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THE THROWING SHOULDER: A REVIEW OF FUNCTIONAL ANATOMY, BIOMECHANICS, INJURY PREVENTION AND REHABILITATION STRATEGIES

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ABSTRACT

Consistent performance of high velocity, accurate overhead throwing is a remarkable achievement by the shoulder joint. The action of throwing is a full body action, where the goal is the successful transfer of lower body generated force through to the hand to maximise ball velocity. The ability of the shoulder girdle to perform this action, given the magnitude of mobility at the glenohumeral joint is accomplished by many structures.

The shoulder joint has tremendous range of motion at the expense of structural stability. Glenohumeral stability is achieved by a range of static and dynamic structures. The capability for the shoulder to move through range either under load or with high velocity is due to an intricate coordination of muscles acting on the scapula and humerus, delicately altering muscle lengths and forces to achieve glenohumeral stability. This coordination is controlled by constant neural information provided by several specialised structures within the muscles, tendons and ligaments of the shoulder girdle.

Overhead throwing places enormous demands on the shoulder joint through range, velocity and force. Overhead throwers adapt to repetitive throwing with several changes to the static and dynamic structures. However, some of these protective and performance enhancing alterations to the structure, or function of the links in the scapulothoracic and glenohumeral chains, can still lead to injury.

Successful rehabilitation and injury prevention of such a highly coordinated, highly mobile joint performing repetitive actions of considerable force and velocity, such as throwing, requires knowledge of anatomical adaptations and function to be successful. Injury prevention requires attention to balance of muscular strength, flexibility and endurance of scapular stabilisers and the rotator cuff. The monitoring of throwing technique and volume, particularly in developing athletes is critical. The first step in successful rehabilitation is accurate diagnosis. Shoulder pain can result from unsuccessful accommodation of scapulothoracic structures. The restoration of scapular stability is a key component of shoulder rehabilitation. Biomechanical intervention to the throwing action may be required to reduce the likelihood of re-injury.

INTRODUCTION

The shoulder joint has the greatest range of any joint of the body (2, 20, 65). In a trade-off for freedom of movement, the highly mobile “ball and socket” joint offers little stability (20, 65). This freedom allows for athletic actions such as overhead throwing, freestyle swimming and gymnastics events such as the uneven bars or rings. However, this high level of mobility comes at the cost of stability, particularly in throwing athletes due to the “coordinated, high-velocity, multiple joint” nature of throwing (47). In Major League Baseball, between 1999 and 2004, 23% of reported injuries were to the shoulder and almost 50% of all pitchers lose match time at some stage in their careers (13, 58). The mobility of the glenohumeral joint requires a stable base of support to be provided by the scapula. As the humerus moves, the position of the glenoid must move to maintain stability. This relationship has been termed scapulohumeral rhythm (48).

For strength and conditioning coaches working with throwing athletes, an understanding of the anatomy, structure and function of the shoulder is required in order to assist with performance enhancement of throwers, injury prevention and rehabilitation. It is also important, when training throwers, to understand the adaptations occurring in the shoulder as a result of throwing.

It is acknowledged that, given the interrelationships amongst the components of the functioning shoulder, it is a limitation of this review to present components in a compartmentalised format. Therefore, it is the purpose of this review to investigate and understand the relationships between the components of the functional anatomy of the shoulder, the nature of throwing and the biomechanical demands it places on the shoulder joint and guidelines and protocols identified by the literature as critical to a healthy shoulder joint for injury prevention and rehabilitation.

FUNCTIONAL ANATOMY

The shoulder joint is “designed for function and mobility at the expense of stability” (45). A complex interaction of dynamic and static stabilisers permit the shoulder joint the greatest range of any joint in the body (65). A intricate coordination between the scapula and humerus during upper limb movements must be maintained (2, 47). It is a fine balance between dynamic muscular coordination, ligaments, bony articulations and joint forces that allow such function (11). Dynamic control includes the rotator cuff, scapulothoracic motions and negative intra-articular pressure (45). The glenoid labrum and shoulder capsule ligaments provide static stabilisation. The scapula plays a substantial role in providing a stable base for glenohumeral movement (72). These areas of the shoulder shall be discussed in greater detail.
STATIC STABILISATION

The surface of the humeral head can be three to four times greater than the articulating surface of the glenoid, so only 25 to 30% of the humeral head is actually in contact with the glenoid at any one time – an example of the trade-off of stability for mobility (28, 45, 65). Despite this, through a complex interaction of stabilisers, the humeral head in a healthy shoulder can be fixated within 1-2mm of the centre of the glenoid fossa (65).

The glenoid labrum (labrum) is a fibrous “cup” connected to the glenoid that serves to increase the depth of the joint and enhance stability. The labrum can increase the concavity of the joint by 5-9mm (65). Injury to the labrum, usually though a traumatic event (eg. collision in a tackle or a fall) can have a substantial effect on the stability of the joint. The shoulder capsule encases the glenohumeral joint, being thicker in the anterior compared to posterior (45). The capsule provides two key areas of stability. Firstly, the orientation of the ligamentous fibres can become taunt, or wind up (like wringing a towel) in extreme abduction and external rotation, as in the overhead throwing motion (20, 45). This tightness occurs only in extreme ranges. In mid-ranges, the effect on stability is minimal and dynamic structures play a greater role (45, 65). Increased laxity can have a significant impact on the stability of the humeral head during abduction and external rotation of the humerus (45). Secondly, the joint capsule helps seal the joint creating a closed compartment (45). The Glenohumeral joint contains a very small amount of fluid, that in the well-sealed capsule, creates a negative pressure that provides a suction force on the humeral head, adding to stability (65). The vacuum effect can be lost through injury to the joint capsule which will allow some translation of the humeral head (45).

Due to the large motion achieved at the shoulder joint and the high forces that can be experienced through many common sporting movements, static stability through the above mentioned mechanisms alone, is insufficient.

DYNAMIC STABILISATION

Humeral Stabilisation

The humeral head is centred and compressed in the glenoid fossa by coordinated actions of the rotator cuff (45). The rotator cuff comprise four muscles (subscapularis, supraspinatus, infraspinatus and teres minor) originating on the scapula and inserting on the humerus, close to the axis of rotation (62). This group work to stabilise the humeral head and as such, are sometimes referred to as the "compressor cuff", as a reflection of that role (36, 38). When compared to the larger muscles acting on the humerus (for example, latissimus dorsi, deltoid and pectoralis major), they have a smaller cross-sectional area, possess smaller moment arms and are very well suited to stability during movement (65). The tendon of the supraspinatus travels through the small space between the acromion and glenoid fossa. The narrow space can make the tendon susceptible to impingement in times of humeral elevation with poor scapula control (43). The supraspinatus tendon merges with the posterior joint capsule, along with the teres minor and infraspinatus tendon (28, 62, 65). Together with the medial deltoid, the supraspinatus create a force couple stabilising humeral head translation (26). Electromyographic (EMG) analysis has shown the supraspinatus to be active as a vital stabiliser and rotator of the humeral head during glenohumeral motion (25). In addition to external rotation of the humerus, the supraspinatus also serves to abduct or elevate the arm (65).

The infraspinatus can assist preventing posterior subluxation through tightening of the posterior capsule (28). The infraspinatus originates inferior to the scapula spine and its tendon “blends” into the joint capsule (65). In conjunction with the teres minor they are dominant external rotators of the humerus and have an essential role in anterior capsule stability (11, 65).

The subscapularis is a multi-pennate, internal rotator, that originates on the anterior surface of the scapula and its tendinous attachment assists anterior capsule reinforcement (28, 62). It is a depressor of the humeral head and important stabiliser (28).

Anatomically, the tendons of the rotator cuff merge with the ligaments of the shoulder capsule at their attachment sites on the humerus. Contraction of the rotator cuff results in enhanced tension in the shoulder capsule complex, increasing...
stability during movement (11, 45). It is believed that stretch receptors located within the ligaments of the capsule facilitate the development of tension, and that injury or repetitive stretch to these ligaments, can reduce the rotator cuff contribution to stability, leading to further injury (45).

**The Scapula**

The anatomy of the scapula, its “wide, thin configuration” permits gliding on the thoracic wall and a large surface area for muscle attachments (36). Healthy positioning and movement of the scapula, particularly during overhead movement, is critical to proper shoulder function. The positioning of the scapula is entirely dependent on the coordinated complex of muscle interactions attached to it since it lacks structural bony articulation (37). Scapula motion is an intricate coordination of three individual motions and two translations (scapular retraction and protraction, and depression and elevation) (5). Motions include upward and downward rotation along a horizontal axis perpendicular to the scapula, anterior and posterior tilt in a plane horizontal to the scapula and internal and external rotation in a vertical axis (39).

The scapula has several roles in shoulder joint performance. Firstly, it provides articulation as a part of the glenohumeral joint. Secondly, the protraction and retraction movements of the scapula along the thoracic wall enable actions like the wind-up and recovery phases of throwing facilitating the utilisation of the stretch-shortening contraction (the tightening of anterior structures during the wind-up phase) or deceleration of the arm during such activities (36). Furthermore, these actions also require the scapular to transfer kinetic energy developed in the lower body and trunk through to the arm and hand (20, 36). The scapular also rotates and elevates to facilitate arm elevation. This movement avoids impingement of the supraspinatus by the acromion and also decreases coracoacromial arch compression (36). Finally, the scapula is a muscle attachment site for the humeral head stabilisers and scapular stabilisers (36).

**Scapula Stabilisation**

The muscles acting on the scapula play a significant role since the position of the scapula is critical to humeral head stability as it affects the mechanical advantage, length tension and angles of force, of the rotator cuff muscles (20, 45, 48). The coordinated movement of the scapula maintains the humeral head localised within the glenoid (36). The rotator cuff muscles that surround and stabilise the humeral head, originate on the scapula (37). Sound scapulothoracic movement places the rotator cuff muscles in the most effective position for glenohumeral compression (40). Through coordinated muscular control, “the most efficient position of the intrinsic muscles of the rotator cuff allow compression into the glenoid socket, thereby enhancing the muscular constraint systems around the shoulder” (36).

The major muscles include the serratus anterior, rhomboids and trapezius muscles, which are involved in controlling scapulothoracic movement. The term “force couples” is used to describe a pair of muscles working to “control the movement or position of a joint (36)”. The force couples acting on the scapula include the upper and lower trapezius and serratus anterior and rhomboids. Different combinations of force and positions of the scapula will result in different movements (30, 36).

The serratus anterior (fig. 4) is solely responsible for maintaining the scapula against the rib cage and is of great importance for optimal shoulder function, particularly in overhead activities (16). In conjunction with trapezius, the serratus anterior assists scapular upward rotation (the upper portion of the trapezius) and abduction (the lower portion of the trapezius) (73). The serratus anterior and lower trapezius also provide a critical inferior stabilising force. It is only with concurrent upward rotation and abduction of the scapula that full humeral elevation can be achieved (73). The resultant force of contraction of the serratus anterior around the acromioclavicular joint pulls the medial border and inferior angle of the scapula onto the thoracic wall (44). Poor serratus anterior control, strength or endurance can often be seen in “winging” (fig. 5) or protrusion of the medial aspect of the scapula (20).

An example of the importance of scapular stability is in the tennis serve where in some serves, it is possible for the feet to be off the ground when shoulder rotation velocity is at its peak. The “entire stable base of the arm, in this situation, rests on the scapula” (36). It is a combination of these dynamic stabilisers, in conjunction with static structures, that produce a compression effect on the humeral head, into the glenoid fossa (65). An injury to any of these structures – dynamic or static – that can result in a loss of this compression and lead to instability (65).
SENSORIMOTOR CONTROL

Riemann and Lephart describe the sensorimotor system as “the sensory, motor, and central integration and processing components involved in maintaining joint homeostasis during bodily movements” (59). Functional joint stability is a complicated relationship between static and dynamic components whose contributions are ever changing dependent upon the nature of the task. Being the most mobile joint in the body, the sensorimotor system at the shoulder coordinates a complex of muscles for stability and performance (28, 53).

Dynamic stability is achieved by the sensorimotor system through activation of the muscles that surround the shoulder joint (53, 60). Mechanoreceptors are located in the capsular ligaments. At mid-range, the lax ligaments do not stimulate the mechanoreceptors. It is only during extreme ranges of motion that mechanoreceptors are activated (52). Muscle spindle activity is adjusted continuously through range providing proprioceptive information regarding joint position sense (52). There exists a relationship between muscle spindles and mechanoreceptors of the tendons and capsular ligaments in the detection of movement and position sense (52). It is speculated that regulation of muscle spindle activity in the muscles surrounding the shoulder joint is the means by which stability is provided. By increasing the muscle activation level, or tone, the muscle-tendon unit becomes “stiffer”. Combined with a shorter reflex latency period, the shoulder is better able to withstand perturbations (53). Golgi tendon organs, located in the tendinous regions of muscle provide a protective reflex mechanisms through relaxation of the antagonist muscle group (52).

The blending of the rotator cuff tendons with the joint capsule is a means of increasing the stability of the joint through increased activation of the rotator cuff developing increased stiffness and stability (53). Efficient sensorimotor control of the rotator cuff muscles achieve a co-contraction increasing capsular tension and produces a resultant compressive force, “centralising the humeral head within the glenoid, minimizing translations of the humeral head” (52, 53).
The joint capsule plays a greater role in joint stability towards the extremes of range, when the fibres “wind up” (fig. 6). At mid-range positions, muscular control plays a more dominant role, and there exists a sensorimotor “reflex arc” between the structures of the capsule and the muscular stabilisers (21). The presence of mechanoreceptors throughout the joint capsule highlights the synergy between the static ligamentous stability of the joint capsule and dynamic stability of surrounding musculature in overall shoulder stability (21). An understanding of the neural component of shoulder stability is important when considering injury prevention and rehabilitation programs.

As previously indicated, the great mobility of the shoulder joint requires several means of determining position. Proprioception comprises afferent neural information such as joint position and forces applied to the joint or within the joint to the sensorimotor system for regulation of dynamic muscular control (53). Injury to the shoulder complex can affect proprioceptive pathways for joint position sense, impairing the intricate dynamic stabilisation (63). The sensorimotor system is affected by injury and pain (53). The sensorimotor system appears to be affected by fatigue and may need to be trained to resist fatigue (53). Restoring proprioceptive function is of great importance during rehabilitation of shoulder injury (53, 63, 77). Increased proprioceptive awareness improves the direct and indirect neural pathways involved in healthy shoulder stability and function (31).

**Figure 6 - Joint capsule “tightening” in humeral external rotation.**

**SHOULDER DYSFUNCTION**

Insufficient upward rotation of the scapula during humeral elevation may result in a “loss of centre of rotation and a change in alignment between the humeral head and the glenoid cavity” (40). This loss of coordination between the scapula and humerus is suggested to result in a decrease in force production by changing the base of support for the muscles attached to the scapula (9).

The serratus anterior and lower trapezius have been linked with shoulder pain and rehabilitation in many studies. The inhibition of the serratus anterior and lower trapezius have been found in throwers with shoulder pain (25). It has been found in subjects with shoulder pain that the lower trapezius will attempt to accommodate for inadequate lower serratus anterior activation (43). The authors of this investigation strongly encouraged focus on the serratus anterior during shoulder rehabilitation. Cools et al. found a lack of serratus anterior force output, indicating decreased strength capacity, on the injured side compared to non-injured side in overhead athletes with shoulder pain (16). “A fatigued serratus anterior muscle will reduce scapular rotation and protraction and allow the humeral head to translate superiorly and anteriorly, transferring stress to anterior restraints and can reduce the acromial space possibly leading to secondary impingement and rotator cuff tears” (19, 25).

Failure of the scapulothoracic muscles, through fatigue, strength imbalance or injury, can result in shoulder impingement. The term “shoulder impingement” is somewhat of a global term encompassing a broad range of impingements – including, internal impingement, coracoid impingement and sub-acromial impingement (31). Impingement pain in diagnosis can be the result of a number of scapulothoracic dysfunctions (38). Impingement can occur in movements that bring the greater tuberosity and coracoacromial arch closer. In this situation, the scapula does not maintain a position that allows sufficient clearance between the tuberosity and the acromion during external rotation and abduction actions (45). Scapular dysfunction associated with this occurrence include increases in the upper trapezius activation, imbalance between the upper and lower trapezius and reduced activity or strength of the serratus anterior (43).

Internal impingement is often seen in the “late cocking stage of pitching” when the arm is abducted and at the extreme of external rotation and may be attributed to scapular instability (31, 61). This injury can manifest as a tightening or stiffness in the early stages and will affect pitching ability. Pushing through this phase will prolong recovery (31). The early stages of primary impingement are often due to acute overload and unlikely to be a result of posterior capsule tightness, however, it is vital to restore any lost range of motion (31, 77).

Secondary impingement is defined as having an underlying instability component. Therefore, the scapulothoracic muscles, and not rotator cuff, are the main target for rehabilitation in this scenario (31). Coracoacromial impingement can also occur due to muscle weakness or inactivity of the rotator cuff muscles sufficiently stabilising the humeral head during elevation through deltoid contraction. The action of the deltoid is made more efficient through coordinated rotator...
cuff activation (55). The treatment guidelines for impingement involve restoring normal range of motion by targeting the flexibility of the posterior capsule and posterior muscles, and strengthening the dynamic stability provided by the rotator cuff muscles (31, 77).

**BIOMECHANICS AND ANATOMY OF THROWING**

To better prepare injury prevention and injury rehabilitation programs for the throwing shoulder, it is important to understand how the shoulder functions during the throwing motion. It is also vital to possess an understanding of the specific adaptations of the throwing shoulder for performance training and rehabilitation purposes.

**Baseball**

An efficient overhead throwing motion in baseball, aims to maximise end-segment velocity through the generation and sequential transfer of force from the legs, pelvis and trunk, through the shoulder (1, 23, 42, 55, 56). At the shoulder, dynamic muscular control and static support from ligaments and capsule structures are required at the extremes of glenohumeral range at extremely high speeds (4, 55). The technique of the baseball pitch has been studied in tremendous depth and for the purpose of this investigation, shall be divided into five phases: wind-up, early cocking, late cocking, acceleration, and follow-through (61).

Throughout the course of the throwing motion, the scapula retracts and protracts to its maximum capacity. In the wind-up phase, the scapula is fully retracted, a process that facilitates the storage of elastic energy in the anterior chest muscles and internal rotators (36, 37). The cocking phase in baseball pitching has been found to account for approximately 80% of the total pitching time (56). During the cocking phase of throwing, the teres minor and infraspinatus are critical to anterior stability, which is supported by EMG studies (11, 33). In professional Major League baseball pitchers, the acceleration phase, the point from maximal external rotation of the shoulder through to ball release can take as little at 50ms – 2% of the entire pitching sequence (56).

During follow-through, the scapula becomes fully protracted, following the thoracic wall to facilitate maximum range for deceleration of the arm (36, 37, 68). During the recovery phase of the throw, the protracting scapula assists deceleration by lengthening the range in which to slow down the arm (36). The deceleration during the follow-through phase has been found to be as high as -500,000 deg/sec/sec at the shoulder and elbow. The posterior shoulder muscles and biceps being active at this time (56). The rotator cuff muscles generate very high forces to resist humeral head distraction, horizontal adduction and internal rotation while decelerating the combination of forces developed by the kinetic chain in overhead throwing (24, 33). As a result, the eccentric capacity of the external rotators is paramount (76). The tensile strength of the rotator cuff can be tested during this time and highlights the importance of rotator cuff strength in the throwing athlete (61). The eccentric capacity of this muscle group may be of great importance, and it has been suggested that testing of this group be done eccentrically rather than concentrically (76).

The long head of the biceps brachii crosses the shoulder joint and originates on the superior aspect of the glenoid labrum and may have a role in glenohumeral compression during the throwing action (24, 25). However, whilst peak bicep brachii activity has been found in the follow through phase of throwing, brachialis demonstrates a similar EMG pattern which suggests contraction of the biceps brachii may be involved in controlling rapid elbow extension (32).

Abduction of the scapula is required to facilitate high levels of horizontal shoulder flexion during the follow through. However, this range and speed of scapula abduction places substantial stress on the muscles attached to the medial border contracting eccentrically to control this motion (55). This phase presents the most risk of injury through the high eccentric loading (33, 55). This demonstrates the requirement for eccentric strength and control of these muscle groups. The serratus anterior activity is observed through all phases of throwing, positioning the scapula against the thoracic wall and providing a stable glenoid (32).

**Baseball Throwing Adaptations**

An effective means of increasing internal rotation velocity, and subsequent hand velocity and ball release, is to accelerate the arm through a greater range of motion. This can be achieved by increasing in the range of external rotation (10). Overhead throwing athletes consistently demonstrate internal and external glenohumeral adaptations in their throwing shoulder, compared to the non-throwing shoulder (17, 50). This range is developed by varying amounts at the glenohumeral and scapulothoracic joints (56). In particular, throwing athletes commonly display glenohumeral internal rotation deficit and external rotation gain (9, 36). Glenohumeral internal rotation deficit (GIRD) is defined by Burkhart as, “the loss in degrees of glenohumeral internal rotation of the throwing shoulder compared with the non-throwing shoulder” (10). Theoretically, a normal shoulder should possess 90 degrees of internal rotation and external rotation for a total of 180 degrees, or an equal range on both arms (77). An athlete is considered to have GIRD when they display a 25 degree difference between shoulders (10). Contributing theories for the development of GIRD include alterations in the static and dynamic structures from repeated micro trauma (4), tightening of the posterior joint capsule (10) and adaptive changes to the bony structures of the joint (17). The loss in internal rotation range is viewed as critical determinant in injury risk (10). Internal rotation range can change in as little as 12 weeks of competition, highlighting the need for constant monitoring (67). Athletes with GIRD are at greater risk of injury. It has been found that the level of GIRD increases with the level of competition and preventative measures, such as monitoring throwing volume, continual
assessment of glenohumeral rotation range, specific posterior shoulder flexibility regimes and strengthening exercises of the scapular retractors and depressors, should be incorporated in development level programs to prevent GIRD (68).

Significant differences have been found between the rotation range in baseball pitchers as opposed to field players (35). The “total motion concept” by Wilk is the passive range of external and internal rotation added together (77). Unpublished data by Wilk and Arrigo assessed the shoulder range of over 300 professional baseball players discovered that the total motion between throwing and non-throwing shoulder was within 5 degrees, however, external rotation was greater on the throwing shoulder and internal rotation greater on the non-throwing shoulder (77). In particular, pitchers demonstrate a significant difference in their throwing arm compared to the throwing arm of non-pitchers. Pitchers have been shown to exhibit greater external rotation at 90deg of abduction than non-pitchers (35).

This agrees with the findings of Crockett et al (17) who noted that the “total motion was the same in both glenohumeral joints (throwing and non-throwing). The authors suggested, “that the arc of motion, while the same value for each shoulder, was further externally rotated or “spun back” on the dominant side”. Humeral head retroversion allows for more external rotation of the humerus to be achieved before the range is constrained by the anterior capsule (17). The authors in this study commented that the increase in humeral head retroversion in throwing shoulders may be a developmental process, a process subject to adaptation perhaps during years of throwing during adolescence when bone maturation is still occurring (17).

Throwers with internal impingement demonstrate significantly increased posterior tightness and GIRD in, compared to asymptomatic throwers (50). Tightness in the posterior shoulder is believed to be a specific adaptation to throwing, a response to the volume of forces acting on the posterior structures during follow-through (10). Posterior capsule tightness is a common cause of impingement, especially during combined abduction and external rotation movements. The stiff posterior capsule alters the biomechanics of the glenohumeral joint, shifting the humeral head upwards, towards the acromion during shoulder flexion (50). Horizontal shoulder flexion during the deceleration phase of throwing may be compromised by posterior capsule tightness. Reduced range can overload the posterior structures as less range is available for deceleration, increasing the force requirements (55). A loss of glenohumeral range may result in compensation by increased lateral movement of the scapula and increased stress on medial scapular stabilisers (55).

The internal rotators can become overdeveloped as a result of the throwing action creating a muscle imbalance favouring internal rotation. This may predispose the shoulder to injury via an inability of the rotator cuff to stabilise the humeral head in the glenoid. Isokinetic testing of the rotator cuff ratio in high school and professional Major League baseball players was found to favour internal rotation (49, 76). Ratios of 53% to 65% have been reported in the literature (76). Increasing the concentric external:internal rotation ratios to approximately 80% has been suggested as a target beneficial in glenohumeral stability (49).

![Figure 7 - The total motion concept (from Wilk, et al., 2002).](image)

**Figure 7 - The total motion concept (from Wilk, et al., 2002).**

**Technique Assessment**

Due to the high volume of throwing in most overhead throwing sports, it is imperative that athletes demonstrate sound technique to minimise injury risk. As discussed, there are very high forces and velocities involved at the end of the kinetic chain that can result in injury. Several studies have investigated the overhead throw.

In a study by Aguinaldo et al (1) it was discovered that there were less shoulder rotational demands on baseball pitchers with late trunk rotation compared to pitchers with early trunk rotation. This suggests that improved technique and transfer of forces can reduce shoulder stress. This finding was supported in a later study by Davis et al (18). In an assessment of five key points of technique in adolescent and youth baseball pitching this study found that correct performance of two major points – the hand-on top position and the closed-shoulder position (fig. 8) – resulted in less humeral internal rotation torque. The closed shoulder position being an indication of late trunk rotation. Early, high positioning of the arm during the throwing sequence was also deemed to be a critical technical element. By placing the arm high early, prior to trunk rotation, stabilisation of the scapula can occur and subsequent efficient energy transfer (18). Assessing these key elements of overhead throwing can assist coaches to intervene in problematic throwers, or these cues can be incorporated in throwing rehabilitation.
The repetitive technical nature of throwing makes assessment and intervention successful. In an investigation on Major League baseball pitchers, Pappas discovered high consistency in individual pitcher delivery and a strong similarity in pitching technique among subjects. This assists with technique assessment as deviations from previous technique, or proven normal motor patterns will assist with injury rehabilitation and further injury prevention (55, 56). Therefore, throwing technique analysis has a role to play in prevention and rehabilitation of throwing related shoulder injuries.

Figure 8 - The two key major technical elements of overhand throwing (from Davis, et al. 2009).

**Waterpolo**

Despite its similarity to other throwing sports, the combination of throwing and swimming presents a unique situation for the shoulder. The water polo athlete is unable to utilise lower body and trunk sequential force development for the generation of ball velocity, like a land based thrower, due to their position in the water (12, 75). Additionally, the water polo ball is larger, both in circumference and mass compared to a baseball and this combination (lack of leg contribution and larger ball) relies more heavily on the shoulder for force development (78). Whilst there is a lesser contribution from the kinetic chain, due to the nature of the sport, players do often not have time for appropriate force transfer and rely even more on shoulder force alone (12, 46, 75, 78). Furthermore, tactical throwing may involve baulking which may reduce the contribution of the stretch shorten cycle, seen in the cocking phase of land based throwing, to the impending throw, increasing the force generation requirement of the shoulder. The release velocity of the ball in water polo is between 15 to 20 m/s. The ball release velocity in a penalty throw is between 13.7 and 18.9m/s (22). Much slower than the 30 to 36 m/s recorded in baseball (22).

In a comprehensive biomechanical analysis of the penalty throw, Feltner and Taylor found two basic styles of throw: the overhand (OH) technique and the sweep (SW) technique (22). The OH technique displays a high arm position and a larger contribution of glenohumeral internal rotation to generate ball velocity, whereas the SW technique uses more horizontal adduction (pectoralis major) of the arm and less internal rotation (22). In this investigation, significant positive correlations between anthropometry and internal rotation contribution to ball speed were identified, suggesting muscular strength may influence throwing style (22). The OH technique requires more strength than the SW technique. This finding has implications for training and injury prevention, as weaker players attempting OH throwing may be overloading connective structures leading to injury. Furthermore, from a tactical viewpoint, a lack of strength will also limit throwing variety making them more predictable. Additionally, the SW throw, requiring less force development may reduce an athlete’s risk of injury. Coaches must ensure the development of adequate levels of strength for players required to throw overhead (22).

Injury can occur when scapulothoracic function is lost. During the swimming motion, the serratus anterior is active from the catch through the pull (34). This indicates a high involvement and potential source of fatigue, that when combined with scapular control in high velocity throwing, may be a cause of injury in water polo players. This suggests that high strength and endurance of the serratus anterior may be of benefit to the water polo player (34). Poor technique during swimming may also result in shoulder injuries and water polo players should be assessed to ensure technical proficiency (34). In a comprehensive literature review, Webster concluded that shoulder pain in water polo is multifactorial – increased shoulder mobility, rotator cuff imbalance and throwing volume in the water, were contributors (74).
Water Polo Throwing Adaptations

Like baseball pitchers, water polo players also exhibit significantly greater glenohumeral external rotation in their throwing shoulder compared to the non-throwing shoulder. This increased range allows a greater throwing range of motion (78). Whilst swimmers exhibit symmetrical changes in glenohumeral rotation due to the bilateral nature of swimming, studies in water polo have found asymmetrical differences which can be attributed to the presence of a dominant side for throwing (78). Changes to the range of motion from the osseous humeral retroversion seen in youth baseball players is hypothesized to be unlikely in water polo. This is believed to be due to the later age of introduction to the sport (as compared to baseball), the decreased volume and intensity of throwing and the general strength adaptation that comes with gaining the necessary competence required in swimming prior to participation in structured water polo (78). The increased external rotation adaptation in water polo is more likely due to changes in soft tissue (78). This increased laxity has implications for strength training prescription, being mindful of loading in extreme ranges.

Isokinetic testing has revealed similar internal:external rotation imbalances between baseball pitchers and water polo players (46). Further analysis has shown that water polo players have weaker shoulder abduction (ie. a lateral raise action) compared to addition strength compared to control subjects (46). This strength dominance of adduction is required for the swimming motion and also for the acceleration phase of throwing (12). These imbalances have not been as thoroughly investigated in water polo as in baseball, yet in baseball pitching, these results serve as indicators for injury risk (46, 78). Due to the soft tissue changes in water polo, injury prevention programs focusing on improving rotator cuff balance and abductor strength has been recommended (46).

With regard to scapular posture, Witwer and Sauers (78) were unable to find any significance bilateral difference in scapular upward rotation or posterior shoulder tightness. The authors suggested the lack of upward rotation may be due to the presence of increased glenohumeral laxity possibly associated with long-term swimming. However, the authors noted that the subjects in this particular investigation were asymptomatic.

REHABILITATION

Rehabilitation Overview

Due to the complex relationships at the glenohumeral and scapulothoracic joints, it is not the intention to present a specific rehabilitation program. Rather, the focus of this section will be to present findings from research on the principles and guidelines for successful shoulder rehabilitation and the merit of investigated interventions.

Healthy shoulder function is an intricate process and the complexity of injury can make rehabilitation difficult if poorly diagnosed (38). The identification of the root of scapulothoracic dysfunction is critical for accurate prescription, yet very difficult due to the lack of accuracy of some shoulder assessment protocols (27, 41). Given the intricate functional anatomy, accurate diagnosis is best achieved by specialists.

The high forces and repetition of overhead throwing, such as in baseball pitching or water polo, results in microscopic trauma that can test the threshold of anatomical structures responsible for shoulder health (55, 61, 77). The complex relationships that exists in the healthy shoulder can be disrupted by changes in throwing technique, changes in equipment, fatigue from overtraining and muscle weaknesses or imbalances (38, 77). Alterations to strength and muscle activation patterns can result in injury and must be restored (16, 25). Due to the complexity of interactions between structures involved in healthy shoulder function, the rehabilitation of shoulder injury must be thorough and meticulous, addressing the workings of the entire shoulder girdle, not just the injured area (31, 69). The ability of the shoulder to achieve movement and position, whilst possessing the stability to transfer force is a complex process achieved by coordinated muscle activity. Therefore, it is imperative that proper muscular activity be the goal of shoulder rehabilitation (38, 39). Decreased muscle activity or poor muscular coordination must be corrected in rehabilitation (25). Progressive rehabilitation goals for the throwing athlete should include the restoration of normal passive and dynamic range, correct motor patterning and stabilisation, improving muscle balance, increasing muscular strength and endurance of scapular and humeral stabilisers and finally, a return to throwing (55, 61). Exercise protocols to restore and enhance scapulothoracic stability is essential for the dynamic control of the shoulder complex (28).

Kibler has described several principles guiding shoulder rehabilitation: accurate diagnosis, pain management, kinetic chain training, scapular stabilisation, restoration of abduction, closed chain exercises, plyometrics, and rotator cuff training (38). The first stage of a successful rehabilitation is accurate diagnosis. It is suggested that diagnosis and rehabilitation commence with the scapula and progress to the rotator cuff only when health scapulothoracic function is achieved (20).

The complex coordination of force is made possible by sound scapulothoracic and glenohumeral motion allow optimum joint positions and muscle lengths. Restoring glenohumeral and scapulothoracic range is critical in early rehabilitation to allowing stabilising muscles to work in their anatomically correct range and is the first stage of shoulder rehabilitation (36, 55). Improving strength prior to improving range can strengthen poor movement patterns. The scapula is the base of all shoulder movements and is commonly compromised by poor activation patterns. The restoration of scapular stabilisation is a crucial aspect of shoulder rehabilitation.
Rehabilitation – Early Stages

Early stages of rehabilitation should focus on activating the muscles involved in controlling scapular position whilst minimising pain and glenohumeral shear, forming the foundation for more advanced protocols (39). Stability exercises form the first stage of rehabilitation, followed by closed- and then open-chain exercises (36). Closed-kinetic chain (CKC) exercises, defined as “activity that occurs about a distally fixed segment” are incorporated into shoulder rehabilitation (71).

During the early stages of rehabilitation, training pain free is critical since glenohumeral function can compromised in the presence of pain (38). Shoulder pain can have a negative, inhibitory effect on muscle activation patterns (3, 20). It is therefore critical that in the early stages of shoulder rehabilitation, the restoration of scapulohumeral kinematics through exercise remains pain free. To reduce pain during early rehabilitation, patients should avoid painful movements, have adequate rest, practice cryotherapy and medication as appropriately prescribed (38). Resistance exercises should be introduced to pain-free motion (29).

CKC scapular exercises allow for the retracting of scapular stabilisation patterns while allowing protection for repairing tissue (8). Scapular movement is paramount to a functional shoulder joint and achieving many upper limb positions. EMG investigations have demonstrated the control of the upper, lower and middle trapezius, levator scapula, rhomboids and serratus anterior, during movements of the upper arm (15, 39, 48). These muscle groups allow positioning of the scapula in order to maintain the correct length tension and line of pull of the rotator cuff muscles to maintain the humeral head-glenoid fossa alignment (36). Rehabilitation can commence with exercises that place the glenohumeral joint in a position of minimal impingement and shear, and promote lower trapezius and serratus anterior activation through isometric contraction (28, 39). These arm positions also minimise upper trapezius involvement. Since muscle strength imbalance or increased activation of the upper trapezius has been shown to be a common quality of shoulder joint injury, exercises that reduce upper trapezius involvement should be favoured during the early stages of rehabilitation (14, 39).

An investigation conducted on professional baseball players, found that those with a lower trapezius strength deficit demonstrated an inability to properly upwardly rotate the scapula during overhead movements (40). This is a significant finding as previous investigations have found relationships between inappropriate scapula kinetics and injury (9, 43). The findings also demonstrate the presence of lower trapezius inadequacies in high level overhead throwing athletes (40). These findings support earlier investigations which found significant EMG activity ratios between upper, middle and lower trapezius between injured and non-injured sides (14). The lower trapezius is a prominent scapular stabiliser in movements above 90 degrees of shoulder abduction (3, 30). These findings highlight the importance of restoring lower trapezius strength during shoulder rehabilitation. Strength and conditioning professionals working with overhead throwing athletes should endeavour to assess and monitor lower trapezius function for healthy glenohumeral mechanics.

Stretching of the posterior capsule is important to maintain or increase internal rotation, an important requirement for the deceleration phase of throwing (17). Burkhart et al. believe that stretching of the posterior capsule will can reduce GIRD to an acceptable level (10). Measurement of posterior tightness in this context is indirectly through the internal/external rotation range GIRD assessment. As internal rotation range has been shown to change in a short period of time, monitoring of this quality during rehabilitation, and when injury free, would be a prudent practice (67). GIRD can be assessed through passive and active range with a goniometer in supine (supports scapular stabilisation) and standing (more functional position for throwing) positions (64). However, while there are several methods to assess shoulder range of motion, they present with limitations in reliability or lack of association to pathology, and the Strength and Conditioning professional should be aware of this when assessing (6, 7, 51).

Early stages of rehabilitation should include exercises that assist with technical elements of the chosen sport to assist with the maintenance and possible retraining of the kinetic chain. Since many sporting actions of throwing or hitting involve the fluid transfer of kinetic energy, they should be included at levels appropriate for the healing shoulder joint (38). They may also include overcoming limitations in hip and trunk flexibility and strength which may have resulted in accommodating, yet destructive, techniques at the shoulder. Compensatory flexibility, to overcome a loss of flexibility in another area, will interfere with the normal sequence of movement and can contribute to injury (55). For example, tightness in the hip external rotators of baseball pitchers has been linked to shoulder injuries, given the total body contribution to throwing (55).

As a guideline for rehabilitation, Kibler encourages achievement of 90 degrees abduction as an early stage goal (38). This is based on the principle that it allows activation of scapulothoracic glenohumeral motor patterns similar to throwing (which requires abduction up to 110 degrees on average), without compromising acromial elevation and undue ligamentous stress (38). Due to the interaction of moment arms and the length-tension relationship, the mechanical efficiency of the external rotators, the teres minor and infraspinatus, in 90 degrees of abduction, is greatest between the neutral and final position (69). It is through this range that early strengthening of these muscles is recommended due to the lower loading.
Rehabilitation – Advanced Stages
Co-contractions and force couples can be appropriately developed through CKC exercises. Research has shown that CKC exercises improve proprioception and muscular control of the glenohumeral joint (28, 63). Early stage CKC exercises should commence below 90 degrees of abduction, are focussed on scapular stabilisation over movement, and progressed as appropriate. Kibler stresses the importance of CKC exercises against a fixed resistance (eg. A wall or table) before moving to moveable objects (e.g. Swiss ball) (36, 38). From an open-chain perspective, the combination of moment arms and the length-tension relationship, create a mechanical efficiency of the external rotators, the teres minor and infraspinatus, at 90 degrees of abduction (69). Several studies encourage the re-training of rotator cuff muscles in CKC exercises. As this muscle group acts to stabilise the humeral head as a group, not as an individual muscle, isolated exercises are given only to train deficient muscles (28, 38). Kibler suggests that increased clinical shoulder symptoms resulting from isolated rotator cuff training may indicate kinetic chain weaknesses and that the scapular stabilisers should be further investigated (38). During the advanced stages of rehabilitation, the progression of greater loading and dynamic movements is recommended to improve performance (29).

Three sessions per week, for 5 weeks has been demonstrated to significantly improve shoulder strength. Padua et al (54) found greater improvements in shoulder rotation strength using open-kinetic chain exercises compared to CKC. The changes in a 5 week program are likely to be of a neural adaptation, as the time frame is generally perceived as too short for hypertrophy. Rogol et al (63) demonstrated significant improvements in shoulder joint position awareness after a 6 week strengthening program comprised of either push-ups (CKC exercise) or supine DB press (DB Bench Press) (open kinetic chain exercise). This finding supports the use of resistance style exercises as a means to improve proprioceptive responses in the shoulder.

Proprioception is an important aspect of shoulder rehabilitation (28). A consideration in the re-training of proprioception is the contribution from the different types of receptors depending on the joint position. In the mid-range of motion, joint tension changes less compared to muscle length, thus the muscle spindles and Golgi tendon organs are more stimulated than capsular receptors. In end-range movement, there are larger changes in joint capsule tension affecting the joint proprioceptive receptors (Pacinin corpuscles and Ruffini end-organs) more than contractile receptors (63). These differing mechanisms of proprioception are important to understand during the rehabilitation process in order to ensure adequate stimulus and adaptation of the previously injured, or underperforming proprioceptive pathway (63). Proprioceptive neuromuscular facilitation (PNF) stretching is an effective technique recommended to increase range in the rehabilitation of the throwing shoulder (55).

Throwing is a high velocity action involving powerful stretch shortening activities. Plyometric training is an important end-stage rehabilitation phase, when healing of damaged tissue is complete. Of particular importance in upper body plyometric exercise for the shoulder is the proprioceptive requirements and fine tuning of muscle activation patterns (38). In the early stages, concentric and eccentric contractions should be balanced, but near the end stages, emphasis should shift to eccentric (29).

Rehabilitation – Literature Exercise Recommendations
The use of rubber resistance is common in shoulder rehabilitation. The advantage over free weights is the ability for the orientation of the resistance to be readily aligned to any angle, and the small, progressive increments available by changing the stretch length of rubber (29). Additionally, the focus of early resistance programming is neuromuscular adaptation and timing rather than force production (44). During the advanced stages of rehabilitation, the progression of greater loading and dynamic movements is recommended to improve performance (28, 29). Improving throwing technique is an important factor in end stage rehabilitation (25).

The trapezius muscle also demonstrates task-specific recruitment. The upper trapezius and lower trapezius are recruited earlier in open kinetic chain exercises compared to CKC. It is common for athletes with shoulder symptoms to be overactive in their upper trapezius. In these instances, open kinetic chain exercises should be withheld until later stages of rehabilitation (39). The timing of activation of a muscle can be manipulated by the choice of exercise. For example, in an investigation by Kibler et al (39), the on-set of serratus anterior activation was earlier in exercises starting in a retracted scapula position, compared to exercises starting in a protracted scapula position. Whilst the magnitude of...
contraction was the same, the timing was different. This may be of benefit during the early stages of rehabilitation due to pain and limitations of range.

The upper and lower trapezius are both retractors and rotators of the scapular. Moseley et al (48), through the use of EMG, was able to show isolation of the lower trapezius in elevation of the arm in the sagital plane. In this movement, it upwardly rotated the scapula. This may be of benefit in athletes with a poor lower to upper trapezius strength or activation imbalance. Since muscle strength imbalance or increased activation of the upper trapezius has been shown to be a common quality of shoulder joint injury, exercises that reduce upper trapezius involvement should be favoured during the early stages of rehabilitation (39).

The position of the shoulder during the "Inferior Glide" exercise (fig 11.) produces shoulder forces that helps widen the subacromial space, which in turn, may reduce impingement pain (39). To perform this exercise, the subject is required to concentrate on isometric arm adduction and scapular depression for up to five seconds per repetition. As a guideline during early stages of rehabilitation, subjects can perform one to three sets of six to eight repetitions. In the absence of pain, subjects may be able to activate muscle recruitment patterns that may alleviate impingement (39). This exercise depresses and retracts the scapula through contractions of the serratus anterior and lower trapezius.

The scaption exercise, (fig 12.) requires substantial activation of the upper and lower trapezius, levator scapula, rhomboids and serratus anterior (48). Due to the high activation of muscle involved, this exercise has been endorsed as a core exercise in shoulder rehabilitation (48). During scaption, the humeral head is well stabilised in the glenoid and there is no impingement of the rotator cuff under the coracoacromial arch. Moseley et al (48), through the use of EMG, investigated the activation intensity and range of activation of scapular retractors in a battery of common scapular rehabilitation exercises. The authors recommended early rehabilitation programs include the combination of scaption, rowing, push up with a plus (fig 13.) and the press-up. The "plus" component of the push up with a plus exercise, is an exaggerated scapular protraction movement. This movement was ranked higher than a standard push up by EMG analysis (48).
Scaption in a side lying position, with shoulder flexion in the horizontal plane was suggested by Cools et al as an exercise with a low upper trapezius:lower trapezius ratio (15). By side lying, it is hypothesised that the postural recruitment of the upper trapezius is minimised by eliminating gravity. This exercise can be performed isometrically at various ranges of shoulder flexion. Furthermore, when performed standing, forward flexion of the shoulder produces high upper trapezius EMG values, excessive by rehabilitation standards for patients with upper trapezius activity (15). An exercise with similar upper trapezius involvement is the prone extension. When performed standing, the upper trapezius is activated posturally due to gravity. When performed prone the ratio is beneficial and also has a high middle trapezius involvement (15).

Townsend et al (70) investigated the EMG activity of muscle acting on the humerus. In this investigation, the authors concluded that a combination of scaption in internal rotation, flexion, horizontal abduction and the press-up, be core exercises for glenohumeral muscle rehabilitation based on their EMG activity.

Exercises with a higher force production, that emphasize scapular rotation and protraction, are the “Push-up Plus” or the “Serratus Anterior Punch” (or “Forward Punch” – fig 14.), have been found to produce high levels of serratus anterior activity by EMG (19, 29, 48, 71). The Push-up Plus exercise can be quite stressful if integrated too early. Simple progressions involve being performed supine with a dumbbell in the hand, the bench assisting stabilisation of the scapula, to being performed against a wall, to a bench then to the floor (8, 44).

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Research has also identified movements such as the isometric “Low Row” exercise (fig 15.) as a positive exercise in the early stages of shoulder joint rehabilitation due to the favourable serratus anterior to upper trapezius ratio. The Low Row demonstrates high serratus anterior activity and low upper trapezius activity, making the exercise a beneficial exercise in early stages (39). Caution should be taken when prescribing rowing style activities with injuries to subscapularis, as it has been demonstrated to be active in rowing exercises with internally rotated grips (29).

The “Lawnmower” exercise (fig 16., similar to a DB Row – fig 17.) has been found to recruit the upper and lower trapezius and serratus anterior to similar levels (39). This exercise has been suggested as an appropriate intermediate exercise for rehabilitation, once healing and joint range are restored. The lower trapezius was found to be particularly well recruited in this exercise (39).
The “Empty-can” raise for supraspinatus strengthening should be prescribed with care. In order to perform the exercise correctly, the humerus must be internally rotated, which can lead to scapular internal rotation and anterior tipping. These two accommodating movements decrease the subacromial space and are associated with impingement. Research has suggested that the “Full-can” raise may be a more suitable alternative based on the lack of scapular movement and EMG comparison (57, 66).

Early return to throw strategies include Mirror Throwing, where the athlete mimics their throwing action standing in front of a mirror. This allows the athlete to be mindful of each phase of the throwing action and can help re-train crucial aspects of their action. Returning from a long rehabilitation period following injury, it is likely that the athlete has developed inappropriate patterns to avoid pain in the later stages of injury which require retraining (55). Of particular significance during this exercise is the concentration on the deceleration phase and the improved awareness of the eccentric control of scapulothoracic movements necessary for safe deceleration (55).

PRACTICAL APPLICATIONS AND STRATEGIES TO IMPROVE THROWING PERFORMANCE

- Success in overhand throwing is a combination of many elements, with technical proficiency being a critical component. A study by Davis et al (18) provides a starting point for simple, overhead throwing assessment, that can be easily implemented (or modified, for cricket for example) on large groups of land-based throwers and provide immediate teaching cues demonstrated to reduce shoulder loading. Elite level throwers demonstrate high levels of consistency in their technical execution.
- Understanding the kinetic transfer involved in throwing highlights the importance of lower body and trunk strength and endurance in throwing. As well as appropriate timing, throwers should endeavour to strengthen the entire kinetic chain, not just the shoulder.
- Shoulder injury can develop from a lack of shoulder maintenance. Monitoring shoulder internal and external rotation range, stretching of the posterior capsule and not throwing through pain are regular injury prevention tasks for the advanced thrower.
- Managing throwing volume in both the developing and advanced level athlete is also important.
- Injury prevention programs require an understanding of the biomechanical principles of throwing and methods to improve the ability to stabilise the scapular during high levels of deceleration should be included.

CONCLUSION

The most mobile joint in the body is stabilised by a complex coordination of static and dynamic restraints. The large humeral head is restrained within the shallow glenoid fossa during athletic activities by several mechanisms that include the ligaments of the joint capsule, intraarticular pressure and the compressive actions of the rotator cuff. The rotator cuff group originate on the scapular and maintain effective moment arm forces through synchronized scapular movement.
Force couples provided by the major muscle groups, serratus anterior and lower and upper trapezius are responsible for scapula positioning. Their coordinated actions are regulated by the sensorimotor system. Fatigue, weakness or poor activation patterns in these muscles can alter the scapular positioning leading to shoulder pain.

The objective of throwing is to maximise ball velocity through full body kinetic energy transfer. The speed of humeral rotation in the throwing motion places high demands on the connective tissues of the shoulder. With time, specific adaptations can occur for performance enhancement permitting faster ball release velocities. Throwers develop muscle strength imbalances favouring internal rotation strength. Baseball pitchers develop bony structural changes to the humerus facilitating greater external rotation. Increased tightness of the posterior shoulder structures is an adaption response to the high forces of deceleration. Water polo players are likely to demonstrate greater laxity in soft tissue structures to achieve their shoulder range of motion. The lack of lower body involvement and ball dimensions require a greater contribution of shoulder force development. However, the adaptations in the shoulder can be inherently disadvantageous and if not monitored can result in overuse injuries.

Strength and conditioning coaches should have an understanding of the specific adaptations developed in the throwing shoulder and incorporate individual specific strategies to optimise shoulder functioning while throwing. Injury prevention strategies include monitoring the range of internal and external rotation, stretching of the posterior shoulder, maintaining scapular stability through increased emphasis on serratus anterior and lower trapezius strength and being aware of increases in throwing and/or swimming volume. Rehabilitation practices require minimising pain during early stages, retraining and strengthening of the scapular stabilisers, improving posterior shoulder flexion and eccentric strength of the external rotators and scapular stabilisers. End stage rehabilitation incorporates throwing technique retraining.

REFERENCES
