Shoulder anatomy, biomechanics and rehabilitation considerations for the whitewater slalom athlete: Part I

Kristinn I. Heinrichs, M.Ed., P.T., A.T.,C., C.S.C.S.
U.S. Canoe and Kayak Team
Charlottesville, Virginia

Canoe and kayak slalom at its highest level demands a combination of power and flexibility, as well as boat handling and water reading skills. While direct traumatic injuries occur occasionally, most injuries are due to the use of improper biomechanics or repeated overloading of the muscle-tendon unit. Wrist problems have been noted to be the most frequent injury to the flatwater athlete (39), but the shoulder has been observed by the author over the past three competitive seasons to be the most vulnerable and most frequently injured structure in slalom canoe and kayak athletes.

This article will deal with shoulder anatomy, biomechanics, injury mechanisms and rehabilitation for the elite whitewater slalom athlete. Certain pathologies demand that modifications be made in the conditioning program, the stroke technique or the equipment used to protect the vulnerable shoulder structures and return an athlete to the highest levels of competition.

Correct diagnosis of the shoulder pathology maximizes the benefit of any rehabilitation program. Shoulder dysfunction ican be caused by underlying ligamentous instability, overuse or impingement sydromes, bursitis and muscular imbalance or weakness. Each problem requires a different emphasis during rehabilitation and subsequent conditioning programs; a correct diagnosis will facilitate appropriate program design.

Whitewater slalom competition takes place on a 600-meter course with 25 gates. The 10 upstream gates require the athlete to drop below the gate and approach it against the current. The athlete's head, shoulder and torso must pass between the gate's poles. Touching a pole results in a five-second penalty, while a missed gate results in a 50-second penalty added to the elapsed time of the run. Each racer has two runs, and the best time (including penalties) is taken as the best score. Speed and precision are equally important in this sport. To be fast and clean is the goal of each racer, because a hundredth of a second could decide the final rankings in a competition.

There are significant differences between the canoe (singles, C1, or doubles, C2) and kayak (one-woman kayak, K1W, or one-man kayak, K1M) in structure and design, the athlete's position in the boat and the paddles used. In C1 and C2 the athlete uses a single-bladed paddle and kneels in the boat, whereas the kayak athlete uses a double-bladed paddle and sits with both legs fully extended. Injuries to these athletes will be different, so different stroke technique or equipment modifications, and a slightly different emphasis in the conditioning program, may need to be made.

Event times for K1M athletes at the international level of competition range from 150 to 200 seconds. K1W times fall in the range of 110 percent of K1M times for the same course; C1 and C2 times generally are within 105 to 110 percent, respectively (9). The longer the course, the greater the disparity between canoe and kayak

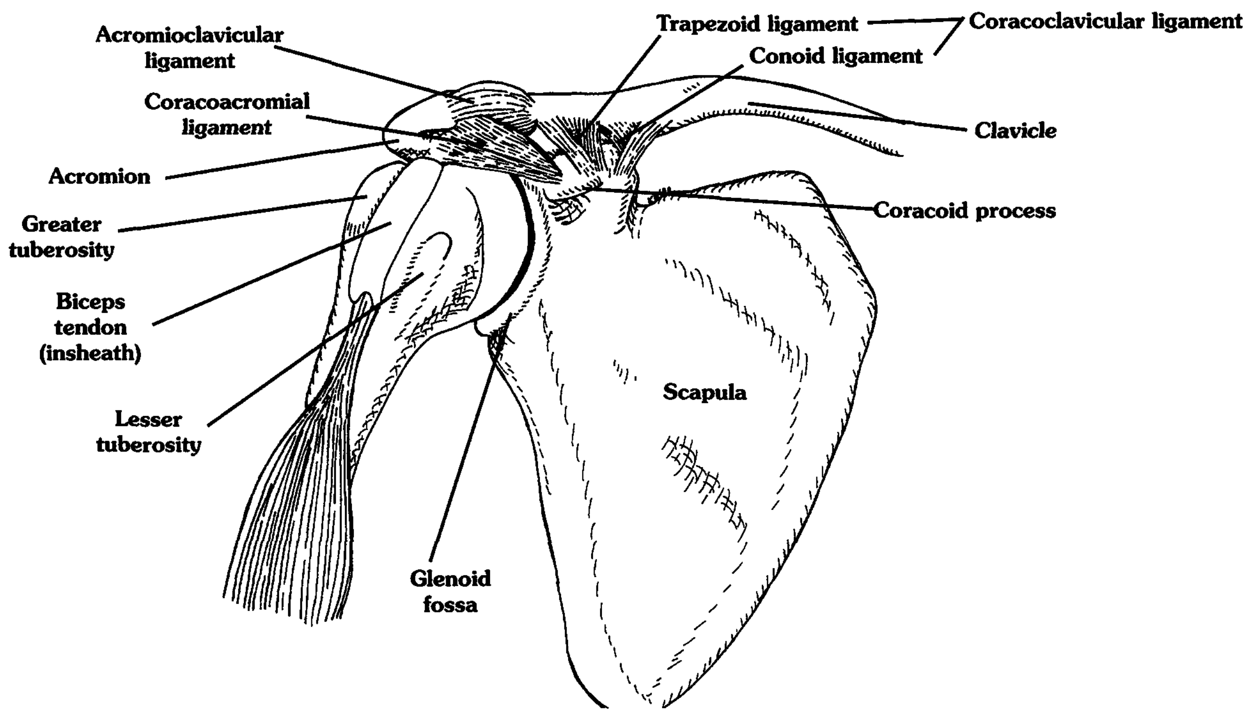

Figure 1. Surface anatomy and ligamentous structures of the anterior aspect of the shoulder. The long head of the biceps is intracapsular as it originates from the supraglenoid tubercle and glenoid labrum. It turns sharply as it passes over the humeral head to descend in the bicepsital groove.

actual times. In addition, the times are influenced by the water type and are closer together in courses comprised of heavy whitewater. Thus, the percentage method of ranking times using the K1M race time normalizes the performance and allows comparisons between boat classes.

Kayak times are faster than canoe times for three reasons: the boat demonstrates a faster hull speed; the double-bladed paddle allows for twice the turnover speed, although leverage in the power phase is reduced; and each stroke is counterbalanced, eliminating the need for correction strokes to keep the boat on course.

The slalom athlete's skill in selecting the correct approach line and placing the boat in the correct position on the wave at the correct instant is at least as important as absolute strength and power. In certain situations, no athlete is more powerful than the current. Strength is not a factor when the athlete must position the boat correctly using boat and edge control (much like a surfer) to move across the river without falling downstream. When the boat moves with the current, however, power becomes an important factor. In navigating upstream gates, the athlete stops and reverses direction sharply in a calm section of water. In this situation, the more force applied to the paddle, the more boat speed is affected.

Anatomy and Biomechanics

Passive stability of the shoulder joint is provided by a number of fibrous tissue structures including the glenoid labrum, joint capsule, glenohumeral ligaments, coracohumeral ligament and the subscapularis tendon (31) (**Figures 1** and **2**). The shoulder complex is composed of the glenohumeral, acromioclavicular, sternoclavicular and functional scapulothoracic joints. Passive mobility (i.e., synchronous movement of the scapula and humerus throughout arm elevation), flexibility, joint stability and muscular control are primary concerns for the prevention of shoulder injuries. Slalom strokes demand rapid force production as well as rapid changes in direction of the forces that are centered in the shoulder joint.

Most shoulder motion occurs at the glenohumeral joint. The head of the humerus articulates with the glenoid fossa of the scapula. Due to the difference in surface area, only one-third of the humeral head articulates with the glenoid fossa at any time. The glenoid labrum, a ring of dense fibrocartilage that is firmly attached to the glenoid margins, increases the surface area available for contact with the humeral head to 75 percent (33, 34).

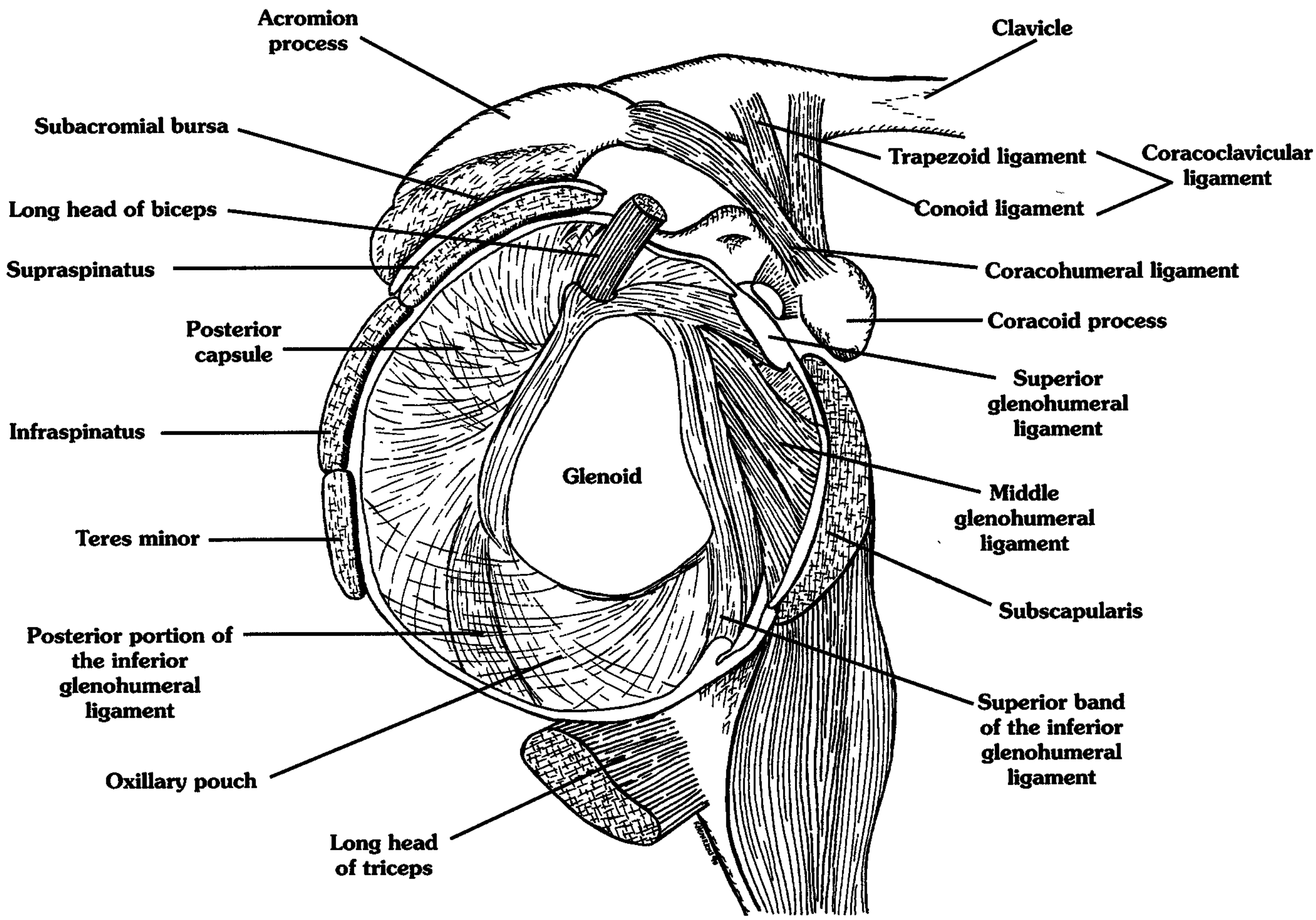

Figure 2. Lateral view of the glenohumeral joint showing the glenoid labrum, capsule, and ligamentous and muscular structures. Not shown are the subscapularis and subcoracoid bursae, which are located on the anterior aspect of the joint between the subscapularis muscle and the coracoid process and the coracoacromial ligament.

The glenoid surface of the labrum is made of hyaline cartilage, while the fibrous portion of the labrum blends with the joint capsule (6) (**Figure 2**). In addition, the wedge-shaped glenoid labrum restricts anterior and posterior movement of the humerus.

The long head of the biceps is attached to the superior glenoid labrum and the supraglenoid tubercle of the scapula. Tension in the biceps tendon, resulting from internal or external shoulder rotation, also will place tension on portions of the glenoid labrum (7). Internal shoulder rotation, occurring in the top arm during completion of a duffek stroke or the follow-through phase of a pitch, will stress the posterior superior portion of the glenoid labrum. Passive external shoulder rotation, occurring in the bottom arm of a duffek stroke or brace position, will stress the anterior superior portion.

A degree of capsular laxity (movement between joint surfaces) exists due to the attachments and redundancies of the joint capsule, but the arm position selectively tightens the capsule. When the arm is at the side, the superior portion of the capsule is taut and the inferior portion is folded. When the arm is overhead, the inferior portion of the capsule tightens and laxity is demonstrated in the superior portion. External rotation tightens the anterior capsule, while full horizontal adduction tightens the posterior capsule (**Figure 2**).

Glenohumeral capsular ligaments (superior, middle and inferior) stabilize the anterior and inferior shoulder joint capsule (**Figure 3**). The superior glenohumeral ligament stabilizes the shoulder when the arm is adducted at the side, and originates with the biceps tendon from the coracoid process and the superior aspect of the glenoid labrum. When the arm is abducted 45 degrees from the side of the body, the shoulder is stabilized by the middle glenohumeral ligament, whose origin blends with the joint

capsule. The inferior glenohumeral ligament, consisting of three parts, originates from the anteroinferior aspect of the glenoid labrum and stabilizes the shoulder at approximately 90 degrees of abduction (3, 38).

Beyond 90 degrees of abduction, the capsule-glenoid labrum junction limits forward displacement of the humeral head. If an athlete is injured or has repeated stress to the shoulder with the arm overhead, the inferior glenohumeral ligament may overstretch or the labrum may detach from the glenoid fossa, allowing the head of the humerus to glide anteriorly (23). External shoulder rotation at 90 degrees of abduction, during a high brace posi-

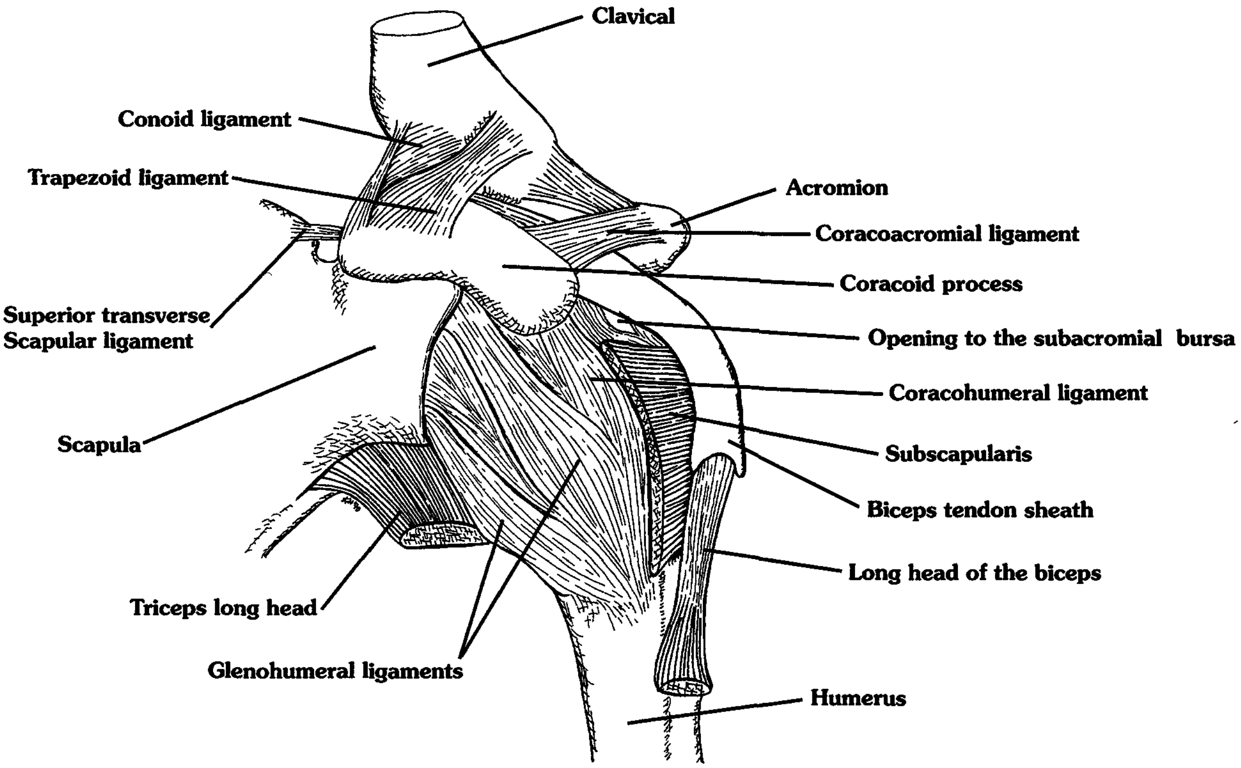

Figure 3. The glenohumeral ligaments and shoulder joint capsule selectively tighten, depending on the position of the arm. The coracoclavicular, acromioclavicular, coracohumeral and glenohumeral ligaments are pictured. In addition, the opening for the subracromial bursa, the long head of the biceps and its sheath, the subscapularis muscle, and the long head of the triceps are shown.

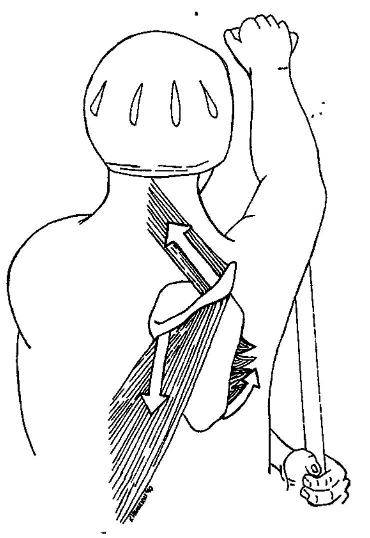

Figure 4a. Upward scapular rotation must occur during shoulder elevation (flexion or abduction), for example, just before the catch phase of planting a cross-draw (as shown) or a duffek stroke. The upper and lower fibers of the trapezius, as well as the serratus anterior, are responsible for upward scapular rotation. The middle trapezius is also active to assist in stabilizing the scapula, particularly as 90 ° of flexion or abduction is approached.

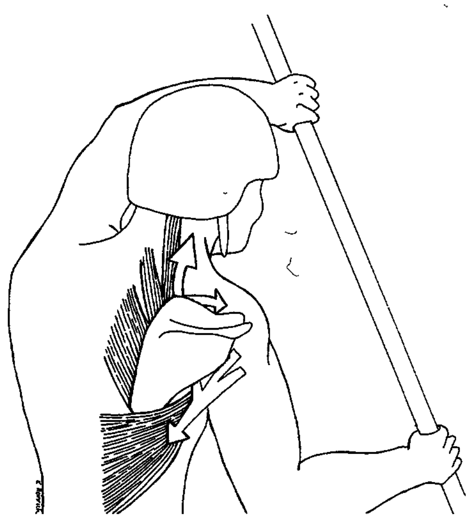

Figure 4b. Downward scapular rotation occurs during shoulder extension and hyperextension; for example, during the pull phase of the forward stroke or stabilization phase of the duffek stroke. The serratus anterior, pectoralis minor and lower fibers of the pectoralis major form the anterior portion of the force couple. The levator scapulae, rhomboids and latissimus dorsi form the posterior portion of the downward rotation force couple. The scapulothoracic muscles stabilize the scapula to provide a stable base for the rotator cuff to act upon.

tion or during a pitching motion, (**Photo 1**) tightens and moves the inferior glenohumeral ligament to extend over the middle aspect of the glenohumeral joint (24, 38). After an anterior dislocation, this ligament becomes overstretched and results in an anterior instability, particularly in the abducted and externally rotated shoulder position.

The coracohumeral ligament, with the dynamic joint compression by the supraspinatus and posterior deltoid muscles, prevents downward displacement of the shoulder. The coracoacromial ligament forms an arch over the humeral head from the coracoid process to the acromion process, and prevents upward migration of the humeral head (26). The supraspinatus and the intra-articular portion of the long head of the biceps tendons must pass under this ligament to attach to the humerus. In addition, the subacromial bursa is located between the acromion process and the supraspinatus.

The sternoclavicular joint, between the proximal end of the clavicle and the sternum, is the only joint that connects the shoulder girdle to the axial skeleton. During normal movement the scapula contributes 60 degrees and the sternoclavicular joint contributes 30 degrees of the total shoulder range of motion. This joint is rarely injured in the slalom athlete.

The acromioclavicular joint, at the other end of the clavicle, demonstrates more movement due to increased joint capsule laxity compared to the sternoclavicular joint, and is more susceptible to dislocation. The joint is supported by the coracoclavicular and acromioclavicular ligaments. A direct fall on the point of the shoulder or on an outstretched arm is the usual cause of injury to this joint, although it is relatively uncommon in the slalom athlete.

Scapular motion is translated to the clavicle through the coracoclavicular ligament, while the acromioclavicular ligament strengthens the superior aspect of the joint. Of the 60 degrees of total scapular movement, 30 degrees occurs at the acromioclavicular joint during shoulder elevation (abduction) early in the movement and near the end of the range of motion.

Scapular rotation occurs through action at the acromioclavicular and sternoclavicular joints, placing the glenoid fossa in a better position for action of the rotator cuff muscles and prime movers (13, 25). Muscles forming the force couples for scapular movement stabilize the scapula to allow the rotator cuff to function. Downward (medial) rotation of the scapula occurs with glenohumeral extension and adduction, and is accomplished by the force couple of the rhombiods, levator scapulae, serratus anterior, latissimus dorsi, pectoralis major and pectoralis minor (**Figure 4a**).

Upward (lateral) rotation of the scapula occurs with glenohumeral elevation (flexion/abduction) and is accomplished by the force couple of the upper and lower fibers of the trapezius and the serratus anterior.

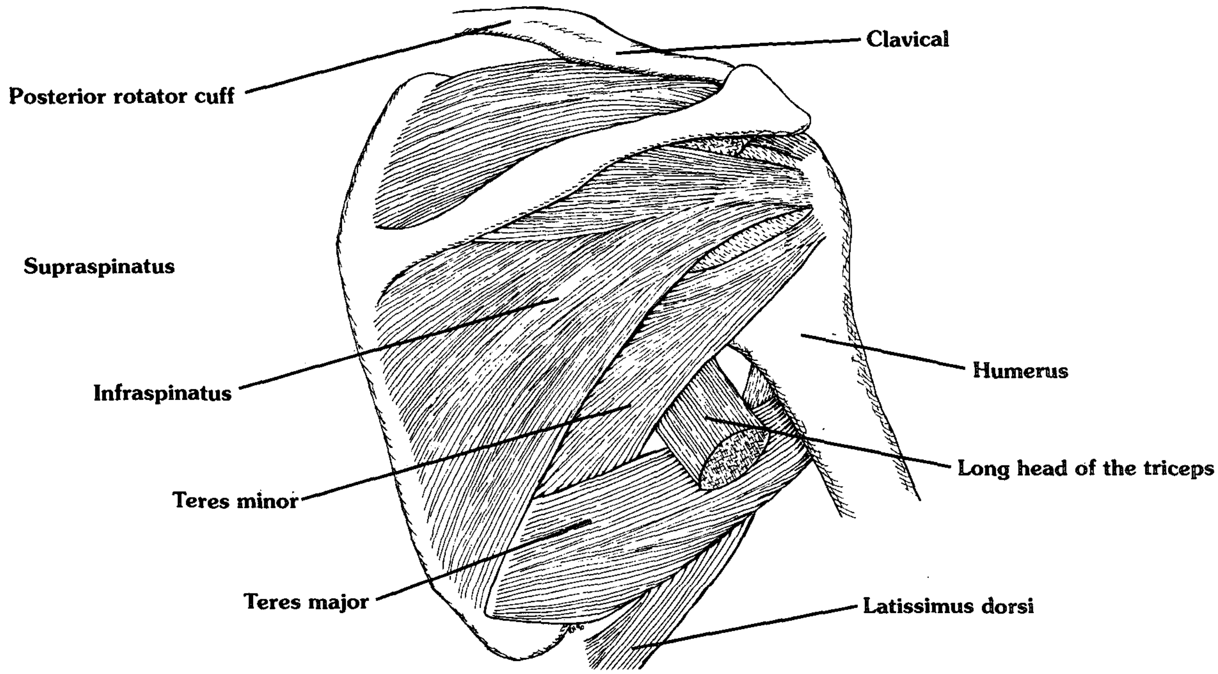

Figure 5a. Posterior view of the rotator cuff muscles. The supraspinatus, infraspinatus and teres minor are shown. The subscapularis covers the anterior aspect of the glenohumeral joint.

Upward rotation occurs when the scapula has moved on the chest wall to find the most stable position during the first 30 to 45 degrees of abduction (**Figure 4b**).

Normal shoulder elevation is comprised of scapulothoracic and glenohumeral motion, which occurs in a synchronous manner. For every three degrees of glenohumeral movement into abduction or flexion, two degrees of scapular rotation must occur for arm elevation (30, 35). Tightness of the serratus anterior or rhomboid muscles may result in less fluid motion at the scapulothoracic joint, limiting the athlete's forward movement of the scapula on the trunk during the catch phase of the forward stroke.

In addition to scapulothoracic and glenohumeral muscular action, trunk extension and rotation is crucial for proper placement of the upper extremity to gain maximum power, stroke efficiency and joint protection. During sprints between gates, the most effective propulsive force is generated when the paddle shaft is perpendicular to the water (21). Maximum torso rotation prolongs this phase and allows for more propulsive force to be generated.

Anatomy of the Rotator Cuff

The subscapularis muscle, part of the rotator cuff, has a broad tendon with several fibrous attachments, and provides passive and dynamic restraint to the shoulder depending on position. This muscle attaches to the anterior surface of the scapula with fibers that converge to form a broad tendon, which passes over the anterior aspect of the glenohumeral joint and attaches distally to the lesser tubercle of the humerus.

The subscapularis internally rotates the shoulder and is a dynamic restraint for anterior shoulder dislocation. As the arm is abducted beyond 45 degrees, the subscapularis tendon's contribution to anterior joint stability decreases as the tendon is displaced upward. In positions greater than 45 to 90 degrees, it no longer covers the inferior portion of the humeral head.

The infraspinatus and teres minor are closely related in location and function. The infraspinatus originates just below the spine of the scapula, while the teres minor originates from the lateral scapular border. The tendons of both muscles blend into the posterior aspect of the shoulder capsule as they pass to insert on the greater tubercle of the humerus (the infraspinatus attaches to the middle facet, the teres minor to the lower facet). Both muscles contract strongly during shoulder external rotation.

The supraspinatus originates from just above the spine of the scapula, forms a tendon, and passes laterally under the ligamentous coracoacromial arch to the upper facet of the greater tubercle. With the other rotator cuff muscles and serratus anterior, it stabilizes the shoulder joint and steers the humeral head as the shoulder and arm are flexed or abducted (**Figures 5a** and **5b**).

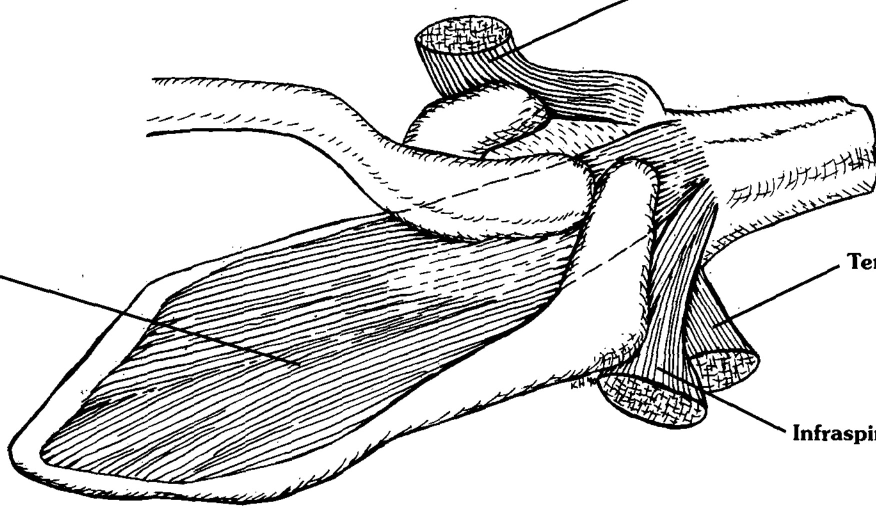

Figure 5b. Rotator cuff muscular attachments to the humeral head, as seen from above.

Rotator Cuff-Deltoid Force Couple

The rotator cuff, made up of the supraspinatus, infraspinatus, teres minor and subscapularis, steers the humeral head during shoulder flexion or abduction (34). The rotator cuff muscles compress the joint and prevent upward migration of the humeral head against the acromion. At the onset of elevation, with the arm at the side, the deltoid is inefficient due to its angle of pull. This results in an upward shearing force on the humeral head. As elevation continues, the deltoid leverage and the angle of pull improve so that the shearing force of the deltoid becomes more compressive. The rotator cuff muscles continue compressive force production to hold the head of the humerus in the glenoid fossa throughout the range of motion (**Figure 6**). When the arm is above horizontal, the rotator cuff's contribution to joint stability begins to diminish (13, 31).

Electromyographic analysis (13) has shown that rotator cuff muscles throughout the full range of motion provide a downward force to counteract the upward pull of the deltoid, so conditioning of these muscles should emphasize endurance. More recently, EMG analysis has shown that the supraspinatus and infraspinatus are active throughout elevation, but that the teres minor was active primarily during activities requiring external rotation and terminal flexion. The subscapularis muscle was most active during activities that required internal rotation (34). Because of the angle of pull of the supraspinatus, its force results in compression and joint stabilization.

Shoulder Tendinitis and Rotator Cuff Impingement

Maintenance of the balanced force couple between the rotator cuff muscles and the deltoid is essential for normal shoulder movement and function. Several factors contribute to shoulder tendinitis and impingement syndrome. The most common is the eccentric overload of the supraspinatus during the acceleration and follow-through phases of pitching, for example. This is followed by fatigue inflammation and permanent tendon degenerative changes. The loss of control and subsequent upward migration of the humeral head result in secondary impingement and subdeltoid bursitis (26). Weakness or injury to the rotator cuff (most frequently by overuse of force overload) may impinge the supraspinatus. Injury results in a vicious cycle of pain that inhibits muscle action and results in disuse, which leads to weakness, poor endurance and inability of the rotator cuff to counterbalance the deltoid's vertical force. This further compresses the injured tissues. By strengthening the rotator cuff, impingement of the supraspinatus tendon by the upward migration of the humeral head against the acromion will be prevented. Because hypertrophy of the muscle-tendon unit may exacerbate subacromial space problems, conditioning should emphasize muscular endurance. Free-weight exercises for the supraspinatus should not exceed seven to 10 pounds of resistance or five sets of 10 repetitions.

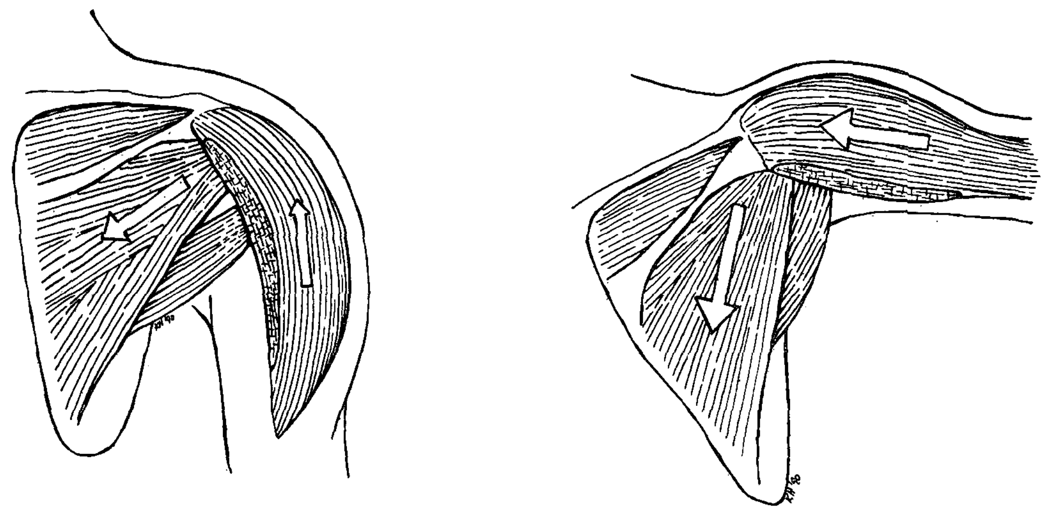

Figure 6. Normal biomechanics of the shoulder joint. From 0-90 degrees, the deltoid exerts a strong upward shearing force as the rotator cuff muscles exert a compressive force. As the angle of pull changes and shoulder flexion or abduction occurs, the deltoid becomes more efficient and the force it imparts becomes more compressive in nature. This occurs at approximately 90 degrees of shoulder elevation. Until the shift in the applied force changes, the space between the coracoacromial arch and the humeral head may be compressed. If the rotator cuff muscles are weak, the upward shearing force of the deltoid is unopposed and impingement of the supraspinatus tendon occurs.

Mechanical impingement of the long head of the biceps or supraspinatus tendon may occur between the coracoacromial ligament and the acromion during shoulder flexion or abduction combined with internal rotation. In addition to the upward migration of the humeral head, repeated microtrauma results in an inflammatory response and edema of the supraspinatus tendon. This reduces the space available for the supraspinatus tendon to pass under the coracoacromial arch. If the undersurface of the supraspinatus tendon is torn, the tendon will buckle slightly as it passes under the coracoacromial arch, causing a catching sensation.

Activities like the catch phase of the forward stroke or cross bow draw, the end of the preparatory phase of a tennis serve, or the start of the acceleration phase of a baseball pitch all move from shoulder abduction to full flexion and from external to internal rotation. The internal rotators move from a position of maximum stretch; the latissimus dorsi, pectoralis major and teres major contract strongly to accelerate the arm while the rotator cuff muscles contract eccentrically to decelerate the arm (19).

Conditioning programs that emphasize the shoulder internal rotators (e.g., latissimus dorsi, pectoralis major, subscapularis, teres major, anterior deltoid) while neglecting the external rotators (i.e., posterior rotator cuff) may lead to a strength imbalance between external and internal rotation. This could cause a force overload in the rotator cuff, as well as weakness, pain and damage to the cuff muscles. In addition, contraction mode (concentric versus eccentric) as it relates to the specific sport must be considered.

Overuse syndromes of the rotator cuff muscles, particularly involving the supraspinatus, occur frequently in the whitewater slalom athlete. Although modalities, medication and rest reduce the symptoms, exercise is the best way to treat the injury. Rehabilitation exercises begin with shoulder isometrics within the pain-free range of motion at less than 90 degrees of abduction, progressing to rotator cuff exercises and specific isokinetic concentric/eccentric programs (generally at 120 degrees per second or more to reduce the joint compressive forces), and finally to velocity- and movement-specific programs.

Supraspinatus impingement usually begins insidiously, with no known injury. Three progressive stages of rotator cuff impingement have been defined (1, 16, 19, 25). Reducing the force overload, promoting healing and strengthening tissue will reverse the first stage and early portions of stage II impingement. However, impingement will progress to stage III if repeated trauma occurs and the tissue thickens, becomes fibrotic and degenerates. The result may be a rotator cuff tear. In all stages, management specific to the pathology is necessary, even in the presence of a small rotator cuff tear (1, 26). Range of motion is generally full, but may be painful between 70 and 120 degrees. Flexion and internal rotation imay impinge the subacromial bursa as the subacromial space is reduced. Overhead flexion or abduction may also result in a catching sensation, which can be relieved by externally rotating the shoulder.

The intracapsular portion of the long head of the biceps tendon may demonstrate similar impingement symptoms. Because the long head of the biceps must change direction sharply as it passes over the humeral head, it is vulnerable to a compromise in vascularity. Movements that require shoulder flexion and external rotation (e.g., golf swing follow-through) may produce a painful catching sensation that can be relieved by internal shoulder rotation. Resisted biceps muscular motions may be painful.

Principles of Shoulder Rehabilitation

Shoulder injury rehabilitation is not limited to one segment of the training year, but begins as soon as possible after an injury.

The treatment of shoulder pain due to supraspinatus or biceps tendon impingement includes five components: pain relief and reduction of inflammation, rest, ice (and other appropriate modalities), appropriate flexibility and strengthening exercises, and correction of faculty posture and biomechanical factors (1, 14, 26). Signs of acute inflammation include pain, swelling, tenderness, warmth and redness. If acute inflammation is left untreated, pain due to tendinitis (tendon inflammation) or joint pain will not improve, nor will the athlete be able to work without incurring further tissue damage. In cases of musculoskeletal dysfunction, the adage "no pain, no gain" has no place in rehabilitation or conditioning. To ignore the signs and symptoms will only postpone the athlete's return to training and competition.

The first component in the treatment of inflammation includes analgesic and non-steroidal anti-inflammatory medication (22). These are commonly prescribed and should be taken only with a physician's approval. One medication usually can relieve pain and reduce inflammation.

The second component of treatment is rest. Training intensity and duration are reduced to promote tissue healing. This does not mean total rest, but a relative rest in which activities are avoided that exacerbate the pain, overload the involved muscle-tendon unit, or cause excessive fatigue and muscular imbalance between the rotator cuff and the deltoid. Initially, stroke modifications are made (the C1 paddler pulls in the elbow slightly to increase relative external shoulder rotation, the kayak athlete paddles in the base position, and both reduce forward reach in the acute phase), stroke intensity is reduced and the athlete trains on flatwater gates to reduce the force overload and subsequent inflammation of the involved structures. Only in the most recalcitrant cases of inflammation is complete shoulder rest advocated.

The application of ice after each workout or rehabilitation session is the third component of treatment. Ice reduces swelling and hemorrhages. Sports physical therapists and athletic trainers may use electrical stimulation to reduce acute pain and inflammation. As the healing process continues, other modalities such as moist heat, ultrasound or lasers may be used. In the case of supraspinatus or bicipital tendinitis, reducing tendon swelling will increase the space available for the tendon to pass under the coracoacromial arch.

After the structure is isolated, specific flexibility and strengthening exercises, appropriate to the degree of muscular weakness or imbalance, are prescribed by the physical therapist or athletic trainer. The goal of the initial rehabilitation program is to improve muscle function and movement. Exercise for an acutely injured shoulder may begin with pain-free submaximal isometric contractions to minimize muscular forces acting on the involved joint. After each rehabilitation and training session, the athlete is re-evaluated for program tolerance and results. The athlete moves to the next training level after he or she is able to tolerate three or four training sessions without an increase in symptoms (10). Later goals include conditioning the shoulder to meet the specific demands of the sport. During this phase the combined efforts of the therapist or trainer and the conditioning coach will ensure a smooth transition from injury rehabilitation to optimal athletic performance.

Perhaps the most important factor to consider is the evaluation and elimination of faulty biomechanical techniques or equipment modifications to reduce the force overload on vulnerable structures. For example, the kayak athlete's control arm is often subject to lateral epicondylitis (tennis elbow). The new bent-shaft kayak paddle places the wrist and forearm extensors in a less stressful position. This reduces overload at the proximal muscle-tendon junction of the wrist extensors and allows for an improved pull-through.

Any change in equipment, particularly from wood to carbon shaft paddles, may cause supraspinatus tendinitis. Pulling the elbow in slightly, angling the T-grip of the paddle and raising the seat have been used to reduce stress on vulnerable shoulder structures in C1 paddlers. Faulty posture (forward head, round shoulders, reduced trunk and poor hamstring flexibility), which further compromises shoulder mechanics, must be identified and corrected.

The athlete's rehabilitation progress must be evaluated daily. If treatment or exercise increases pain, swelling or stiffness, then it may be too aggressive. If the symptoms do not increase, the program may advance to the next level. Each athlete will respond differently to medication, physical modalities and exercise, so the program must be individualized. ●

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