC incorporates the principles of coordination and integration of care (such as with athletic trainers, physical therapists and physicians), providing information and education (in the community via lectures), involvement of family, and continuity of care (through development of relationships with athletes) (65). These concepts are all necessary for a successful injury prevention program in sports.

Future Directions

The next evolution in treatment of overhead throwers is injury prediction (30). Using predictive screening tools that combine overuse factors, biomechanical deficiencies and intrinsic factors (such as velocity) and extrinsic factors (such as height), could lead to a decrease in overall throwing injuries in the shoulder. For example, stride length (which can be correlated to height in a pitcher) has been shown as one factor in designing injury prevention and return to pitch programs after injury and for prevention of injury (41,109).

One such injury predictive scoring assessment measure is the Kerlan-Jobe Orthoapedic Clinic Shoulder and elbow (KJOC) score. The KJOC score is a subjective questionnaire that has been validated and been shown to be sensitive and specific in overhead athletes (39). Scores range from 0 to 100. Typically, KJOC scores for asymptomatic overhead throwers should be greater than 90 (63). KJOC scores in minor league baseball pitchers revealed that pitchers not currently injured and without injury in the previous 12 months had significantly higher scores (40). The KJOC score also has been used as a tool in swimming to assess for the functional status of a swimmer's shoulder, but has not yet been used in other overhead throwing sports (139). A second screening measure is the Youth Throwing Score (YTS) which has been shown to be a valid and reliable instrument for assessing young baseball players' arm health (1). Other outcome measures than can be used to identify potential shoulder injuries in this population and to prevention shoulder injury include GIRD, rotator cuff strength, and scapular dyskinesis (4,8,18,20,46,60,85).

Conclusions

Shoulder injuries are common among overhead throwing athletes. Reinforcement of the timing and execution of events along the kinetic chain is vital in prevention and rehabilitation. Transference of the energy from the lower extremities to the upper extremity is paramount to keep overhead throwing athletes healthy on the field of play. Biomechanical deficits any kinetic chain flaws should be addressed through hip and core strengthening, lower extremity balance and optimization of timing of the events in the throw. Timely treatment and rehabilitation of the glenohumeral joint and its associated soft tissue structures is vital to imperative future and recurrent overhead throwing injuries.

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References

1. Ahmad CS, Padaki AS, Noticewala MS, *et al*. The youth throwing score. *Am. J. Sports Med*. 2017; 45:317–24.
2. Aldridge R, Stephen Guffey J, Whitehead MT, Head P. The effects of a daily stretching protocol on passive glenohumeral internal rotation in overhead throwing collegiate athletes. *Int. J. Sports Phys. Ther*. 2012; 7:365–71.
3. Almeida GP, Silveira PF, Rosseto NP, *et al*. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J. Shoulder Elbow Surg*. 2013; 22:602–7.
4. Andersson SH, Bahr R, Clarsen B, Myklebust G. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *Br. J. Sports Med*. 2016.
5. Andrews JR, Carson WG, McLeod WD. Glenoid labrum tears related to the long head of the biceps. *Am. J. Sports Med*. 1985; 13:337–41.
6. Andrews Sports Medicine. Andrews Sports Medicine Thrower's Ten. Andrews Sports Medicine. http://www.andrewssportsmedicine.com/getortho.php?name=Throwers_Ten. Accessed September 29, 2016.
7. Arroyo JS, Hershon SJ, Bigliani LU. Special considerations in the athletic throwing shoulder. *Orthop. Clin. North Am*. 1997; 28:69–78.
8. Beckett M, Hannon M, Ropiak C, *et al*. Clinical assessment of scapula and hip joint function in preadolescent and adolescent baseball players. *Am. J. Sports Med*. 2014; 42:2502–9.
9. Ben Kibler W, Sciascia A. Rehabilitation of the athlete's shoulder. *Clin. Sports Med*. 2008; 27:821–31.
10. Braun S, Kokmeyer D, Millett PJ. Shoulder injuries in the throwing athlete. *J. Bone Joint Surg. Am*. 2009; 91:966–78.
11. Briner WW Jr, Kacmar L. Common injuries in volleyball. Mechanisms of injury, prevention and rehabilitation. *Sports Med*. 1997; 24:65–71.
12. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy*. 2003; 19:404–20.
13. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: the SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003; 19:641–61.
14. Caine D, Caine C, Maffulli N. Incidence and distribution of pediatric sport-related injuries. *Clin. J. Sports Med*. 2006; 16:500–13.
15. Chambers L, Altchek DW. Microinstability and internal impingement in overhead athletes. *Clin. Sports Med*. 2013; 32:697–707.
16. Chang ES, Bishop ME, Baker D, West RV. Interval throwing and hitting programs in baseball: biomechanics and rehabilitation. *Am. J. Orthop. Belle Mead NJ*. 2016; 45:157–62.
17. Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: new concepts on throwing mechanics and injury. *PM R*. 2016; 8(Suppl. 3):S69–77.
18. Clarsen B, Bahr R, Andersson SH, *et al*. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br. J. Sports Med*. 2014; 48:1327–33.
19. Cook DP, Strike SC. Throwing in cricket. *J. Sports Sci*. 2000; 18:965–73.
20. Cools AM, Johansson FR, Borms D, Maenhout A. Prevention of shoulder injuries in overhead athletes: a science-based approach. *Braz J. Phys. Ther*. 2015; 19:331–9.
21. Copeland S. Throwing injuries of the shoulder. *Br. J. Sports Med*. 1993; 27:221–7.
22. Cricket.com.au. Cricket Participation in 2013–2014 in Australia. [cited September 15, 2016]. Cricket.com.au. Available from: http://www.cricket.com.au/news/media-release-national-cricket-participation-hits-one-million/2014-08-11.
23. Davidson PA, Elattrache NS, Jobe CM, Jobe FW. Rotator cuff and posterior-superior glenoid labrum injury associated with increased glenohumeral motion: a new site of impingement. *J. Shoulder Elbow Surg*. 1995; 4:384–90.
24. Dennis RJ, Finch CF, Farhart PJ. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *Br. J. Sports Med*. 2005; 39:843–6.
25. Dhillon MS, Garg B, Soni RK, *et al*. Nature and incidence of upper limb injuries in professional cricket players a prospective observation. *Sports Med. Arthrosc. Rehabil. Ther. Technol*. 2012; 4:42.
26. Dick R, Sauers EL, Agel J, *et al*. Descriptive epidemiology of collegiate men's baseball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J. Athl. Train*. 2007; 42:183–93.
27. Digiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. *J. Shoulder Elbow Surg*. 1992; 1:15–25.
28. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J. Orthop. Sports Phys. Ther*. 1993; 18:402–8.
29. Dines JS, Jones KJ, Kahlenberg C, *et al*. Elbow ulnar collateral ligament reconstruction in javelin throwers at a minimum 2-year follow-up. *Am. J. Sports Med*. 2012; 40:148–51.
30. Erickson BJ, Chalmers PN, Bush-Joseph CA, Romeo AA. Predicting and preventing injury in major league baseball. *Am. J. Orthop. Belle Mead NJ*. 2016; 45:152–6.
31. Escamilla RF, Barrentine SW, Fleisig GS, *et al*. Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *Am. J. Sports Med*. 2007; 35:23–33.
32. Fleisig G, Chu Y, Weber A, Andrews J. Variability in baseball pitching biomechanics among various levels of competition. *Sports Biomech*. 2009; 8:10–21.
33. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012; 4:419–24.
34. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am. J. Sports Med*. 1995; 23:233–9.
35. Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. *Sports Med*. 1996; 21:421–37.
36. Fleisig GS, Barrentine SW, Zheng N, *et al*. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J. Biomech*. 1999; 32:1371–5.

37. Forrest M, Hecimovich M, Dempsey A. Lumbopelvic muscle activation patterns in adolescent fast bowlers. *Eur. J. Sport Sci.* 2016; 16:677–84.

38. Forthomme B, Wieczorek V, Frisch A, *et al.* Shoulder pain among high-level volleyball players and preseason features. *Med. Sci. Sports Exerc.* 2013; 45:1852–60.

39. Franz JO, McCulloch PC, Kneip CJ, *et al.* The utility of the KJOC score in professional baseball in the United States. *Am. J. Sports Med.* 2013; 41:2167–73.

40. Fronek J, Yang JG, Osbahr DC, *et al.* Shoulder functional performance status of Minor League professional baseball pitchers. *J. Shoulder Elbow Surg.* 2015; 24:17–23.

41. Fry KE, Pipkin A, Wittman K, *et al.* Youth baseball pitching stride length: normal values and correlation with field testing. *Sports Health.* 2016.

42. Dobell George. ESPN Cricket Participation in 2014. [cited September 15, 2016]. Available from: http://www.espncricinfo.com/england/content/story/801645.html.

43. Giles K, Musa I. A survey of glenohumeral joint rotational range and non-specific shoulder pain in elite cricketers. *Phys. Ther. Sport.* 2008; 9:109–16.

44. Glazier PS. Is the 'crunch factor' an important consideration in the aetiology of lumbar spine pathology in cricket fast bowlers? *Sports Med. Auckl NZ.* 2010; 40:809–15.

45. Gowan ID, Jobe FW, Tibone JE, *et al.* A comparative electromyographic analysis of the shoulder during pitching. Professional versus amateur pitchers. *Am. J. Sports Med.* 1987; 15:586–90.

46. Green RA, Taylor NF, Watson L, Ardern C. Altered scapula position in elite young cricketers with shoulder problems. *J. Sci. Med. Sport.* 2013; 16:22–7.

47. Gregory PL, Batt ME, Wallace WA. Comparing injuries of spin bowling with fast bowling in young cricketers. *Clin. J. Sports Med.* 2002; 12:107–12.

48. Herrington L. Glenohumeral joint: internal and external rotation range of motion in javelin throwers. *Br. J. Sports Med.* 1998; 32:226–8.

49. Hill JL, Humphries B, Weidner T, Newton RU. Female collegiate windmill pitchers: influences to injury incidence. *J. Strength Cond. Res.* 2004; 18:426–31.

50. Hill J, Leiszler M. Review and role of plyometrics and core rehabilitation in competitive sport. *Curr. Sports Med. Rep.* 2011; 10:345–51.

51. van der Hoeven H, Kibler WB. Shoulder injuries in tennis players. *Br. J. Sports Med.* 2006; 40:435–40; discussion 440.

52. Hurd W, Hunter-Giordano A, Axe M, Snyder-Mackler L. Data-based interval hitting program for female college volleyball players. *Sports Health.* 2009; 1:522–30.

53. Hurd WJ, Kaufman KR. Glenohumeral rotational motion and strength and baseball pitching biomechanics. *J. Athl. Train.* 2012; 47:247–56.

54. Husain I, Bari MA. Mechanical analysis of the overhead throw in cricket. *Int. J. Sports Sci. Eng.* 2011; 5:163–8.

55. Ignjatovic AM, Markovic ZM, Radovanovic DS. Effects of 12-week medicine ball training on muscle strength and power in young female handball players. *J. Strength Cond. Res.* 2012; 26:2166–73.

56. Kaplan KM, Elattrache NS, Jobe FW, *et al.* Comparison of shoulder range of motion, strength, and playing time in uninjured high school baseball pitchers who reside in warm- and cold-weather climates. *Am. J. Sports Med.* 2011; 39:320–8.

57. Kaplan LD, Flanigan DC, Norwig J, *et al.* Prevalence and variance of shoulder injuries in elite collegiate football players. *Am. J. Sports Med.* 2005; 33:1142–6.

58. Kelly BT, Barnes RP, Powell JW, Warren RF. Shoulder injuries to quarterbacks in the National Football League. *Am. J. Sports Med.* 2004; 32:328–31.

59. Kerut EK, Kerut DG, Fleisig GS, Andrews JR. Prevention of arm injury in youth baseball pitchers. *J. La State Med. Soc.* 2008; 160:95–8.

60. Kibler WB, Sciascia A, Thomas SJ. Glenohumeral internal rotation deficit: pathogenesis and response to acute throwing. *Sports Med. Arthrosc. Rev.* 2012; 20:34–8.

61. Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. *Clin. Sports Med.* 2013; 32:637–51.

62. Kim H, Lee Y, Shin I, *et al.* Effects of 8 weeks' specific physical training on the rotator cuff muscle strength and technique of javelin throwers. *J. Phys. Ther. Sci.* 2014; 26:1553–6.

63. Kraeutler MJ, Ciccotti MG, Dodson CC, *et al.* Kerlan-Jobe Orthopaedic Clinic overhead athlete scores in asymptomatic professional baseball pitchers. *J. Shoulder Elbow Surg.* 2013; 22:329–32.

64. Kuhn JE, Lindholm SR, Huston LJ, *et al.* Failure of the biceps superior labral complex: a cadaveric biomechanical investigation comparing the late cocking and early deceleration positions of throwing. *Arthroscopy.* 2003; 19:373–9.

65. Langendoen J. The patient-centredness of evidence-based practice. A case example to discuss the clinical application of the bio-psychosocial model. *Man. Ther.* 2004; 9:228–33.

66. Lear A, Patel N. Softball Pitching and Injury. *Curr. Sports Med. Rep.* 2016; 15:336–41.

67. Leigh, Steven. Forces. The Influence on Throwing Technique and Injury Performance In Javelin Throwers. Dissertation at the University of North Carolina, Chapel Hill, NC. 2012. Available from: https://cdr.lib.unc.edu/indexablecontent/uuid:a980a4bf-2c07-46ac-bed4-1e7501049eda.

68. Lintner D, Noonan TJ, Kibler WB. Injury patterns and biomechanics of the athlete's shoulder. *Clin. Sports Med.* 2008; 27:527–51.

69. Liu H, Leigh S, Yu B. Sequences of upper and lower extremity motions in javelin throwing. *J. Sports Sci.* 2010; 28:1459–67.

70. Lust KR, Sandrey MA, Bulger SM, Wilder N. The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. *J. Sport Rehabil.* 2009; 18:407–26.

71. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am. J. Sports Med.* 2002; 30:463–8.

72. Major League Baseball. Major League Baseball Pitchsmart. [cited Oct 1, 2016]. Available from: http://m.mlb.com/pitchsmart.

73. Marshall SW, Hamstra-Wright KL, Dick R, *et al.* Descriptive epidemiology of collegiate women's softball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J. Athl. Train.* 2007; 42:286–94.

74. McFarland EG, Wasik M. Epidemiology of collegiate baseball injuries. *Clin. J. Sport Med.* 1998; 8:10–3.

75. McNamara DJ, Gabbett TJ, Naughton G. Assessment of workload and its effects on performance and injury in elite cricket fast bowlers. *Sports Med. Auckl NZ.* 2016; 47:503–15.

76. Meister K. Injuries to the shoulder in the throwing athlete. Part one: biomechanics/pathophysiology/classification of injury. *Am. J. Sports Med.* 2000; 28:265–75.

77. Meister K, Andrews JR. Classification and treatment of rotator cuff injuries in the overhand athlete. *J. Orthop. Sports Phys. Ther.* 1993; 18:413–21.

78. MLB. Pitch Smart. Major League Baseball. [cited Aug 31, 2016]. Available from: http://m.mlb.com/pitchsmart/pitching-guidelines/.

79. Morriss C, Bartlett R. Biomechanical factors critical for performance in the men's javelin throw. *Sports Med.* 1996; 21:438–46.

80. Murray TA, Cook TD, Werner SL, *et al.* The effects of extended play on professional baseball pitchers. *Am. J. Sports Med.* 2001; 29:137–42.

81. Myers JB, Laudner KG, Pasquale MR, *et al.* Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am. J. Sports Med.* 2006; 34:385–91.

82. Myklebust G, Hasslan L, Bahr R, Steffen K. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand. J. Med. Sci. Sports.* 2013; 23:288–94.

83. National Federation of State High School Associations. National Federation of State High School Associations. 2014–2015 Participation Data. [cited September 14, 2016]. National Federation of State High School Associations. Available from: http://www.nfhs.org/ParticipationStatics/PDF/2014-15_Participation_Survey_Results.pdf.

84. NCAA.org. NCAA Sports Sportsmanship and Participation 2014–2015. Accessed [cited September 14, 2016]. Available from: http://www.ncaa.org/sites/default/files/Participation%20Rates%20Final.pdf.

85. Niederbracht Y, Shim AL, Sloniger MA, *et al.* Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *J. Strength Cond. Res.* 2008; 22:140–5.

86. Okada T, Huxel KC, Nesser TW. Relationship between core stability, functional movement, and performance. *J. Strength Cond. Res.* 2011; 25:252–61.

87. Oliver GD, Keeley DW. Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. *J. Strength Cond. Res.* 2010; 24:3015–22.

88. Olivier B, Taljaard T, Burger E, *et al.* Which extrinsic and intrinsic factors are associated with non-contact injuries in adult cricket fast bowlers? *Sports Med.* 2016; 46:79–101.

89. Olsen SJ, Fleisig GS, Dun S, *et al.* Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am. J. Sports Med.* 2006; 34:905–12.

90. Orchard J, James T, Alcott E, *et al.* Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *Br. J. Sports Med.* 2002; 36:270–4; discussion 275.

91. Oyama S, Yu B, Blackburn JT, *et al*. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. *Am. J. Sports Med*. 2014; 42:2089–94.

92. Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching. A preliminary report. *Am. J. Sports Med*. 1985; 13:216–22.

93. Pei-Hsi Chou P, Huang YP, Gu YH, *et al*. Change in pitching biomechanics in the late-inning in Taiwanese high school baseball pitchers. *J. Strength Cond. Res*. 2015; 29:1500–8.

94. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am. J. Sports Med*. 2004; 32:1158–64.

95. Plummer HA, Oliver GD. The effects of localised fatigue on upper extremity jump shot kinematics and kinetics in team handball. *J. Sports Sci*. 2017; 35:182–8.

96. Plummer HA, Oliver GD. The relationship between gluteal muscle activation and throwing kinematics in baseball and softball catchers. *J. Strength Cond. Res*. 2014; 28:87–96.

97. Polster JM, Bullen J, Obuchowski NA, *et al*. Relationship between humeral torsion and injury in professional baseball pitchers. *Am. J. Sports Med*. 2013; 41:2015–21.

98. Popchak A, Burnett T, Weber N, Boninger M. Factors related to injury in youth and adolescent baseball pitching, with an eye toward prevention. *Am. J. Phys. Med. Rehabil*. 2015; 94:395–409.

99. Posner M, Cameron KL, Wolf JM, *et al*. Epidemiology of major league baseball injuries. *Am. J. Sports Med*. 2011; 39:1676–80.

100. Post EG, Laudner KG, McLoda TA, *et al*. Correlation of shoulder and elbow kinetics with ball velocity in collegiate baseball pitchers. *J. Athl. Train*. 2015; 50:629–33.

101. Prokopy MP, Ingersoll CD, Nordenschild E, *et al*. Closed-kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. *J. Strength Cond. Res*. 2008; 22:1790–8.

102. Raeder C, Fernandez-Fernandez J, Ferrauti A. Effects of six weeks of medicine ball training on throwing velocity, throwing precision, and isokinetic strength of shoulder rotators in female handball players. *J. Strength Cond. Res*. 2015; 29:1904–14.

103. Ramsey DK, Crotin RL, White S. Effect of stride length on overarm throwing delivery: a linear momentum response. *Hum. Mov. Sci*. 2014; 38:185–96.

104. Ranson C, Gregory PL. Shoulder injury in professional cricketers. *Phys. Ther. Sport*. 2008; 9:34–9.

105. Reeser JC, Fleisig GS, Bolt B, Ruan M. Upper limb biomechanics during the volleyball serve and spike. *Sports Health*. 2010; 2:368–74.

106. Reeser JC, Gregory A, Berg RL, Comstock RD. A comparison of women's collegiate and girls' high school volleyball injury data collected prospectively over a 4-year period. *Sports Health*. 2015; 7:504–10.

107. Reeser JC, Joy EA, Porucznik CA, *et al*. Risk factors for volleyball-related shoulder pain and dysfunction. *PM R*. 2010; 2:27–36.

108. Reinold MM, Wilk KE, Reed J, *et al*. Interval sport programs: guidelines for baseball, tennis, and golf. *J. Orthop. Sports Phys. Ther*. 2002; 32:293–8.

109. Riff AJ, Chalmers PN, Sgroi T, *et al*. Epidemiologic comparison of pitching mechanics, pitch type, and pitch counts among healthy pitchers at various levels of youth competition. *Arthroscopy*. 2016; 32:1559–68.

110. Robinson TW, Corlette J, Collins CL, Comstock RD. Shoulder injuries among US high school athletes, 2005/2006-2011/2012. *Pediatrics*. 2014; 133:272–9.

111. Saeterbakken AH, van den Tillaar R, Seiler S. Effect of core stability training on throwing velocity in female handball players. *J. Strength Cond. Res*. 2011; 25:712–8.

112. Scher S, Anderson K, Weber N, *et al*. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *J. Athl. Train*. 2010; 45:191–7.

113. Sciascia A, Thigpen C, Namdari S, Baldwin K. Kinetic chain abnormalities in the athletic shoulder. *Sports Med. Arthrosc. Rev*. 2012; 20:16–21.

114. Seil R, Rupp S, Tempelhof S, Kohn D. Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *Am. J. Sports Med*. 1998; 26:681–7.

115. Seroyer ST, Nho SJ, Bach BR, *et al*. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health*. 2010; 2:135–46.

116. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS. Incidence of injuries in high school softball and baseball players. *J. Athl. Train*. 2011; 46:648–54.

117. Slenker NR, Limpisvasti O, Mohr K, *et al*. Biomechanical comparison of the interval throwing program and baseball pitching: upper extremity loads in training and rehabilitation. *Am. J. Sports Med*. 2014; 42:1226–32.

118. Solomito MJ, Garibay EJ, Woods JR, *et al*. Lateral trunk lean in pitchers affects both ball velocity and upper extremity joint moments. *Am. J. Sports Med*. 2015; 43:1235–40.

119. Stretch RA. Cricket injuries: a longitudinal study of the nature of injuries to South African cricketers. *Br. J. Sports Med*. 2003; 37:250–3; discussion 253.

120. Stuelcken MC, Ferdinands RE, Ginn KA, Sinclair PJ. The shoulder distraction force in cricket fast bowling. *J. Appl. Biomech*. 2010; 26:373–7.

121. Takenaga T, Sugimoto K, Goto H, *et al*. Posterior shoulder capsules are thicker and stiffer in the throwing shoulders of healthy college baseball players: a quantitative assessment using shear-wave ultrasound elastography. *Am. J. Sports Med*. 2015; 43:2935–42.

122. den Tillaar Roland Van. The biomechanics of the elbow in overarm throwing sports. *Int. Sport Med. J*. 2005; 6:7.

123. Walton J, Paxinos A, Tzannes A, *et al*. The unstable shoulder in the adolescent athlete. *Am. J. Sports Med*. 2002; 30:758–67.

124. Wang HK, Cochrane T. A descriptive epidemiological study of shoulder injury in top level English male volleyball players. *Int. J. Sports Med*. 2001; 22:159–63.

125. Wasser JG, Vincent HK. Functional screening for atraumatic low back pain in baseball players. *Curr. Sports Med. Rep*. 2016; 15:9.

126. Wasser JG, Zaremski JL, Herman DC, Vincent HK. Assessment and rehabilitation of chronic low back pain in baseball. *Res. Sports Med*. 2017; 25:1–13.

127. Wasser JG, Zaremski JL, Herman DC, Vincent HK. Prevalence and proposed mechanisms of chronic low back pain in baseball: part i. *Res. Sports Med. Print*. 2017:1–12.

128. Wasserman E, Lynall R, Kerr Z. Comparison of pitching injuries between ncaa softball and baseball pitchers. *J. Athl. Train*. 2016; 51:S157.

129. Whiting WC, Gregor RJ, Halushka M. Body segment and release parameter contributions to new-rules javelin throwing. *Int. J. Sport Biomech*. 1991; 7:111–24.

130. Wilk KE, Andrews JR, Arrigo CA. *Preventive and Rehabilitative Exercises for the Shoulder and Elbow. American Sports Medicine Institute*. 5th ed. Birmingham, AL: 2001.

131. Wilk KE, Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. *J. Orthop. Sports Phys. Ther*. 1993; 18:365–78.

132. Wilk KE, Arrigo CA. A standardized isokinetic testing protocol for the throwing shoulder: the Throwers' Series. *Isokinet Exerc. Sci*. 1991; 1:5.

133. Wilk KE, Arrigo CA, Hooks TR, Andrews JR. Rehabilitation of the overhead throwing athlete: there is more to it than just external rotation/internal rotation strengthening. *PM R*. 2016; 8(Suppl. 3):S78–90.

134. Wilk KE, Macrina LC, Fleisig GS, *et al*. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am. J. Sports Med*. 2011; 39:329–35.

135. Wilk KE, Macrina LC, Fleisig GS, *et al*. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. *Am. J. Sports Med*. 2014; 42:2075–81.

136. Wilk KE, Macrina LC, Fleisig GS, *et al*. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *Am. J. Sports Med*. 2015; 43:2379–85.

137. Wilk KE, Obma P, Simpson CD, *et al*. Shoulder injuries in the overhead athlete. *J. Orthop. Sports Phys. Ther*. 2009; 39:38–54.

138. Wilk KE, Yenchak AJ, Arrigo CA, Andrews JR. The advanced throwers ten exercise program: a new exercise series for enhanced dynamic shoulder control in the overhead throwing athlete. *Phys. Sportsmed*. 2011; 39:90–7.

139. Wymore L, Fronek J. Shoulder functional performance status of national collegiate athletic association swimmers: baseline Kerlan-Jobe orthopedic clinic scores. *Am. J. Sports Med*. 2015; 43:1513–7.

140. Yang J, Mann BJ, Guettler JH, *et al*. Risk-Prone pitching activities and injuries in youth baseball: findings from a national sample. *Am. J. Sports Med*. 2014; 42:1456–63.

141. Zaremski JL, Horodyski M, Donlan RM, *et al*. Does geographic location matter on the prevalence of ulnar collateral ligament reconstruction in collegiate baseball pitchers? *Orthop. J. Sports Med*. 2015; 3:2325967115616582.

142. Zaremski JL, Krabak BJ. Shoulder injuries in the skeletally immature baseball pitcher and recommendations for the prevention of injury. *PM R*. 2012; 4:509–16.

143. Zaremski JL, Zdziarski LA, Krabak B, *et al*. Pitching injury prevalence in collegiate baseball pitchers based on geographic location of high school baseball participation: a multi-centered study. *Clin. J. Sports Med*. 2016; 26:e56–7.

144. Zeppieri G, Lentz TA, Moser MW, Farmer KW. Changes in hip range of motion and strength in collegiate baseball pitchers over the course of a competitive season: a pilot study. *Int. J. Sports Phys. Ther*. 2015; 10:505–13.