

## Review

**\*Corresponding author:**

**Jonathan C. Sum, PT, DPT, OCS, SCS**  
Assistant Professor of Clinical Physical  
Therapy;

Director, USC Physical Therapy  
Associates-HSC  
Division of Biokinesiology & Physical  
Therapy

Ostrow School of Dentistry  
University of Southern California  
1640 Marengo St, Ste 102  
Los Angeles, CA 90033, USA

Tel. (323) 865-1200

Fax: (323) 865-1258

E-mail: [sum@usc.edu](mailto:sum@usc.edu)

Volume 1 : Issue 5

Article Ref. #: 1000SEMOJ1122

**Article History:**

Received: June 15<sup>th</sup>, 2015

Accepted: October 7<sup>th</sup>, 2015

Published: October 7<sup>th</sup>, 2015

**Citation:**

Cole S, Sanderson T, McNeill B, Sum JC. A proposal for functional screening of the throwing kinetic chain in baseball pitchers to assess shoulder and elbow injury risk. *Sport Exerc Med Open J.* 2015; 1(5): 150-157. doi: [10.17140/SEMOJ-1-122](http://dx.doi.org/10.17140/SEMOJ-1-122)

**Copyright:**

© 2015 Sum JC. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

# A Proposal for Functional Screening of the Throwing Kinetic Chain in Baseball Pitchers to Assess Shoulder and Elbow Injury Risk

**Shawn Cole, PT, DPT<sup>1</sup>, Tom Sanderson, PT<sup>1</sup>, Brian McNeill, PT, DPT, OCS<sup>2</sup> and Jonathan C. Sum, PT, DPT, OCS, SCS<sup>2\*</sup>**

<sup>1</sup>Momentum Physical Therapy LLC, Tucson, AZ, USA

<sup>2</sup>Division of Biokinesiology & Physical Therapy, Ostrow School of Dentistry, University of Southern California, Los Angeles, CA 90033, USA

**ABSTRACT**

Overhead throwing athletes are susceptible to overuse injuries in the upper extremity, specifically of the shoulder and elbow. These injuries can include rotator cuff tears, labral tears, and ulnar collateral ligament sprains and can affect athletes at all levels of their sport. To address this growing epidemic, musculoskeletal screens and assessments are used to identify risk factors associated with injuries. Though the baseball pitching delivery has been extensively studied in biomechanical laboratories, a clear consensus agreement of the essential tests and measures is still lacking, both as a pre-participation assessment of injury risk and for return to sport criteria. Most recent research has been focused on the contributing factors of the entire kinetic chain, relating deficits in the kinetic chain to impairments seen in the upper extremity which may lead to shoulder and elbow injury. The purpose of this article is to use the essential components of the throwing kinetic chain to propose a novel screening assessment for the overhead throwing athlete, which can be used as a pre-participation assessment of injury risk or for return to sport criteria.

**KEYWORDS:** Elbow injury; Pitchers; UCL.

**ABBREVIATIONS:** UCL: Ulnar Collateral Ligament; MLB: Major League Baseball; SLAP: Superior Labrum Anterior to Posterior; GIRD: Glenohumeral Internal Rotation Deficit; TRM: Total Rotational Motion; MVIC: Maximal Voluntary Isometric Contraction; NCAA: National Collegiate Athletic Association.

**INTRODUCTION**

Overhead throwing athletes are at an increased risk for overuse injuries primarily of the shoulder and elbow due to the cumulative microtrauma associated with repetitive throwing.<sup>1-4</sup> In Major League Baseball pitchers, injuries to the shoulder account for 28% of all injuries, injuries to the elbow account for 22-26%, and combined account for more missed games than injury to any other anatomical region.<sup>5-7</sup> Injuries at the professional level appear to be on the rise. In May of 2014, Jose Fernandez of the Miami Marlins became the 18<sup>th</sup> player to undergo Tommy John surgery to repair the Ulnar Collateral Ligament (UCL) of his pitching elbow since the start of that Major League Baseball (MLB) season. This was just one shy of the total number of Tommy John surgeries performed in all of the previous season. At this rate, the 2014 season was on pace to surpass the record setting 2012 season of 36 surgeries; ultimately finishing with 29 players undergoing surgery.<sup>8,9</sup> Shoulder and elbow injuries are present at other levels of baseball as well. A survey of 490 junior high, high school, and college baseball players with shoulder and elbow injuries found, that all elbow injuries and the majority of shoulder injuries were prevalent at the high school and college levels. Thirty-seven percent of the elbow injuries involved the UCL and 19.8% of all shoulder injuries were Superior Labrum Anterior to Posterior (SLAP) lesions.<sup>2</sup>

UCL injuries are of particular interest due in part to the significant amount of time required to return to elite level pitching following surgery. UCL reconstruction has been on the rise in high school-aged baseball players for several years. Literature suggests that year-round training and competition increases the likelihood of a youth baseball pitcher suffering a shoulder or elbow injury.<sup>10,11</sup> The number of pitches thrown, the type of pitches thrown, and the overall physical fitness of the youth baseball pitcher can increase the risk for shoulder and elbow injuries.<sup>10,12,15</sup> Fifteen percent of college-level pitchers consider injuries sustained playing youth baseball have limited current performance.<sup>14</sup>

To help reduce the risk of injury in pitchers, several recommendations have been proposed, including pitch count restrictions and required rest days.<sup>15</sup> Youth players should limit breaking balls thrown until they have passed the developmental stages of puberty.<sup>12,15</sup> Finally, throwing athletes should undergo biomechanical assessment encompassing whole body screening. This would ensure all aspects of the kinetic chain have the mobility and stability required to safely and effectively throw without increased risk for injury.<sup>10,16,17</sup>

With shoulder angular velocities exceeding  $7250^{\circ} \text{ sec}^{-1}$  and varus torques at the elbow of nearly 100 Nm any weakness, tightness, or lack of neuromuscular control of the body can cause subtle changes in the pitching motion.<sup>6,7</sup> These subtle changes in the pitching motion can alter the kinetic chain, which may increase physical stresses on other anatomical areas such as the elbow and shoulder. Over time these changes can lead to tissue failure and injury.<sup>5</sup> Being able to effectively and efficiently screen for individuals that have kinetic chain deficits may help to identify individuals who are at an increased risk for injury and allow the athlete to receive proper training, conditioning, and intervention to prevent injury. The purpose of this article is to propose a novel screening assessment for the overhead throwing athlete using the essential components of the throwing kinetic chain, which can be used as a pre-participation assessment of

injury risk or for return to sport criteria.


## BACKGROUND



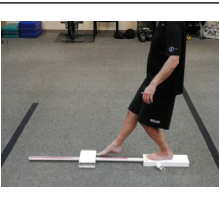
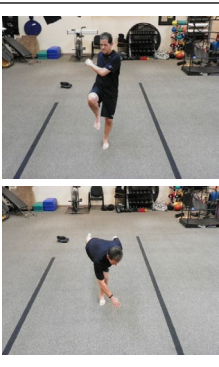

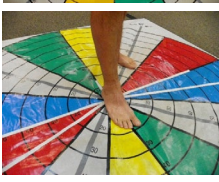


Overhead throwing is a movement that is not isolated to the shoulder and elbow. It is a complex interaction of total body strength, range of motion, static and dynamic balance, proprioception, and neuromuscular coordination. All of these systems need to work together to effectively transfer energy from the ground, through the lower extremities, to the core, and out the upper extremity. The pelvis and torso contribute as much as 50% to the kinetics of throwing.<sup>3,18</sup> Any deficits along this kinetic chain can place added physical stress to other anatomical regions required to complete the task of throwing a baseball. Specifically in overhead throwing, an impaired ability to control the position of the trunk and legs can alter the position of the arm and potentially lead to injury of the shoulder and elbow.<sup>3,4,11,16,18-24</sup> In order to properly screen, train, and rehabilitate a throwing athlete, an approach that examines balance, core stability, and lower extremity mobility and stability is necessary.<sup>16,19,22</sup>

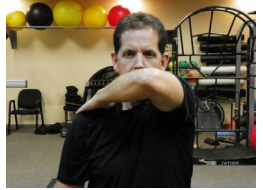

## METHODS

The screen presented in this article will encompass testing of mobility and stability of the shoulder, trunk/core, and lower extremities. Athletes are taken through a series of tests and measure designed to assess critical components of a pitching delivery. These measures address tissue irritability, range of motion, coordination and strength. The rationale of these assessment techniques are described further in the discussion. While this screen examines much of the kinetic chain required to safely and effectively pitch, it does not cover all aspects of the chain such as a detailed examination of the thoracic spine or scapula. This is by design, as the purpose of a screen is to quickly identifies those at risk for injury so these deficits can be addressed, or the individual can be referred to a healthcare professional if needed.

## PROCEDURE

Assessments	Verbal description of all tests and measure	
<p><b>Total Rotational Motion</b></p>	<p>The athlete lies supine with hips and knees flexed. The humeral head and coracoid process are palpated, but not stabilized, to determine the end-range of rotation. Goniometric Placement: Axis= olecranon process of the ulna. Stationary arm= perpendicular to the ground. Moving arm= along the ulnar shaft to the styloid process. The sum of passive glenohumeral joint external rotation and internal rotation at <math>90^{\circ}</math> of abduction in the plane of the scapula are measured and calculated. A side-to-side difference of more than <math>5^{\circ}</math> indicates greater risk for shoulder and elbow injury.</p>	

<p><b>Passive Shoulder Flexion</b></p>	<p>The athlete lies supine with hips and knees flexed and the scapula lightly stabilized as the humerus is passively flexed to end-range. Goniometric placement: axis= acromion process, through the head of the humerus. Stationary arm= parallel to the trunk. Moving arm= longitudinal axis of the humerus. A side-to-side difference of more than 5° indicates greater risk for elbow injury.</p>	
<p><b>Single Leg Stance Balance</b></p>	<p>Assessment is performed without shoes with eyes open looking toward direction of pitch. Hands together, hip flexion to 90°. The standard is set to 30 seconds with no Trendelenburg or trunk lean, and no major loss of balance. Test is performed bilaterally with quality and quantity being symmetrical. Poor single leg stance balance indicates poor core stability and neuromuscular control, indicating greater risk for shoulder injury.</p>	
<p><b>Single Leg Stance - Anterior Lower Extremity Reach</b></p>	<p>Assessment is performed without shoes. The stance leg is the leg being tested, and the stance leg heel should remain flat at all times. The contralateral lower extremity reaches forward to slide a box as far as possible without touching the ground, kicking the box, or losing balance. Athlete returns to the starting position of the reaching foot on the ground next to the stance leg. Record the best of 5 reaches. A greater than 4 cm difference side-to-side indicates a greater risk for elbow injury.</p>	
<p><b>Single Leg Stance - Upper Extremity Cross Over Reach</b></p>	<p>The athlete begins by standing on one leg, contralateral hip flexed to 90° with bilateral hand brought together over the flexed hip. The athlete reaches down and across in front of the stance leg with the contralateral upper extremity without touching the floor as the opposite leg moves backward for counterbalance. The athlete then returns to the starting position. There should be no major loss of balance, the trailing leg remains in the air at all times, the hand cannot reach down to touch the ground, and the athlete must successfully complete ten of twelve attempts bilaterally.</p>	
<p><b>Single Leg Stance - Total Lower Extremity Rotation:</b></p>	<p>A grid was created that has two lines 15° below the horizontal. The athlete's lower extremity to be tested is placed in the center of the grid with the medial malleolus aligned with the horizontal line and the second toe in line with the vertical axis. The athlete flexes the contralateral hip to 90° with the tibia held perpendicular to the ground. Two markers are placed along the arc of motion the athlete's raised tibia will follow in the transverse plane. One marker is placed on the horizontal line in the direction that the stance leg would move into relative external rotation and the other on the line 15° below the horizontal in the direction that the stance leg would move into relative internal rotation. The athlete will move the pelvis and torso into relative internal rotation of the stance leg so that contralateral, vertical lower leg contacts the marker at 15° below the horizontal, and then moves the pelvis and torso into relative external rotation of the stance leg to contact the other marker on the horizontal line. This is a pass/fail test, and the athlete must keep the airborne tibia vertical, contact both markers, and do so without a loss of balance three times bilaterally.</p>	   

<b>Shoulder Impingement Test:</b>	The athlete places one hand on the contralateral shoulder and raises the elbow as high as possible. Test is performed bilaterally. Pain indicates failure of this test and a shoulder examination should be performed by a qualified healthcare provider.	
<b>Valgus Stress Test to the Elbow:</b>	Assessment is performed at 90° of elbow flexion. The athlete reaches underneath the arm to be test and grabs the thumb. The grasped thumb is pulled laterally to stress the medial elbow. Test is performed bilaterally. Pain indicates failure of this test and an elbow examination should be performed by a qualified healthcare provider.	

## DISCUSSION

### Shoulder Screening

The concept of Glenohumeral Internal Rotation Deficit (GIRD) has been well documented and is defined as a loss of internal rotation range of motion of the throwing arm compared to the non-throwing arm, anywhere from 12-20°. <sup>6,11,25</sup> Historically, GIRD was thought to be a primary contributing factor to both shoulder and elbow injuries in overhead throwing athletes due to the concomitant hyperexternal rotation associated with the loss of internal rotation. GIRD has been attributed to tightness in the posterior glenohumeral joint capsule, myofascial restrictions, laxity of anterior glenohumeral joint capsule, and osseous changes that result in humeral retroversion. Humeral retroversion is due to the torque placed on the humerus with throwing during skeletal maturity resulting in apparent increases in external rotation with loss of internal rotation without true changes at the glenohumeral joint. <sup>25</sup> Due to recent scientific evidence demonstrating that throwing athletes with GIRD do not exhibit capsular limitations, the latter theory has gained more popularity. <sup>6,26</sup> Humeral retroversion and GIRD is normal and advantageous for the overhead pitcher, and may not be an adequate predictor of injury.

However, a significantly strong inverse relationship exists between humeral retroversion of the throwing arm and severe injuries to the shoulder ( $r=-0.90$ ) and elbow ( $r=-0.85$ ), indicating that greater humeral retroversion correlates with less severe arm injury. <sup>25</sup> Pitchers with GIRD are just as likely to develop an elbow injury as those without GRID (odds ratio=1.0). <sup>7</sup> Similar results regarding shoulder injuries were found when comparing those with and without GIRD (odds ratio=1.9), but these results were not statistically significant. <sup>26</sup> Polster, et al. demonstrated a 30% reduction in injury risk for every 10° of humeral retroversion of the dominant arm compared to the non-dominant arm. <sup>25</sup> These results suggest that GIRD due to osseous torsion may be advantageous for pitchers as humeral retroversion will allow the thrower to move through a longer throwing arc and achieve

greater throwing velocity without additional physical stress to the glenohumeral joint and its supporting structures. <sup>25</sup>

Total Rotational Motion (TRM), defined as the sum of passive glenohumeral external rotation and internal rotation at 90° of abduction in the plane of the scapula, is considered deficient if there is a side-to-side difference of more than 5°. <sup>6</sup> The odds ratio for the development of a shoulder or elbow injury in a pitcher with a TRM deficit was 2.5 and 2.6 respectively, and both were found to be statistically significant. <sup>6,7</sup> Interestingly, 78% of those pitchers that developed a shoulder injury had a throwing arm TRM greater than 176° suggesting that there is a limit to how much motion should be achieved. <sup>6</sup> A flexion deficit is defined as a passive glenohumeral flexion range of motion side-to-side difference of more than 5°, and those pitchers with a flexion deficit were found to be significantly more likely to develop an elbow injury (odds ratio=2.8) when compared to those without a flexion deficit. <sup>7</sup> These results are echoed in another study conducted by Garrison, et al. <sup>11</sup>

The above evidence suggests that GIRD alone is not a valid predictor for the development of shoulder or elbow injuries in baseball pitchers, but measurements of TRM deficits and glenohumeral flexion deficits appear to be better predictors of injury. Based upon evidence, measurements of shoulder TRM and passive shoulder flexion would be more valuable and provide greater assessment of injury risk than measurements of GIRD and should be included in a pre-participation screen and made part of return to sport criteria.

### Balance and Core Stability Screening

Assessment techniques such as single leg balance, front and side planks, and the Y-Balance test can be used to evaluate the static and dynamic lower extremity and core function. Prior studies have shown no significant difference between overhead athletes with a non-traumatic shoulder injury compared to those without an injury when it comes to measures of core function utilizing the front plank, side plank, double straight leg lower-

ing test, and Sorensen's test.<sup>23</sup> A significant difference existed between the two groups when core stability and neuromuscular control is tested using single leg balance, demonstrating that those with a shoulder injury had decreased single leg balance.<sup>23</sup> In the context of the throwing kinetic chain, without adequate lower extremity and core stability, energy transfer is compromised, which can place excessive physical stress on distal structures such as the shoulder and elbow.

The lower extremity and core function dynamically during overhead throwing and do so in multiple planes of movement. The Y-Balance is a reliable and valid test of dynamic lower extremity mobility and stability, core stability, and neuromuscular postural control in multiple directions, and has been shown to be a valid predictor of injury risk.<sup>11</sup> High school baseball pitchers with a confirmed UCL tear demonstrated significantly decreased composite scores on the Y-Balance test on both lower extremities compared to pitchers without a UCL tear.<sup>11</sup> The deficits in dynamic balance, lower extremity range of motion, core stability, and postural control associated with poor performance on the Y-Balance test can create dysfunctions throughout the kinetic chain and may successfully predict those overhead throwing athletes that are more likely to develop shoulder and elbow injuries.

In an effort to make this proposed screen efficient and allow for many athletes to be screened in a short amount of time, multi-directional testing of the Y-Balance test was reduced to a single plane of movement. Sagittal plane motion of the hip and knee can account for 90% of the variance seen in medial and lateral lower extremity reaches.<sup>20</sup> In another study examining basketball players, only the anterior reach portion was predictive of injury, with those with a right/left reach difference of greater than or equal to 4 cm being three times more likely to be injured.<sup>27</sup> This evidence justified the use of including only the anterior reach portion of the Y-Balance test to efficiently screen dynamic core lower extremity neuromuscular control. Recognizing that tri-planar function is necessary for efficient movement and performance, athletes would need to be further assessed in other planes when the screen identifies an individual with deficits.

#### Hip and Lower Extremity Mobility and Stability Screening

Several studies note the critical role of the pelvis and lower extremity sequencing during the overhead throwing delivery. Campbell, et al. used surface EMG on bilateral lower extremity musculature on healthy college baseball pitchers, demonstrating that during the early phases of throwing all lower extremity musculature demonstrate minimal to moderate activity, indicating that they are acting primarily as stabilizers.<sup>19</sup> As the pitcher progresses through foot contact, cocking phase, and ball release, there is a gradual increase in nearly all trailing leg muscle activity to greater than 100% of Maximal Voluntary Isometric Contraction (MVIC) with the exception of the rectus femoris.<sup>19</sup> On the stride leg at foot contract, the gluteus

maximus, rectus femoris, and gastrocnemius demonstrated significantly high activity greater than 100% MVIC. All lower extremity muscle activity tested on the stride leg peaked from the cocking phase to follow-through, and all were well above 100% MVIC.<sup>19</sup> It was concluded that the gradual increase in trail leg muscle activity from foot contact to ball release and the peak values of stride leg muscle activity through the follow-through phase suggest that the pitcher does not "push off the rubber" when throwing, but rather is more a "controlled fall."<sup>19</sup> The gluteus maximus of the trailing leg may contribute to pelvic rotation velocity, but the stride leg musculature is acting as a base that must eccentrically control the momentum of the forward moving pelvis, trunk, and upper extremity critical for generating ball velocity.<sup>19</sup>

If the overhead throwing athlete does not possess the necessary mobility and stability to control the moving trunk over the striding lower extremity, the athlete may compensate by spending less time on the leg and/or changing the position of the trunk and arm. This in turn can place added stress on the shoulder and elbow with throwing and can lead to injury. One such compensation would be inadequate trunk flexion or adopting a more upright posture when throwing so as not to have to eccentrically control a forward flexing trunk over the striding leg. This specific compensation can lead to shoulder and elbow injuries in pitchers.

Other studies have described gluteal muscle activation and its relationships with pelvis and trunk kinematics during pitching, noting similar results as Campbell, et al.<sup>18</sup> Stride leg gluteus maximus and medius activity were both greater than 150% of MVIC as the pitcher progressed from the foot contact to ball release phases of throwing, with the greatest activity at the late cocking phase of throwing.<sup>18</sup> There was a statistically significant positive correlation between trailing leg gluteus maximus activity and increased pelvic rotation velocity at maximal glenohumeral external rotation ( $r=0.73$ ) and at ball release ( $r=0.831$ ).<sup>18</sup> This suggests that the changes seen in pelvic rotation velocity are strongly related to gluteus maximus activity and account for a large portion of the variance seen in pelvic rotation during pitching.

The rate of pelvic rotation is significantly related to the rate of torso rotation ( $r=0.917$ ) at the phase of maximal glenohumeral external rotation suggesting that hip and pelvic movement during throwing strongly impacts what happens at the torso, which can impact what happens at the throwing arm.<sup>3</sup> Studies have found that if the sequence of pelvic and torso rotation is not timed appropriately, the pitcher will throw in an "open position" or a "closed position," and place greater physical stress on both the shoulder and elbow that could potentially increase the risk for injury.<sup>1,3,4,18,22</sup>

Laudner, et al. demonstrated a positive correlation between total rotational hip motion of the lead leg measured in

prone with shoulder external rotation torque in National Collegiate Athletic Association (NCAA) Division I collegiate baseball pitchers ( $r=0.56$ ).<sup>14</sup> A significant relationship was also found with total rotational hip motion of the trailing leg and shoulder horizontal adduction during throwing ( $r=0.43$ ).<sup>21</sup> The authors concluded that limitations in hip mobility of the lead leg can place added torque on the shoulder, and that limitations in hip mobility of the trailing leg can cause pitchers to “throw across their bodies” and further stress the shoulder and limit performance.<sup>21</sup> If hip rotation is not controlled during pitching, then the pitcher risks throwing in an “open position” which can prematurely initiate the cocking phase of throwing which has been shown to place greater torque on the shoulder and potentially lead to injury.<sup>24</sup> Typically, transverse plane hip function is assessed with active and passive range of motion measurements in seated and in the prone positions. Isolated, open kinetic chain measurements of the hip would not adequately assess the transverse plane mobility and stability of the entire lower extremity kinetic chain. Thus, total lower extremity rotation mobility and stability needs assessed in a more functional, closed kinetic chain fashion in order to adequately screen for kinetic chain deficits and injury risk in throwers, which is depicted in this proposed screen.

Currently, there are no standards that exist for the degree of functional transverse plane lower extremity mobility and stability necessary to pitch. There is controversy in the literature as to whether rotation should be symmetrical bilaterally, and whether internal rotation should be equal to external rotation within a single lower extremity.<sup>21,24</sup> Based on clinical experience, it was decided that a total lower extremity rotational arc of motion of  $165^\circ$  was needed to safely and effectively pitch with sound biomechanics. External rotation would account for  $90^\circ$ , and internal rotation would account for  $75^\circ$ . These measurements should be symmetrical bilaterally.

#### Provocative Tests

Two clearing tests were incorporated into this proposed injury screen, a shoulder impingement test and a valgus stress test to the elbow performed at  $90^\circ$  of elbow flexion. These two tests were added to determine the presence of pain and pathology within the shoulder and elbow, and will alert the screener to refer the athlete to a healthcare professional.

#### CONCLUSION

Baseball pitching requires a complex interaction of lower extremity mobility and stability, hip and pelvic mobility and stability, and core stability to effectively transfer energy from the ground, through the shoulder and elbow, and finally to the ball. If there is dysfunction anywhere along this kinetic chain, the potential for pain, performance reduction, and injury increases; especially at the shoulder and elbow. The proposed functional screen presented in this article can therefore be used to assess these major components essential to throwing, and can

alert both coaches and athletes to potential injury risks.

#### CLINICAL IMPLICATIONS AND LIMITATIONS

Although the existing literature presented in this article is used to provide support for a functional kinetic chain injury screen for baseball pitchers, this evidence can be used to support rehabilitation principles for the inclusion of lower extremity and core training in the treatment of those with shoulder and elbow pathologies related to overhead throwing or similar activities. It can also be used to determine an athlete’s readiness to return to throwing following surgical procedures such as a UCL reconstruction. For instance, an athlete would have to successfully pass this proposed screen prior to the initiation of a return to throwing program.

#### FURTHER RESEARCH

There is little to no evidence that currently exists on the functional assessment of the lower extremity and core as it relates to overhead throwing. As such, there are no standards that exist regarding the degree of mobility and stability needed to throw while minimizing the risk for injury. The standards chosen for this screen were based on knowledge of sport and clinical experience in the treatment of baseball pitchers with shoulder and elbow pathologies. Further research is needed to ascertain evidence-based standards and the effectiveness of this screen at predicting injury.

#### CONFLICTS OF INTEREST

This article is originally written by the authors listed, and has not been published before. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the manuscript.

#### CONSENT

All participants depicted in the appendix are either one of the authors, or they have been de-identified.

#### REFERENCES

- Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*. 2009; 1(4): 314-320. doi: [10.1177/1941738109338546](https://doi.org/10.1177/1941738109338546)
- Han KJ, Kim YK, Lim SK, Park JY, Oh KS. The effect of physical characteristics and field position on the shoulder and elbow injuries of 490 baseball players: confirmation of diagnosis by magnetic resonance imaging. *Clin J Sport Med*. 2009; 19(4): 271-276. doi: [10.1097/JSM.0b013e3181aad7b1](https://doi.org/10.1097/JSM.0b013e3181aad7b1)
- Oliver GD, Keeley DW. Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball

- pitchers. *J Strength Cond Res.* 2010; 24(12): 3241-3246. doi: [10.1519/JSC.0b013e3181cc22de](https://doi.org/10.1519/JSC.0b013e3181cc22de)
4. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. 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(9): 2089-2094. doi: [10.1177/0363546514536871](https://doi.org/10.1177/0363546514536871)
5. Feigenbaum LA, Roach KE, Kaplan LD, Lesniak B, Cunningham S. The association of foot arch posture and prior history of shoulder and elbow surgery in elite-level baseball pitchers. *J Orthop Sports Phys Ther.* 2013; 43(11): 814-820. doi: [10.2519/jospt.2013.4504](https://doi.org/10.2519/jospt.2013.4504)
6. 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(2): 329-335. doi: [10.1177/0363546510384223](https://doi.org/10.1177/0363546510384223)
7. Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers. *Am J Sports Med.* 2014; 42(9): 2075-2081. doi: [10.1177/0363546514538391](https://doi.org/10.1177/0363546514538391)
8. Bell S. Fernandez joins growing list of arm injuries. *ESPN.* [http://espn.go.com/blog/stephania-bell/post/\\_id/2468/fernandez-joins-growing-list-of-arm-injuries](http://espn.go.com/blog/stephania-bell/post/_id/2468/fernandez-joins-growing-list-of-arm-injuries) 2014; Accessed May 14, 2014.
9. MLB Reports. Tommy john surgery tracker: all-time list. Available at: <http://mlbreports.com/tj-surgery/> Accessed March 2015.
10. American Sports Medicine Institute. Position statement for Tommy john injuries in baseball pitchers. Available at: <http://www.asmi.org/research.php?page=research&section=TJpositionstatement> 2014; Accessed July 2014.
11. Garrison JC, Arnold A, Macko MJ, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate decreased balance compared to healthy controls. *J Orthop Sports Phys Ther.* 2013; 43(10): 752-758. doi: [10.2519/jospt.2013.4680](https://doi.org/10.2519/jospt.2013.4680)
12. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *Am J Sports Med.* 2006; 34(3): 423-430. doi: [10.1177/0363546505280431](https://doi.org/10.1177/0363546505280431)
13. 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(4): 463-468.
14. American Physical Therapy Association. Baseball pitching: understanding the mechanics of throwing a baseball may help protect the shoulder and elbow. *J Orthop Sports Phys Ther.* 2011; 41(5): 304. doi: [10.2519/jospt.2011.0503](https://doi.org/10.2519/jospt.2011.0503)
15. Kerut EK, Kerut DG, Andrews JR. Prevention of arm injury in youth baseball pitchers. *J La State Med Soc.* 2008; 160(2): 95-98.
16. American Physical Therapy Association. Physical therapist's guide to ulnar collateral ligament injury. Available at: [http://www.moveforwardpt.com/symptomsconditionsdetail.aspx?cid=ddb540d-6f4c-4417-9195-14f42aa9dd41#.VE3W-CaLn\\_IU](http://www.moveforwardpt.com/symptomsconditionsdetail.aspx?cid=ddb540d-6f4c-4417-9195-14f42aa9dd41#.VE3W-CaLn_IU) 2014; Accessed July 2014.
17. Falsone S. Avoiding baseball injuries. Move Forward. Available at: [http://www.moveforwardpt.com/Radio/Detailed.aspx?cid=5647de2b-dca5-42b8-bdbe-cb43dab3ae14#.VE3YTqLn\\_IU](http://www.moveforwardpt.com/Radio/Detailed.aspx?cid=5647de2b-dca5-42b8-bdbe-cb43dab3ae14#.VE3YTqLn_IU) 2014; Accessed July 2014.
18. 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(11): 3015-3022. doi: [10.1519/JSC.0b013e3181c865ce](https://doi.org/10.1519/JSC.0b013e3181c865ce)
19. Campbell BM, Stodden DF, Nixon MK. Lower extremity muscle activation during baseball pitching. *J Strength Cond Res.* 2010; 24(4): 964-971. doi: [10.1519/JSC.0b013e3181cb241b](https://doi.org/10.1519/JSC.0b013e3181cb241b)
20. Endo Y, Sakamoto M. Relationship between lower extremity tightness and star excursion balance test performance in junior high school baseball players. *J Phys Ther Sci.* 2014; 26(5): 661-663. doi: [10.1589/jpts.26.661](https://doi.org/10.1589/jpts.26.661)
21. Laudner K, Wong R, Onuki T, Lynall R, Meister K. The relationship between clinically measured hip rotational motion and shoulder biomechanics during the pitching motion. *J Sci Med Sport.* 2014; 18(5): 581-584. doi: [10.1016/j.jsams.2014.07.011](https://doi.org/10.1016/j.jsams.2014.07.011)
22. Oyama S, Yu B, Blackburn TJ, Padua DA, Li L, Myers JB. Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. *Am J Sports Med.* 2013; 41(10): 2430-2438. doi: [10.1177/0363546513496547](https://doi.org/10.1177/0363546513496547)
23. Radwan A, Francis J, Green A, et al. Is there a relationship between shoulder dysfunction and core instability. *Int J Sports Phys Ther.* 2014; 9(1): 8-13.
24. Robb AJ, Fleisig G, Wilk K, Macrina L, Bolt B, Pajaczkowski J. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *Am J Sports Med.* 2010; 38(12): 2487-2493. doi: [10.1177/0363546510375535](https://doi.org/10.1177/0363546510375535)
25. Polster JM, Bullen J, Obuchowski NA, Bryan JA, Soloff L, Schickendantz MS. Relationship between humeral torsion and injury in professional baseball pitchers. *Am J Sports Med.* 2013;

41(9): 2015-2021. doi: [10.1177/0363546513493249](https://doi.org/10.1177/0363546513493249)

26. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *Am J Sports Med.* 2008; 36(3): 523-527. doi: [10.1177/0363546507308935](https://doi.org/10.1177/0363546507308935)

27. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006; 36(12): 911-919. doi: [10.2519/jospt.2006.2244](https://doi.org/10.2519/jospt.2006.2244)