Risk Factors and Injury Prevention in the Throwing Athlete

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Abstract: Arm injuries are the most common throwing injury, with growing concern as the most severe injuries, such as UCL reconstruction, continue to rise. Furthermore, throwing injuries are frequently recurrent, suggesting once injured, players are at increased risk for another arm injury. The increase in injury rates and severity has been attributed to increases in pitching volume and year-round participation, and specialized training. Thus, initial efforts to prevent arm injuries by USA Baseball and Little League have focused on the extrinsic factor of pitching exposure in the form of pitch counts, yet arm injury rates have stayed constant. Therefore, injury prevention strategies should include extrinsic factors and address modifiable, intrinsic factors that are associated with arm injury. Collectively addressing factors, such as shoulder range of motion and strength deficits, trunk and lower extremity function, and implantation of training programs yields a comprehensive approach to reduce arm injury rates. We will use a directed acyclic graph (DAG) to organize how the internal factors (i.e., fatigue, injury history, range of motion, and strength) interact with the external factors (i.e., training load and pitching exposure) and how together they are thought contribute to potential injury and inform arm injury reduction strategies. This will provide a roadmap to build adaptable arm injury reduction strategies to improve the modifiable physical factors in context of the external factors that change over time and between throwing athletes. **Level of Evidence:** Level V, expert opinion.

In the United States, the number of baseball and softball players combine to represent nearly 1 million athletes across the high school and collegiate setting.[1,2] Other throwing athletes, such as quarterbacks and javelin throwers, are under-represented in the throwing literature due to smaller total numbers by sport, position, or event.[3,4] All of these athletes are at an inherently greater risk of injury to the shoulder and elbow as they participate at high exposure rates as both youth and adult athletes.[3-14] Risk of injury is greatest for pitchers, catchers, and individuals who are throwing more frequently and with higher effort during a single session or over a season.[5-13,15-17] Often times, these injuries are chronic or acute-on-chronic in nature.[6,7,9,13,16] Upper extremity injury rates from throwing vary across sport, with ranges from 0.98 to 4.0 injuries per 1,000 athletic exposures.[5-13,17,18] No matter the type of injury sustained, effects can be felt beyond playing throughout their lifetime.[19,20]

While the literature is rich with information regarding the epidemiology of upper extremity injuries in the throwing athlete,[12,21,22] the majority has been focused on the baseball athlete. Though the injury type and severity are known, the direct causes of an upper extremity injury remain ambiguous. Recently, Bullock et al. presented the directed acyclic graph (DAG) on medial elbow injury from the current knowledge base of possible risk factors (Fig. 1).[23] The DAG shows how the internal factors (i.e., fatigue, injury history, range of motion [ROM], and strength) interact with the external factors (i.e., training load and pitching exposure) and how together they are thought to contribute to potential injury.[23] The DAG demonstrates the complex interactions of these risk factors with one another, demonstrating the multiple direct and indirect

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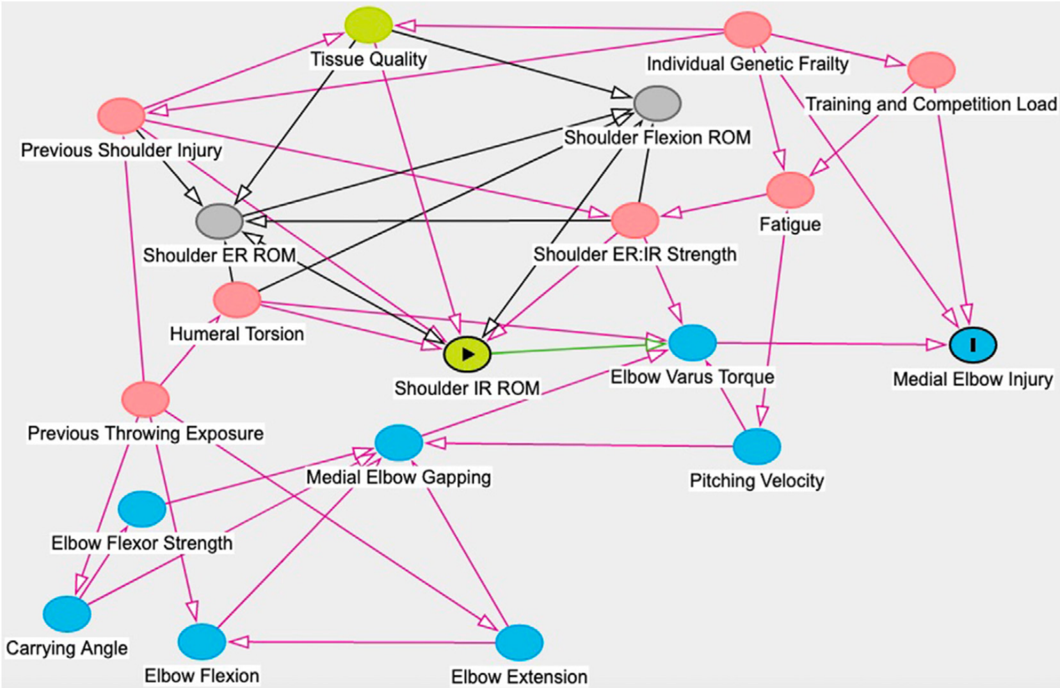

Fig. 1. Directed acyclic graph of medial elbow injury. Reproduced from Bullock et al. "Shoulder Range of Motion Measurements and Baseball Elbow Injuries: Ambiguity in Scientific Models, Approach, and Execution is Hurting Overhead Athlete Health" *Arthrosc Sports Med Rehabil* 2023;5:e297−e304

influence on causation. This is further challenged, as some of these internal and external factors are modifiable, while others are not. Modifiable factors include ROM, strength, and workload, while nonmodifiable factors include components, such as genetics, tissue quality, and bony morphology. While the nonmodifiable risk factors are important when considering an athlete's injury risk, this article will focus on modifiable risk factors of upper extremity injury and discuss strategies to reduce injury.[23]

Range of Motion

Appropriate ROM is foundational for the throwing athlete across sports, age, and gender, and tissue extensibility is the most widely studied factor of the throwing athlete. Negative changes to ROM, often a loss of required motion, have been shown to result in pain and dysfunction both locally, at adjacent joints through regional interdependence and across the body via the global interdependence of the kinetic chain.

Total Arc

Total arc of motion (TARC) has been defined as the total amount of shoulder external rotation (ER) plus internal rotation (IR), which should be similar in cumulative value bilaterally, but individual values may shift between the throwing arm and nonthrowing arm.[24] Total arc of motion differences >5°, with decreased ROM in the dominant arm, are present in athletes across all age and skill levels and is associated with injury. This has been specifically identified in both major and minor league baseball settings.[5,18,24,25] This does not include normal ROM loss that occurs in the short term immediately after pitching and can last at least 24 hours.[26,27] Changes in the TARC of the throwing arm occur throughout the season and throughout a career.[28-30] Over the season, professional and collegiate pitchers demonstrate increased ER and TARC, as well as minimal IR loss.[28-31] By the end of a professional career, however, the literature demonstrates a decrease in TARC.[32] Wilcox et al. found that younger athletes (14 years and under) had significantly less IR than older athletes, high school to professional, and reduced TARC overall.[33]

External and Internal Rotation

The components of TARC play an important role, as each individual measure has been linked to injury risk. Although an increase of ER can be seen immediately after throwing, it is followed over the next few days by loss of motion (Figure 2).[26,27] Over the course of a youth or professional season, ER is expected to increase.[28,30,31] Research has demonstrated that a reduction in ER greater than 5° may be associated with injury.[25,28,29,31,34-36]

Aberrant IR, primarily referencing a deficit of IR, can have large repercussions for the throwing athlete. This can lead to TARC loss or glenohumeral internal rotation

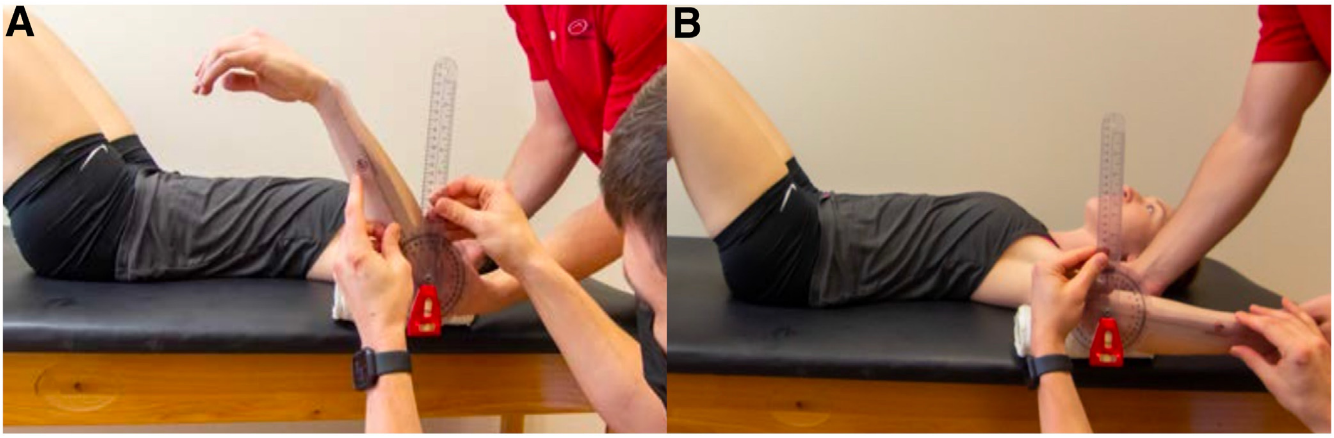

Fig. 2. Shoulder external and internal rotation range of motion. (A) Internal range of motion measure. (B) External range of motion measure.

deficit (GIRD). GIRD refers to the loss of shoulder IR after throwing due to soft tissue and neuromuscular changes.[37] Deficits in IR have been linked to upper extremity injury risk in throwers.[5,18,24,36,38,39] Shanley et al.[5,18] demonstrated a significant association between an IR loss of 13–25° and a 4–6 times greater risk of injury in the youth athlete; Shitara et al.[36] reported a 7° IR loss resulting in 2 times the risk of injury. In the professional population, >20° IR loss has been associated with a 1.9-fold increased risk of shoulder injury.[24] Although IR loss can be seen at all ages, youth athletes under 14 years old present with overall less IR than their older counterparts.[33] Nonpitchers with a history of shoulder injury had more ER and less IR compared to the other side than nonpitchers with no history of injury.[28] This difference could be attributed to osseous changes of humeral torsion (HT).[31,40-42]

Humeral Torsion

Unlike other ROM components, humeral torsion is nonmodifiable. Humeral torsion is the amount of bony rotation at the long axis of the humerus. Increased posterior rotation, referred to as retrotorsion, results in increased ER and consequently less IR.[31,40-43] In the professional setting, increased torsion posteriorly may have a positive effect on injury rates as one study showed that pitchers with shoulder injury demonstrated 4° less of dominant arm humeral torsion than those without injury.[40] In a youth population, HT was not associated with injury. Greenberg et al. identified that after adjusting for HT, the significance of GIRD was no longer observed in youth athletes 9–12 years old.[44] Understanding this information can also assist in knowing the potential TARC.[31,41-43]

Horizontal Adduction

Loss of horizontal adduction (HA) has been associated with shoulder injury and increased joint stresses in throwers of all ages and competitive levels.[5,18,45] Despite an expected 7° loss across a youth season, Shanley et al. demonstrated that a 15° loss of HA of the throwing arm compared to the nonthrowing arm increased injury risk by 4.1 times in adolescents.[5,18,31] This loss of motion can contribute to increased stress at the anterior shoulder and elbow leading to potential injury, and by minimizing HA loss to 10° from neutral can help reduce those stresses.[45] Conversely, major league pitchers display a seasonal increase of horizontal adduction in their dominant arm by an average of 15.7°.[30] A loss of horizontal adduction (Figure 3) in this population, however, remains indicative of injury.[38]

Flexion

Shoulder flexion is another measure associated with potential injury risk to the throwing athlete. Wilk et al.[39] demonstrated that a 5° loss of shoulder flexion has been associated with increased elbow injury. Another study showed that shoulder flexion loss was a major contributor to upper extremity injury risk in conjunction with a loss of ER.[34]

Elbow Extension

While not studied in-depth, elbow ROM is important for the overhead athlete. Wright et al.[46] showed that the dominant elbow of pitches can present with overall less total arc of motion with decreases to both flexion and extension compared to the nondominant extremity. Sakata et al.[47] established an association between elbow extension ROM and medial elbow injuries. With a >5° loss of elbow extension increasing risk in the youth population.

Strength

While ROM is foundational and has received the most attention in research, the ability to control the throwing motion is determined by muscle performance. Most

Fig. 3. Passive horizontal adduction range of motion.

often, muscle performance has been measured as shoulder strength reflecting the large periarticular shoulder muscles and deeper rotator cuff.[36,48,49] Both Byram et al.[48] and Tyler et al.[49] showed similar trends that weakness of dominant arm scaption compared to the nondominant arm could increase risk of injury.

Preseason weakness in the dominant compared to nondominant arm of prone ER, prone IR, and the supraspinatus muscle have been linked to in-season throwing-related injury[36,48] (Figure 4). Achieving symmetry in bilateral upper extremity strength measures and working to improve ER/IR ratios are important injury reduction strategies. Attaining the recommended ER/IR strength ratio is important for dynamic stabilization and acceleration/deceleration of the GHJ during throwing. Byram et al.[48] showed a higher shoulder injury risk on athletes who demonstrated lower prone strength ratios. Therefore, it is important for injury reduction.[36,48] Current research recommends measuring the ER:IR ratios in the 90—90 position and that this ratio be between 0.66 and 0.78 at minimum for return to sport.[50,51] Understanding normative data among throwing athletes will aid in diagnosis, prognosis, and creating an effective plan of care.

Throwing Load

In conjunction with ROM and strength differences, fatigue and overuse are additional modifiable factors that may contribute to upper extremity injury risk.[52-54] Injured and painful athletes regularly demonstrate higher throws per day, total pitches, total innings, and appearances.[47,52,55] Olsen et al.[52] found that pitching with fatigue can increase the risk of injury by 36-fold.

Endurance is an essential element of the rehabilitation process due to the high volume of throws these athletes perform during practice and competition.[56,57] Studies have shown that a higher volume of throws increases injury risk,[47,52,53] and multiple other studies demonstrate that pitching while fatigued increases risk of injury.[52,53] No studies have specifically looked at endurance of throwers, but without proper endurance, these athletes may fatigue quickly causing alterations in their throwing mechanics, which may lead to potential injury.[53,58-61]

Pitch/Throw Count

Olsen et al. and Sakata et al. found that youth athletes throwing over 100 throws or pitches per day can lead to injury.[47,52] Monitoring pitch count to stay within age-appropriate norms would appear to be a simple way to lower overall injury risk from fatigue, but pitch

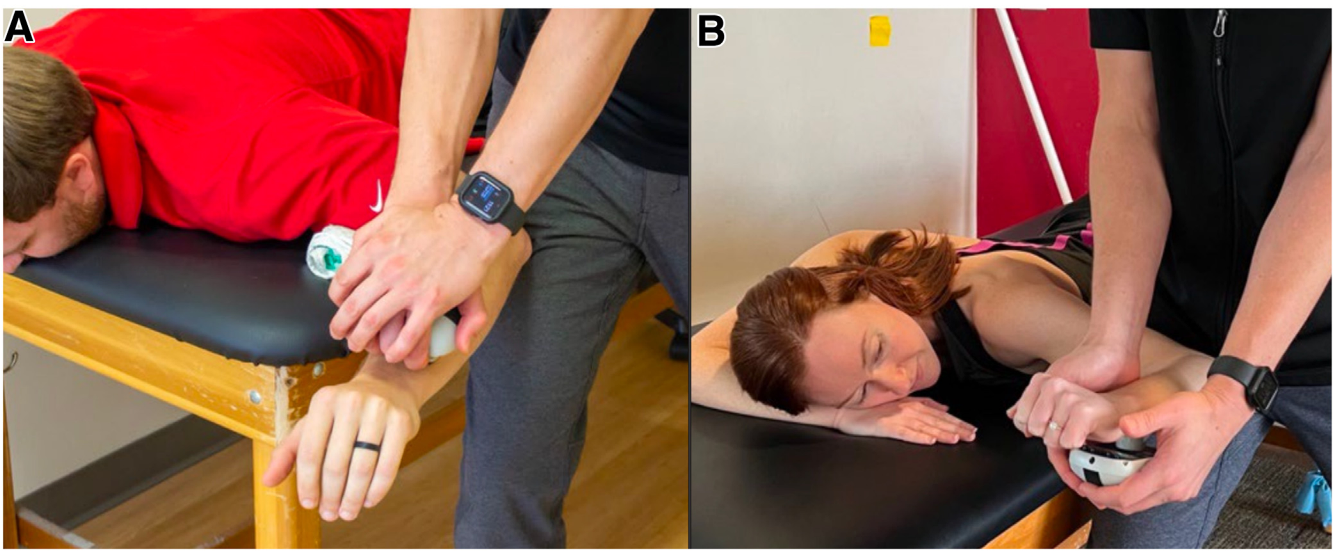

Fig. 4. Strength measures at 90° of abduction in prone. (A) External rotation at 90° of abduction strength test. (B) Internal rotation at 90° of abduction strength test.

counts can be deceiving. In a study of high school pitchers, Zaremski et al.[56] demonstrated that 42% of higher-effort pitching, which was performed as a warm-up or between innings, was unaccounted for in pitch count. Furthermore, a study of a single youth team showed that pitchers on game days can throw an average of 158 total throws versus 119 throws on nonpitching days.[57] MLB's Pitch Smart program provides a good overview of number of pitches per outing and recommended days of rest.[62] (Table 1: number of pitches and days' rest chart). These recommendations are a good starting place and can benefit the athlete to change positions to a spot with less number of high effort or total volume of throws, as these have been shown to increase injury risk.[63] Examples of this would include not performing as a pitcher and catcher in the same session and accounting for total pitches and throws if playing on multiple teams or in different leagues.

High Effort/Velocity

Not only does the total number of throws matter, but high effort and velocity may lead to injury.[52,64-67] Throwing at higher velocity and higher intensity was consistently shown to increase risk of injury to the upper extremity.[64.] Two studies have also linked high amounts of fastball utilization with injury.[65,67] Another possible contributor may be using the strategies for increasing spin rate by trying to create more break on the ball.[68] When possible, it is recommended to consistently use the same monitoring strategy whether it is an arm monitoring inertial device, radar gun, or rating of perceived exertion.

Previous Injury History

Previous injury is a well-documented, nonmodifiable risk factor for injury.[15,69-73] In a large cohort study by Shanley et al.[74], 16 of 63 injured subjects would go on to sustain further injuries throughout their careers. Bullock et al.[70] showed a previous arm injury rate of 69% in all minor league pitchers across an organization. A previous injury within the kinetic chain was present for 43% of those players who sustained an initial arm injury and 50% within the subsequent arm injury group. This same study also identified an increased rate of shoulder injury after a previous shoulder or elbow injury.

Even surgical graft sites have been shown to increase the risk of injuries locally at the site of harvest.[72] Knowledge of a harvest site, previous surgery, or injury to any part of the athlete can affect the whole individual.[70,72,75] As seen in the Bullock et al. study, a nonmodifiable risk factor of previous injury has played a role in injury, which allows us to address the modifiable risk factor of the kinetic chain.[70]

Kinetic Chain

Because of the high demand of throwing on the kinetic chain, previous injury is not limited to the upper extremity.[75] Injuries sustained throughout the body can potentially affect the throwing arm.[70,75-78] A study of 60 people reported that distal limitations in mobility, strength, balance, or stability could affect scapular mechanics and subsequently upper extremity mechanics.[79] Slowik et al. showed in a laboratory study how changing foot placement alone can alter the stresses to the upper extremity.[80] This means for the throwing athlete that even a minor injury to another body part can alter the mechanics of the throwing athlete leading to changes in stresses.

Proximally to the upper extremity, the cervical spine and thoracic spine have been implicated as potential risk factors.[47,81] Throwers who presented with less than 39° during the cervical flexion and rotation test had poorer arm health and increased risk of time loss injury.[81] Cervical spine rotation is extremely important for the throwing athlete, as it helps to control the thrower's ability to acquire the target and sustain focus throughout.[82] Sakata et al.[47] showed an increase in elbow pain and injury when throwers presented with more than 30° of thoracic kyphosis in standing. With the upper extremity being supported by the thoracic spine, an alteration of increased thoracic flexion can lead to poorer scapular mobility leading to decreased shoulder and elbow performance. Kibler and Burkart

Table 1. Number of Pitches and Rest Day Recommendations

Age	Max Daily	No Rest	1 Day's Rest	2 Days' Rest	3 Days' Rest	4 Days' Rest	5 Days' Rest
7–8	50	1–20	21–35	36–50			
9–10	75	1–20	21–35	36–50	51–65	66+	
11–12	85	1–20	21–35	36–50	51–65	66+	
13–14	95	1–20	21–35	36–50	51–65	66+	
15–16	95	1–20	21–35	36–50	51–75	76+	
17–18	105	1–30	31–45	46–60	61–80	81+	
19–22	120	1–30	31–45	46–60	61–80	81–105	106+

Adapted from MLB's Pitch Smart Guidelines.

emphasized the importance of scapular control in the overhead athlete and its effects on injury.[83,84]

While the upper extremity is always the focus of the throwing athlete, the lower extremity is often overlooked. The lower extremity is important from the time motion starts to it finishes. Campbell et al. showed the importance of the lower extremity strength and endurance in pitching mechanics due to the high forces being generated and attenuated through the lower half.[85] Lack of ROM and strength in the lower extremity can alter mechanics leading to changes in stresses seen at the elbow and shoulder.[78] Aberrant hip mobility and strength have also demonstrated links to increased risk for shoulder and elbow injury.[76,86-88] One study of adolescent throwers found a potential link to elbow pain and injury in throwers with limited hip ROM.[86] Plummer et al. showed a decrease in trunk rotation to home plate in pitchers with decreased stance leg internal rotation in a study of high school throwers.[87] Hip abduction strength asymmetry and lower scores on the lower extremity Y-balance have been present in injured athletes.[76,88]

Arm Injury Reduction Program

Arm injury reduction programs are framed by the DAG and informed by the risk factors discussed. Throwing athletes that have an injury history should be prioritized given their reinjury and subsequent injury risk. When considering specific modifiable factors, the program should have three primary components, muscle extensibility, muscle performance, and throwing preparation.

Muscle Extensibility

Mobility and strength deficits throughout full kinetic chain and poor load management can be implicated in injury to the upper extremity of the throwing athlete, as we discussed. Losses of both mobility and strength have been identified across both single sessions and the course of a season.[26,27,31] Screening these athletes, even one time, and developing appropriate, individualized interventions have been shown to reduce overall injury risk.[89,90] Arm care programs should ideally address the mobility and strength of the entire upper extremity (Figure 5). Programs that address maintenance of posterior shoulder tissue extensibility have been shown

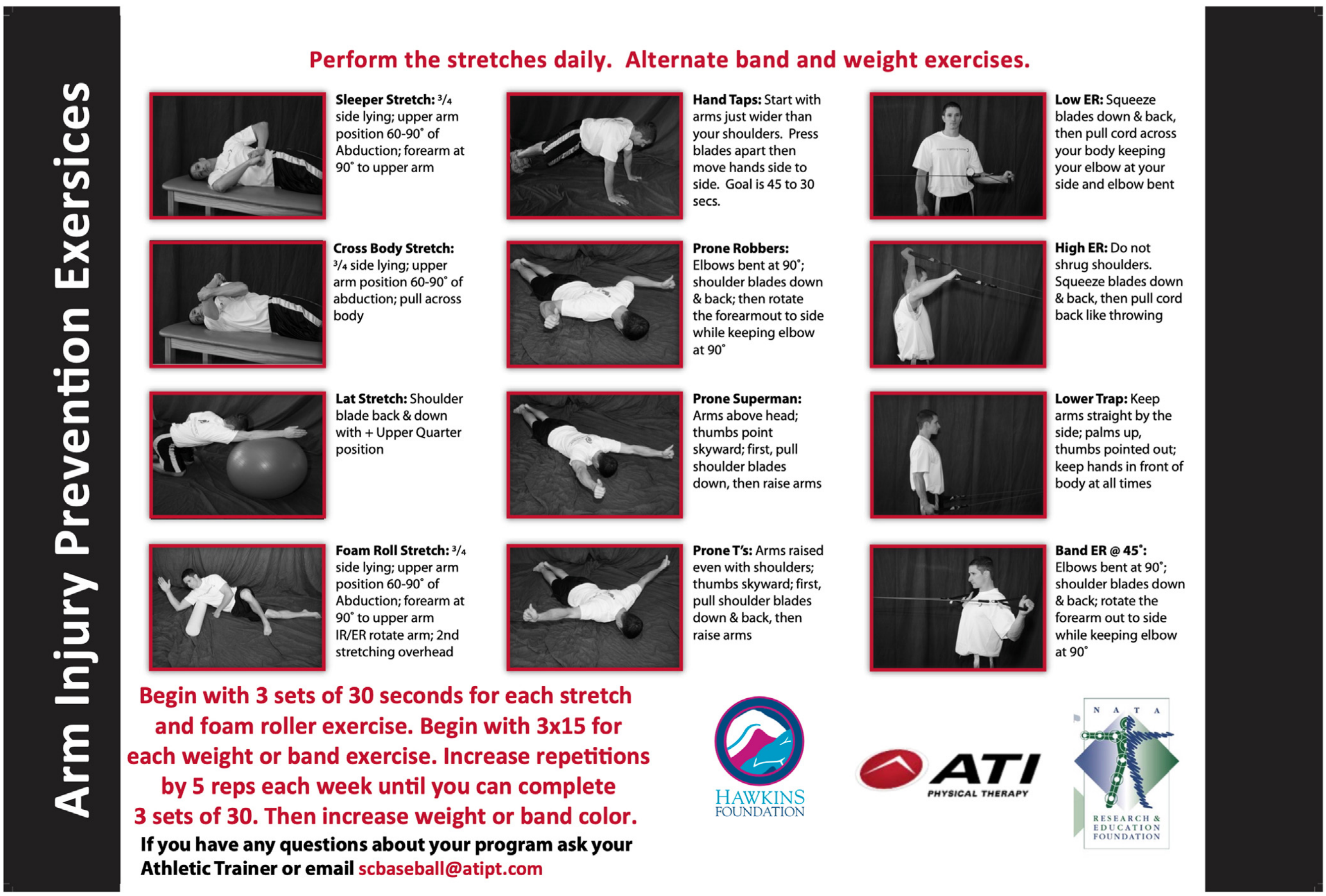

Fig. 5. Example of injury prevention poster.

to be effective in reducing injury risk.[91,92] Appropriate posterior shoulder extensibility can be achieved with horizontal adduction and internal rotation stretching.[92-94] Mobility exercises that address shoulder flexion are important as well for athletes to achieve appropriate arm slots and reduce risk of elbow injury.[25,34]

Muscle Performance

Arm performance maintenance programs have been shown to be effective through simple shoulder exercises performed a few times per week leading up to and during the season. Exercises should emphasize the individual deficits found on assessment to minimize the individual's risk. Weakness or tightness of the posterior cuff has been linked to injury risk, as well as strength deficits possible in athletes after injury; therefore, it is important to address these muscles.[48,49,95] Strengthening the posterior cuff through shoulder external rotations exercises in various planes of abduction can address common deficits (Figure 5). Recruitment activities of scapular stabilizers are beneficial for both athletic performance and upper extremity health.[79,96,97]

Throwing Preparation

Preparing to throw is a recurrent process that starts 8—12 weeks prior to the season and continues throughout the season after every time on the mound. Leading up to the season, this begins with an interval throwing program where athletes initially begin by throwing every other day and progress to throwing every day closer to the season. Distances and efforts should start low and slowly increase over time. Athletes should also design their progressive throwing programs to be similar to their expected weekly throwing volume (i.e., a pitcher replicating their 5- or 7-day weekly pitching routine). During this build-up, using a consistent effort monitoring device or fatigue management system, such as pitch count or inertial devices, is recommended.

As practice or the season begins, a consistent warm-up for throwing athletes should be implemented following best practice. This includes movements that are multi-joint, sport-specific, target ROM deficits, and prep sport-specific prime movers.[59] An example of a warm-up for a throwing athlete could include soft tissue mobility and stretching followed by moving stretches that incorporate balance and key sport positions like lunges and single-leg hip hinging. Dynamic warm-ups and full-body mobility programs have shown success in reducing elbow injury in youth throwers by preparing the entire kinetic chain to participate in the activity of throwing.[94,98,99] Shortened-stretch exercises and muscle preparation activities, known as "2 out drill" has shown to be effective in restoring ROM after a bout of high-effort throwing.[100]

Arm care after throwing is just as important as the preparatory work. With ROM and strength losses occurring immediately after throwing, offsetting the daily compounding effects of throwing is necessary. Performing similar stretching and mobility activities of the upper extremity immediately after completion can be beneficial in restoring motion to prethrow levels. With the repetitive unilateral movement of throwing, full-body mobility exercises addressing the contralateral side and opposite rotational directions can help to restore homeostasis of the kinetic chain. At times, soft tissue intervention from assistance of a health care provider helps restore ROM loss faster than stretching alone.[93] This can be achieved through use of instrumented soft tissue mobility directed as the posterior rotator cuff or other less extensible tissue.

Conclusions

Reducing the risk of upper extremity injury in the throwing athlete is a difficult process due to the multiple factors at play. These risk factors are extensively intertwined with both causative and correlative effects between them.[23] Familiarity with ROM, strength expectations, and normative values can help to identify deficits requiring interventions. Following appropriate guidelines set by Major League Baseball's Pitch Smart Program can assist athletes, parents, and coaches to manage and modify throwing load. Understanding injury history and its effects on the kinetic chain can guide proper interventions to offset faulty mechanics. Combining awareness of all these risk factors with appropriate education and interventions can help providers reduce the risk of upper extremity injury in throwing athletes.

Disclosures

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