JOURNAL OF ATHLETIC TRAINING

VOLUME 35  •  NUMBER 3  •  JULY–SEPTEMBER 2000

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Shoulder injuries are prevalent today throughout the population. These injuries can have a devastating social and economic impact on the athlete or industrial laborer, who misses valuable time from sport or job. In the past few years, our understanding of shoulder anatomy, biomechanics, and pathophysiology has become more sophisticated, leading to improvements in diagnosis and treatment (both surgical and conservative) for all physically active people.

The shoulder has always been considered a complex, dynamic structure, which is challenging for sports medicine professionals to evaluate and manage. We have asked a number of our colleagues, who are among the most respected shoulder specialists in the country, to contribute to this special issue of the Journal of Athletic Training. Our purpose was to provide readers with a current overview of the evaluation and treatment of common shoulder injuries.

This issue addresses a wide breadth of shoulder injuries commonly seen by sports medicine professionals, from acromioclavicular joint injuries to multidirectional instability. A review of pertinent shoulder functional anatomy is the basis for the assessment and management of any injury. Clinical evaluation techniques for differentiating shoulder pathology set the stage for discussions of acromioclavicular joint injuries, glenohumeral joint instabilities, rotator cuff impingement, glenoid labral pathology, and neurologic shoulder injuries. Described treatments include recent surgical procedures to keep the reader abreast of the latest technical changes that will affect the postoperative rehabilitation program. In keeping with the diverse rehabilitation procedures available, the assembled rehabilitation articles provide insights into some of the less-documented areas, such as aquatic, kinetic chain, and scapular rehabilitation, while incorporating thorough reviews of isokinetic and proprioceptive rehabilitation interventions. Greater emphasis is being placed today on the neurologic aspect of rehabilitation, as demonstrated by several articles in this issue.

We thank all the authors, reviewers, editors, and editorial staff for their tireless work in compiling this special issue. We hope that this publication will serve sports medicine professionals as an excellent reference source for evaluating and managing shoulder injuries in the athlete.

Editorial

George M. McCluskey, III, MD; Timothy L. Uhl, PhD, ATC, PT
Guest Editors

Editor’s Note

David H. Perrin, PhD, ATC
Editor-in-Chief

The Associate Editors and I are pleased to present this second special issue of the Journal of Athletic Training. Our first special issue—Anterior Cruciate Ligament Injury in the Female Athlete (volume 34, number 2)—was exceptionally well received by the sports medicine community. We trust you will find this special issue on the shoulder equally useful to your clinical practice. We are indebted to Dr. George McCluskey and Dr. Tim Uhl for defining the topics, selecting and recruiting the authors, and overseeing the review and revision process for the articles in this issue of JAT. We are also pleased to announce that preparations are underway for our third special issue—Concussion in Sports—targeted for publication in 2001.
Functional Anatomy of the Shoulder

Glenn C. Terry, MD; Thomas M. Chopp, MD

The Hughston Clinic, Columbus, GA

Objective: Movements of the human shoulder represent the result of a complex dynamic interplay of structural bony anatomy and biomechanics, static ligamentous and tendinous restraints, and dynamic muscle forces. Injury to 1 or more of these components through overuse or acute trauma disrupts this complex interrelationship and places the shoulder at increased risk. A thorough understanding of the functional anatomy of the shoulder provides the clinician with a foundation for caring for athletes with shoulder injuries.

Data Sources: We searched MEDLINE for the years 1980 to 1999, using the key words “shoulder,” “anatomy,” “glenohumeral joint,” “acromioclavicular joint,” “sternoclavicular joint,” “scapulothoracic joint,” and “rotator cuff.”

Data Synthesis: We examine human shoulder movement by breaking it down into its structural static and dynamic components. Bony anatomy, including the humerus, scapula, and clavicle, is described, along with the associated articulations, providing the clinician with the structural foundation for understanding how the static ligamentous and dynamic muscle forces exert their effects. Commonly encountered athletic injuries are discussed from an anatomical standpoint.

Conclusions/Recommendations: Shoulder injuries represent a significant proportion of athletic injuries seen by the medical provider. A functional understanding of the dynamic interplay of biomechanical forces around the shoulder girdle is necessary and allows for a more structured approach to the treatment of an athlete with a shoulder injury.

Key Words: anatomy, static, dynamic, stability, articulation

Movements of the human shoulder represent a complex dynamic relationship of many muscle forces, ligament constraints, and bony articulations. Static and dynamic stabilizers allow the shoulder the greatest range of motion of any joint in the body and position the hand and elbow in space. This extensive range of motion affords the athlete the ability to engage in a myriad of sports activities; however, this range of motion is not without risk. The bony architecture of the glenohumeral joint, with its large articulating humeral head and relatively small glenoid surface, relies heavily on ligamentous and muscular stabilizers throughout its motion arc (as opposed to the hip with its congruent “ball-in-socket” anatomy). If any of the static or dynamic stabilizers are injured by trauma or overuse, the shoulder is at increased risk for injury. Shoulder injuries account for 8% to 20% of athletic injuries. 1,2

We examine the shoulder girdle from the standpoint of its component structures, namely the (1) bony anatomy (humerus, clavicle, scapula), (2) bony and muscular articulations (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic), (3) static stabilizers (labrum, capsule, ligaments), and (4) muscles or dynamic stabilizers (rotator cuff, deltoid, and scapular stabilizers). Although these components will be discussed separately, they function to produce shoulder movement as a dynamic, interrelated unit. Understanding the functional anatomy and associated frequent sources of injury of the shoulder permits the sports medicine professional a more structured approach to the care of athletic shoulder injuries. The following material provides an overview of the functional components. The reader is encouraged to research further specific topics of interest.

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BONY ANATOMY

Humerus

The humerus is the largest and longest bone of the upper extremity, with its proximal portion consisting of the half-spheroid articulating surface or head, greater tuberosity, bicipital groove, lesser tuberosity, and proximal humeral shaft (Figure 1). The head is inclined relative to the shaft at the anatomical neck at an angle of 130° to 150° and is retroverted 26° to 31° from the medial and lateral epicondylar plane (Figure 2).3 The greater tuberosity has 3 facets into which the tendons of the supraspinatus, infraspinatus, and teres minor insert. The lesser tuberosity is the site of insertion of the subscapularis, completing the rotator cuff. The facets provide for a continual ring insertion of the rotator cuff from posterior-inferior to anterior-inferior on the neck of the humerus. This insertion is interrupted only by the bicipital groove, through which the long head of the biceps brachii passes laterally and distally from its origin on the superior lip of the glenoid. Substantial forces applied to the shoulder (such as those seen in contact sports) often result in glenohumeral dislocation, with or without associated fracture of the proximal humerus. When fractures do occur, they commonly involve 1 or more of the tuberosities, which are then displaced in line with the force generated by the portion of the rotator cuff attached to that tuberosity. For example, a fracture of the greater tuberosity will be pulled superiorly and posteriorly secondary to the combined pulls of the supraspinatus, infraspinatus, and teres minor. The final fracture position is also influenced by the superior force on the humeral shaft by the deltoid and the medial force of the pectoralis major muscle.4

The surgical neck of the humerus is located just distal to the tuberosities at the level of the metaphyseal flare and is a common site of fractures in the elderly.5 The incidence of
proximal humerus fractures increases with age over 40 years and is felt to be due to osteoporosis. The surgical neck has also been implicated as a possible factor in glenohumeral dislocation through abutment on the coracoid in extreme positions, such as hyperabduction. In this case, the humeral head is levered inferiorly out of the glenoid fossa.

**Scapula**

The scapula is a large, thin, triangular bone lying on the posterolateral aspect of the thorax, overlying ribs 2 through 7, that serves mainly as a site of muscle attachment. As a result of the protection of the overlying soft tissues, fractures occur through indirect trauma to the processes (coracoid, spine, acromion, and glenoid). The superior process, or spine, separates the supraspinatus muscle from the infraspinatus and extends superiorly and laterally to form the base of the acromion. The spine functions as part of the insertion of the trapezius muscle, as well as the origin of the posterior deltoid muscle. The acromion serves as a lever arm for function of the deltoid and articulates with the distal end of the clavicle, forming the acromioclavicular joint. The acromion forms a portion of the roof of the space for the rotator cuff, and variations in acromial shape can affect contact and wear on the cuff (impingement). Tendinitis and bursitis are the result of impingement of the humeral head and overlying rotator cuff against the coracoclavicular arch, which is composed of the acromion, coracoclavicular ligament, and coracoacromial ligament. Impingement is often seen in overhead athletes who perform repetitive motions.

The coracoid process projects anteriorly and laterally from the upper border of the head of the scapula. The superior surface serves as the origin of the 2 coracoclavicular ligaments that are torn, along with the acromioclavicular ligament, in acromioclavicular (AC) joint separations. The most common cause of injury is a fall onto the point of the shoulder, as in football. The coracoid tip serves as the origin of the coraco-brachialis muscle and the short head of the biceps brachii, as well as the insertion of the pectoralis minor muscle. The coracoacromial and coracoacromial ligaments originate on the coracoid as well. The scapular notch lies just medial to the base of the coracoid and is spanned by the transverse scapular ligament. The suprascapular nerve passes beneath the ligament to innervate the supraspinatus and infraspinatus muscles.

The glenoid fossa, or cavity, represents the bony articulating surface for the humerus. Its articular surface is only one third to one fourth that of the humeral head (Figure 3), and hence, provides only a small contribution to glenohumeral stability. The glenoid surface is retroverted on average 4° to 12° with respect to the scapular plane. The scapular plane lies 30° to 45° anterior with respect to the coronal plane of the body and, thus, articulates with the retroverted humeral head. This orientation of the scapula to the coronal plane of the body and humeral head provides the bony foundation for the extensive normal range of shoulder motion.

**Clavicle**

The clavicle serves as the sole bony strut connecting the trunk to the shoulder girdle via the sternoclavicular joint medially and the acromioclavicular joint laterally. The clavicle has a double curve along its long axis and is subcutaneous in its full extent. The flat outer third serves as an attachment point for muscles and ligaments, whereas the tubular medial third accepts axial loading. The middle-third transitional zone is the thinnest portion and is a weak area mechanically, which may be 1 reason for the predominance of fractures in this area. The clavicle serves as a site for muscle attachments, a barrier to protect underlying neurovascular structures, and a strut to stabilize the shoulder complex and prevent it from displacing medially with activation of the pectoralis and other axiohum-
eral muscles. Additionally, the clavicle prevents inferior migration of the shoulder girdle through the strong coracoclavicular ligaments. In high-grade AC joint separations, when this stability is lost, the shoulder girdle displaces inferiorly away from the clavicle. As a result, on physical examination, the distal clavicle appears to displace superiorly.

JOINT ARTICULATIONS

Glenohumeral Joint

The glenohumeral joint is suited for extreme mobility with its mismatched large humeral head and small glenoid articular surface. At any given time, only 25% to 30% of the humeral head is in contact with the glenoid fossa. However, despite this lack of articulating surface coverage, the normal shoulder precisely constrains the humeral head to within 1 to 2 mm of the center of the glenoid cavity throughout most of the arc of motion. This precise constraint of the center of rotation through a large arc of motion is the result of an interplay of static (no active energy required, ie, capsule, labrum, ligaments) and dynamic (muscle) forces. The stabilizing effect of the articular surfaces and capsulolabral ligamentous complex is magnified by muscle forces, which produces a concavity-compression effect directed toward the glenoid center. Bio-mechanical dysfunction from injury to the bony anatomy, static capsulolabral ligamentous structures, or dynamic muscle stabilizers through a single traumatic event or a series of repetitive microtrauma results in loss of this precise constraint of the center of rotation, or instability. Depending on the injured structures involved, the direction of instability may be primarily anterior, inferior, or posterior, or a combination of these. The degree of instability may range from mild subluxation to dislocation, with associated injury to the bony or capsulolabral structures, or both, and surrounding musculature. Treatment of instability in the athlete is aimed at surgically restoring the structural integrity of the injured capsulolabral ligamentous complex, followed by rehabilitation of the dynamic stabilizers. Restoration of normal glenohumeral biomechanics through reestablishment of the dynamic interplay of bony, static, and dynamic stabilizers is the final goal. If any of the components contributing to stability are not fully repaired or rehabilitated, the athlete will fail to return to the preinjury level of performance.

Passive Mechanisms

Articular Surface. The bony radius of the curvature of the glenoid is slightly flattened with respect to the humeral head. However, the glenoid articular cartilage is thicker at the periphery, thus creating significant articular surface conformity and resultant stability. This resultant articular conformity additionally provides the foundation for the concavity-compression effect provided by the rotator cuff and surrounding musculature. The normal glenohumeral joint is fully sealed by the capsule and normally contains less than 1 mL of joint fluid under slightly negative intra-articular pressure, which provides a suction effect to resist humeral head translation, thereby increasing stability. In addition, adhesion and cohesion forces are created when fluid separates 2 closely opposing surfaces and, thus, the surfaces cannot be pulled apart easily (an example is 2 wet microscopic slides placed together). The contribution of these factors in stability are probably minor and functional only at low loads.

Glenoid Labrum. The glenoid labrum is a dense, fibrous structure, which is triangular on cross-section. Located at the glenoid margin, the labrum serves to extend the conforming articular surfaces, thereby increasing contact surface area and adding to stability. The labrum also enhances stability by deepening the concavity of the glenoid socket, an average of 9 mm and 5 mm in the superoinferior and anteroposterior planes, respectively, and loss of the integrity of the labrum (through injury) decreases resistance to translation by 20%. The labrum also acts as an anchor point for the capsuloligamentous structures. Bankart deemed the detachment of the labrum from the anterior-inferior glenoid rim the “essential lesion” responsible for the high incidence of recurrent anterior dislocations. In this case, the labrum detaches traumatically along with the anchoring point of the inferior and middle glenohumeral ligaments. Also disrupted is the deepening effect of the labrum. Treatment is aimed at surgically restoring the functional integrity of the labrum and capsuloligamentous anchor. Pagnani et al demonstrated the importance of superior labrum and biceps tendon injuries, noting increased anteroposterior and superoinferior translations in the lower and middle ranges of elevation.

Joint Capsule. The surface area of the capsule is approximately twice that of the humeral head, allowing for extensive range of motion. The capsule is truncated in shape, and the inferior portion, or axillary pouch, is redundant. The capsule tightens or “winds up” in various extremes of position; for example, the inferior pouch tightens in extreme abduction and external rotation, serving to stabilize the joint (Figure 4). Although the capsule and glenohumeral ligaments are often described separately, they are intimately adherent anatomically. The capsuloligamentous structures reciprocally tighten and loosen during rotation of the arm to limit translation. In the midrange of motion, these structures are relatively lax, and stability is mainly provided by the actions of the rotator cuff and biceps through the concavity-compression effect. At the extremes of motion, the ligaments tighten and become functional; they are especially important in providing stabilization when all other stabilizing mechanisms are overwhelmed.

Ligaments. The coracohumeral ligament is a thick band of capsular tissue originating from the base of the lateral coracoid and inserting into the lesser and greater tuberosities. This ligament is taut with the arm in the adducted position and constrains the humeral head on the glenoid. Additionally, the coracohumeral ligament and superior glenohumeral ligament stabilize the humeral head from inferior translation in adduction and from posterior translation in forward flexion, adduction, and internal rotation.

The superior glenohumeral ligament extends from the anterosuperior edge of the glenoid to the top of the lesser tuberosity (Figure 5). It parallels the course of the coracohumeral ligament, and these 2 structures are considered similar in function. Together they constitute the rotator interval region between the anterior border of the supraspinatus and the superior border of the subscapularis. The middle glenohumeral ligament is the most variable of the 3 glenohumeral ligaments, being absent in 8% to 30% of patients. It originates from the supraglenoid tubercle, superior labrum, or scapular neck and inserts on the medial aspect of the lesser tuberosity. Its function is to limit anterior translation of
Dynamic Stabilizers

Rotator Cuff Muscles. The rotator cuff is a group of muscles consisting of the subscapularis, supraspinatus, infraspinatus, and teres minor, which act as a dynamic steering mechanism for the humeral head (Figure 6). Three-dimensional movements or rotations of the humeral head are the result of the dynamic interplay between the muscles comprising the rotator cuff and the static stabilizers. Rotator cuff activation results in humeral head rotation and depression in positions of abduction. As a group, the rotator cuff muscles are smaller in cross-sectional area and size when compared with the larger, more superficial muscles such as the deltoid, pectoralis major, latissimus dorsi, and trapezius. Also, because they lie much closer to the center of rotation on which they act, their lever arm is shorter, and a smaller generated force results. Given this anatomical location, the rotator cuff is very well situated to provide stability to a dynamic fulcrum during glenohumeral abduction (Figure 7A).

Contraction of the rotator cuff results in concavity-compression, and asymmetric contraction acts to cause humeral head rotation or “steering” during shoulder motion. Additionally, force couples occur at the glenohumeral joint in multiple planes (Figures 7B, 7C). Force couples occur when the resultant force of 2 opposing muscle groups achieves a given moment. Inman et al\(^37\) described the cephalad force of the deltoid counteracted by the inferior, or depressing, force of the subscapularis, infraspinatus, and teres minor.

The supraspinatus originates from the supraspinous fossa to insert forward and laterally at the superior aspect of the greater tuberosity. The tendon blends into the joint capsule and infraspinatus tendon below. The supraspinatus stabilizes the humerus and is the thickest portion and the primary stabilizer against anterior translation of the humeral head in the throwing position of abduction and external rotation.\(^{31,36}\) In this position, the complex moves anteriorly and becomes a barrier to anterior translation. Injury to the inferior glenohumeral ligament through repetitive microtrauma (as in pitching) or a single traumatic episode (dislocation) plays an integral role in recurrent instability. As noted above, treatment is aimed at surgically restoring the functional integrity of the inferior glenohumeral ligamentous complex.
Figure 7. A, The muscles about the shoulder can be thought of as primary movers and primary stabilizers. This situation is somewhat analogous to that of a large man and small boy teaming up to raise a long, heavy ladder. Typically the stronger one will lift (move) the ladder while the weaker one will hold it from sliding or lifting off the ground (stabilize it). There comes a point at which the force generated by the stronger one can overpower the resistance of the weaker one and stability is lost. (Reprinted with permission from O'Driscoll SW. Atraumatic instability: pathology and pathogenesis. In: Matsen FA, Fu FH, Hawkins RJ, eds. The Shoulder: A Balance of Mobility and Stability. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1993:307.) B, Force couple in the adducted position. C, Force couple in the abducted position.

glenohumeral joint and serves, along with the deltoid, to elevate the arm. Innervation is from the suprascapular nerve.

The infraspinatus muscle comprises the anterior portion of the rotator cuff. It originates from the subscapular fossa to extend laterally to its insertion on the lesser tuberosity of the humerus. The tendon of the infraspinatus is intimately associated with the anterior capsule. The axillary nerve passes along the inferior border of the scapula and is, therefore, subject to trauma from anterior dislocation. The infraspinatus functions as an internal rotator, especially in maximum internal rotation. Innervation is from the upper and lower subscapular nerves.

The long head of the biceps must also be considered here, because it functions intimately with the rotator cuff as a humeral head depressor. Rodosky et al. have noted that contraction of the long head of the biceps during the late cocking phase of throwing can significantly reduce anterior translation and increase torsional rigidity of the joint resisting external rotation. Pagnani et al. also noted that in lower elevated positions, the long head of the biceps stabilized the joint anteriorly when the arm was internally rotated and stabilized the joint posteriorly when the arm was externally rotated. Injuries to the long head of the biceps and superior labrum may result from an excessively strenuous throwing program and produce loss of stability, decreased performance, and increasing symptoms.

**Acromioclavicular Joint**

The acromioclavicular joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion. The average joint size in the adult is 9 × 19 mm, and the joint is covered by a capsule. Because of the high axial loads transferred through this small surface area, contact stresses on the articular surface are high and may result in early failure, such as osteolysis in weight lifters or osteoarthritis. Stability of the acromioclavicular joint is provided mainly through the static stabilizers composed of the capsule, intra-articular disc, and ligaments.

The capsule, which is thicker superiorly and anteriorly, surrounds the joint. It is reinforced by the acromioclavicular ligaments superiorly, inferiorly, posteriorly, and anteriorly. The fibers of the superior acromioclavicular ligament are the strongest and blend with the fibers of the deltoid and trapezius muscles. The intra-articular fibrocartilaginous disc occurs in 2 forms: partial and complete. The disc varies substantially in size and shape. It undergoes rapid degeneration (perhaps as a result of the high contact stress loads) and is functionally absent by the fourth decade.

Additional stability of the acromioclavicular joint is derived through the coracoclavicular ligaments, which serve as the primary suspensory ligaments of the upper extremity. Two distinct ligaments, the trapezoid and conoid, span the distance from the superior surface of the coracoid to insert on the trapezoid ridge and conoid tuberosity of the clavicle, respectively. These stout ligaments suspend the shoulder girdle from the clavicle at an
average distance of 13 mm. The acromioclavicular ligaments are the primary restraint to AC joint posterior translation, while the coracoclavicular ligaments are the primary restraint to vertical displacement. The common AC separation injury represents gradations of injury level, first to the acromioclavicular joint and then to the coracoclavicular ligaments, and is usually the result of an inferiorly directed force to the superior aspect of the shoulder.

**Sternoclavicular Joint**

The sternoclavicular joint represents the only true articulation between the upper extremity and the axial skeleton (Figure 8). It is a sellar (saddle) joint formed by the articulation of the medial end of the clavicle and the upper portion of the sternum. Given the great disparity in size between the large bulbous end of the clavicle and the smaller articular surface of the sternum, stability is provided by the surrounding ligamentous structures.

The intra-articular disc-ligament is a dense, fibrous structure arising from the junction of the first rib, passing through the sternoclavicular joint, and attaching to the superior and medial clavicle. This disc-ligament acts as a checkrein against medial displacement of the inner clavicle.

The costoclavicular ligament arises from the upper surface of the first rib to attach to the inferior surface of the medial clavicle. Beam has shown experimentally that the anterior fibers resist excessive upward rotation and the posterior fibers resist excessive downward rotation. The interclavicular ligament connects the superomedial aspect of the clavicle with the capsular ligaments and upper sternum. This ligament acts as a checkrein against excessive downward rotation of the clavicle. The capsular ligament covers the anterosuperior and posterior aspects of the sternoclavicular joint. The anterior portion is heavier and stronger than the posterior portion and is the primary stabilizer against upward displacement of the inner clavicle caused by a downward force on the distal end of the shoulder. Under normal circumstances, the sternoclavicular joint is capable of 30° to 35° of upward elevation, 35° of combined forward and backward movement, and 45° to 50° of rotation around its long axis.

**Scapulothoracic Articulation**

Not a true joint, the scapulothoracic articulation represents a space between the convex surface of the posterior thoracic cage and the concave surface of the anterior scapula. It is occupied by neurovascular, muscular, and bursal structures that allow a relatively smooth motion of the scapula on the underlying thorax. With the scapula serving as the bony foundation of the shoulder girdle, the scapulothoracic articulation allows increased shoulder movement beyond the 120° offered solely by the glenohumeral joint. On average, there are approximately 2° of glenohumeral elevation for every 1° of scapulothoracic elevation, although the actual ratio can vary for any portion of the arc of motion.

Seventeen muscles attach to or originate from the scapula and function to stabilize the scapula and provide motion. Among these, the most important are the serratus anterior, which maintains the medial angle against the chest wall, and the trapezius, which helps to rotate and elevate the scapula synchronously with glenohumeral motion (Figure 9). Rehabilitation of the overhead or throwing athlete must include the scapular-stabilizing musculature for optimal results.

Three bursae surround the scapula: 1 at the superomedial angle between the serratus anterior and the subscapularis, another between the serratus anterior and the lateral chest wall,
and the third at the inferior angle. All 3 have been associated with scapulothoracic bursitis and "snapping" scapula.43

**Scapulothoracic Muscles**

The trapezius has an extensive origin from the base of the skull to the upper lumbar vertebrae and inserts on the lateral aspect of the clavicle, acromion, and scapular spine. It functions mainly as a scapular retractor and elevator of the lateral angle of the scapula. It is innervated by the spinal accessory nerve.

The rhomboids, consisting of the major and minor muscles, originate from the spinous processes of C7 and T1 and T2 to T5, respectively. They insert on the medial aspect of the scapula and retract and elevate the scapula. The dorsal scapular nerve innervates the rhomboids.

The levator scapulae originates on the transverse processes of the cervical spine and inserts on the superior angle of the scapula. The levator scapula elevates the superior angle, resulting in upward and medial rotation of the scapular body. Innervation is from the third and fourth cervical spinal nerves.

The serratus anterior takes origin from the bodies of the first 9 ribs and the anterolateral aspect of the thorax and inserts through 3 portions from the superior to the inferior angle of the scapula. Activation of the serratus anterior causes scapular protraction and upward rotation. Innervation is by the long thoracic nerve, and nerve injuries here often manifest as a winged scapula.43

**Other Shoulder Muscles**

The pectoralis major originates from the anterior portion of the second through fifth ribs and inserts on the base of the coracoid. It protracts and rotates the scapula inferiorly. Innervation is from the medial pectoral nerve.

The deltoid muscle consists of 3 portions: an anterior portion originating from the lateral clavicle, a middle portion originating from the acromion, and a posterior portion originating from the spinous process of the scapula. All 3 portions converge distally to insert on the deltoid tuberosity of the humerus. The anterior and middle portions allow for elevation in the scapular plane and assist in forward elevation with help from the pectoralis major and biceps. Innervation is by the axillary nerve.43 As noted above, the deltoid acts in the force couples occurring at the glenohumeral joint.

**SUMMARY**

Shoulder motion is the result of the complex interplay of static and dynamic stabilizers. All 4 joints of the shoulder (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic) must have free movement as a prerequisite. The bony anatomy provides

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Figure 10. Other muscles of the shoulder. A, Note the pectoralis major and the deltoid, and B, the pectoralis minor and the 2 heads of the biceps.
the structural foundation from which the forces are generated and subsequently acted on. With regard to the glenohumeral joint, the capsuloligamentous complex provides static restraint, while the rotator cuff muscles (along with their respective force-couple antagonists) guide, steer, and maintain the head dynamically in the glenoid fossa. Glenohumeral injury and instability can result when 1 or more of the bony, static, or dynamic components of this interaction are disrupted. Additionally, when injury involves structures other than the glenohumeral joint specifically, the effects may be noted secondarily through decreased shoulder performance. Only when all the components contributing to shoulder motion are returned to their fully functional state can the athlete perform to the highest expectations. A thorough knowledge of the functional anatomy of the shoulder allows the medical provider to take a sound approach in the evaluation and management of the athlete’s shoulder.

REFERENCES


Clinical Evaluation of the Athlete's Shoulder

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Objective: To describe the history and physical examination of the athlete's shoulder.

Background: The complex, highly mobile shoulder joint is very susceptible to athletic injury. A comprehensive history and physical examination lay the groundwork for accurate decision making about the nature of the injury and the appropriate treatment plan.

Description: In taking the history, inquire about the patient's lifestyle (dominant hand, occupation, sports, activity level) and then focus on the specific complaint. Ask about the location, quality, and nature of the pain and activities that provoke the pain. If stiffness is a factor, a review of systems and the patient's past medical history are important. Discuss any previously undertaken interventions and their effects. The physical examination consists of inspection, range of motion, palpation, manual muscle testing, and provocative tests.

Clinical Advantages: Once the clinical evaluation has been completed, the nature of the injury will, in most cases, be apparent. If necessary, appropriate diagnostic tests are ordered, and then a treatment plan tailored to the athlete and the injury is instituted.

Key Words: acromioclavicular joint, rotator cuff, throwing athlete, shoulder instability, impingement, glenohumeral ligaments

In order to assess the athlete's shoulder adequately, the examiner must first understand the basic anatomy of the glenohumeral joint and related structures. Once this foundation is in place, skill in clinical examination can be refined. The shoulder is the most mobile joint in the human body, the result of complex anatomical and biomechanical relationships. However, this complexity also makes shoulder problems among the most commonly encountered complaints presented to physicians, therapists, and athletic trainers.

Common complaints about the shoulder can include any combination of pain, instability, and stiffness. The etiology of these symptoms covers a broad range of diagnoses. A comprehensive history and physical examination is the cornerstone to accurate decision making regarding the need for diagnostic studies and formulation of an appropriate treatment plan.

HISTORY

A thorough history begins with the clinical evaluation of the shoulder; it can often narrow the differential diagnosis and serves to guide the physical examination. Clinical data forms are useful means of recording and organizing data obtained during the initial evaluation.

Before inquiring about the patient's specific complaint, obtain initial information including the patient's age, dominant hand, occupation, sporting activities, and activity level. Most complaints about the shoulder include some component of pain. Pain may result from acute trauma, from a chronic, insidious condition, or from an acute exacerbation of a chronic condition. When pain is present, several key points should be investigated.

The location of the patient's pain is important, because the pain of cervical etiology is often referred to the posterior aspect of the shoulder in the scapular region. Shoulder pain is most often present anterolaterally in the area of the subdeltoid bursa. Pain on top of the shoulder, especially after a direct fall, is suspicious for acromioclavicular joint injury. Also pay attention to the quality and nature of the pain. Nocturnal pain is suggestive of rotator cuff pathology and subdeltoid bursitis. Ask about relieving and exacerbating factors, radiation of pain, and any associated numbness or tingling suggestive of neurological involvement.

Provocative activities and the effect of the pain on the athlete's performance are very important. Shoulder pain is an exceedingly common complaint in throwing athletes. When evaluating a throwing athlete, determine the position in the throwing motion that causes pain. Pain on follow-through is frequently due to rotator cuff pathology. Pain in the cocked-arm position may result from instability or internal impingement. Loss of control or velocity, or both, provides important clues to the severity of involvement. Remember also that rotator cuff weakness can present as medial elbow pain in throwing athletes.

Occasionally instability rather than pain is the presenting complaint. Note the onset of the instability, as traumatic instability is treated differently than atraumatic instability. The frequency of the instability episodes and their impact on the patient's daily activities are important. Often the history can give important clues as to the direction of the instability. Provocation of symptoms with the extremity in abduction and external rotation suggests anterior instability. Symptoms with the arm in front of the body in adduction and internal rotation, such as in pushing open a door, are suspicious for posterior instability. Patients with predominantly inferior instability have symptoms while holding objects against gravity with their arms at their sides. These patients generally avoid lifting heavy objects with the affected extremity.

Stiffness alone is not a common complaint. It most often accompanies pain and is usually associated with adhesive capsulitis or postoperative adhesion formation. Internal rota-
tion loss due to tightness of the posterior capsule is frequently encountered in patients with rotator cuff pathology. In a patient with a stiff shoulder, the review of systems and past medical history are important because of the association between endocrine disorders, such as diabetes, and adhesive capsulitis. Finally, review any previous treatments, including medications, physical therapy exercises, modalities, and surgery, along with the duration and timing of these interventions. Record the number, dates, and patient response to any corticosteroid injections on the data sheet, along with any nonsteroidal anti-inflammatory medication or oral steroid use.

PHYSICAL EXAMINATION

Just as the history follows an ordered format, so does the physical examination. Adequate exposure is a must. Males should remove clothing above the waist, allowing access to both shoulders. For females, a tank top or gown modified to expose the shoulders is used. The examination begins with inspection of the shoulders for symmetry. Pay particular attention to the acromioclavicular joints and the scapular region. Assess the infraspinatus and supraspinatus fossae for muscular atrophy suggestive of a suprascapular neuropathy or chronic rotator cuff tear. Scapular winging, if severe, may be evident on inspection. Lateral winging is usually due to loss of the serratus anterior muscle secondary to a long thoracic nerve palsy, while medial winging is seen with loss of the spinal accessory nerve and denervation of the trapezius muscle. Note previous incisions, and inspect the deltoid muscle for atrophy or pull-off.

Assessing range of motion begins with checking both active and passive forward elevation in the plane of the scapula. Measure external rotation at both 0° and 90° of abduction. Evaluate active internal rotation by recording the highest spinal level a patient is able to reach with the “hitchhiking” thumb (Figure 1). While putting the shoulder through a passive range of motion, note any crepitation in the subacromial bursa, glenohumeral joint, or scapulothoracic bursa.

During assessment of motion, observe the scapular rhythm to ensure that the scapula moves in synchrony with the glenohumeral joint. A patient with a “captured” glenohumeral joint from adhesion formation demonstrates loss of the normal 2:1 ratio of glenohumeral:scapular motion during forward elevation. The scapula will be the main contributor to elevation, with very little motion actually occurring at the joint. If scapular dysrhythmia is evident, evaluate the scapular stabilizers for winging by having the patient do a wall push-up. Also, retraction of the scapulae with the patient’s hands on the waist can be used to elicit scapular winging.

Several prominent structures about the shoulder are easily palpable. Both the acromioclavicular and sternoclavicular joints are subcutaneous and easily accessible. The biceps tendon is often palpable in its groove medial to the greater tuberosity. In thin patients, the greater tuberosity may be palpable along with the subscapularis tendon at the lesser tuberosity.

Manual muscle testing plays a key role in the evaluation of the injured shoulder. Pain often exaggerates weakness, and weak musculature may be masked by substitution of stronger muscles. Therefore, an attempt should be made to isolate each muscle for the best possible testing. Muscle strength is graded on a 5-point scale and is compared with the uninjured side. A plus or minus may be added as appropriate.

- Grade 5: symmetric strength
- Grade 4: a noticeable decrease in strength against resistance
- Grade 3: resistance to gravity only
- Grade 2: resistance to gravity with assistance
- Grade 1: visible contraction of the muscle
- Grade 0: no visible contraction of the muscle

We assess the anterior deltoid muscle at 90° of forward elevation and the middle deltoid at 90° of abduction with reference to the coronal plane. The supraspinatus muscle is best isolated in the “empty-can” position: the shoulder is placed in 90° of abduction and 30° of forward flexion with the arm internally rotated by pointing the thumb downward (Figure 2). Assess the main external rotators (the infraspinatus and teres minor muscles) by resisting external rotation with the arm at the patient’s side. Internal rotation strength can also be assessed in this manner. The integrity of the subscapularis muscle is best evaluated with the “lift-off” test described by Gerber and Krushell.2 The patient places the dorsum of the hand against the back in maximal internal rotation and then lifts the hand off (Figure 3). A patient lacking a functional subscapularis is unable to perform this maneuver.

The remainder of the examination consists of provocative tests performed with the patient either seated or supine. These

Figure 1. Evaluate active internal rotation by recording the highest spinal level a patient can reach with the “hitchhiking” thumb.

Figure 2. Isolate the supraspinatus muscle in the “empty-can” position by abducting the shoulder to 90° and forward flexing to 30°, internally rotating the arm by pointing the thumb downward.
provocative tests are guided by the history and general examination. Impingement is common in both the athletic and nonathletic population. To elicit the Neer classic impingement sign, forcibly elevate the shoulder while stabilizing the scapula (Figure 4). If an impingement lesion is present, pain should be reproduced by this test. Hawkins described a modified impingement sign, which can be used to reinforce the classic impingement sign. This maneuver attempts to reproduce pain from impingement by forced internal rotation at 90° of forward elevation and 30° of forward flexion to approximate a throwing position. The “painful arc,” pain with resisted abduction while the shoulder is slightly extended, is considered a third sign of impingement.

Next, the shoulder can be brought to 90° of forward flexion and 15° of adduction. Resist as the patient attempts to elevate the extremity with the thumb pointed down toward the floor, and then repeat with the palm up. This is the O’Brien, or active compression, test for biceps-labral complex pathology or acromioclavicular joint pathology. The thumb-down position is believed to load the biceps-glenoid labrum complex and the acromioclavicular joint. Note the location of the referred pain. Pain on top of the shoulder is thought to be from acromioclavicular joint etiology, while pain deep in the joint is thought to represent a superior labral lesion. For the test to be considered positive, pain must be relieved with the palm up. Horizontal crossed-arm adduction is used to confirm acromioclavicular joint pathology.

The assessment of laxity and instability begins with the patient in a seated position. Laxity is extremely variable and usually symmetric. Relative increases in laxity are common in females and among swimmers, gymnasts, cheerleaders, and tennis players. Asymmetric shoulder laxity may be a normal finding in throwing athletes. Instability is a symptom that results from pathologic laxity, which can stem from multiple etiologies. The purpose of the stability examination is to uncover the direction of the instability, grade it, and determine the pathology responsible.

Initially assess for signs of generalized ligamentous hyperlaxity, such as elbow recurvatum or a thumb-forearm sign. To assess the laxity of the gleno-humeral joint, we assess antero-posterior translation with the load-shift test. The examiner stands behind the patient and stabilizes the scapula, then applies a compressive force to the humeral head, centering it in the glenoid. The humeral head is then translated both anteriorly and posteriorly, and the amount of translation is graded:
- Grade 1: translation up the glenoid face
- Grade 2: translation to the glenoid rim
- Grade 3: frank dislocation

Measuring the sulcus sign assesses inferior translation. Apply downward traction at the patient’s elbow while stabilizing the scapula (Figure 5). Inferior translation is manifested by a widening of the subacromial space evident at the lateral border of the acromion. Grade 1 is 1 cm or less of widening; grade 2 is 1 to 2 cm; and grade 3 is greater than 2 cm. Remember, when assessing laxity, you are really assessing the symmetry of the shoulders.

Patients with glenohumeral instability often display apprehension when the extremity is stressed in a provocative position. The “crank” test can be used to elicit apprehension felt with anterior instability. Apply an anterior force to the humeral head while externally rotating the shoulder from a position of 90° of abduction. Patients with anterior-inferior instability may have a feeling of impending dislocation, which is referred to as an apprehension sign. Posterior apprehension may be elicited by the jerk test. Forward flex, internally rotate, and adduct the extremity while applying a posterior force.

Continue the instability assessment with the patient in the supine position. The integrity of the gleno-humeral ligaments is easily evaluated with the patient supine. Position the patient on the examination table so that the scapula is stabilized by the

Figure 3. In the “lift-off” test, the athlete places the dorsum of the hand against the back in maximal internal rotation and then lifts the hand off. A patient with a nonfunctioning subscapularis cannot perform this maneuver.

Figure 4. For the Neer impingement sign, forcibly elevate the shoulder while stabilizing the scapula, reproducing impingement pain.
edge of the table. Grasp the patient’s wrist with your outside hand and then position the thumb and index finger of the opposite hand on the anterior and posterior aspects of the humeral head. Have the patient relax, and allow gravity to pull the elbow toward the floor, causing the humeral head to translate anteriorly. The amount of translation can be felt between the thumb and index finger. By raising the wrist up and directing a posterior force with the thumb, reciprocal posterior translation can be felt. Assess the ligamentous restraints at 0°, 45°, and 90° of abduction with neutral and 90° of external rotation.

Turkel et al described the major ligamentous restraints to anterior translation with the shoulder in varying degrees of abduction and external rotation. The superior glenohumeral ligament is the major restraint to anterior translation at 45° or less of abduction. The middle glenohumeral ligament becomes the significant checkrein from 45° to 90° of abduction. At 90° and greater abduction, the inferior glenohumeral ligament is the major stabilizer. When the glenohumeral ligaments are intact, external rotation from neutral toward 90° causes the ligaments to tighten, preventing further anterior translation of the humeral head. If the glenohumeral ligaments are disrupted, external rotation of the humeral head causes further anterior translation and apprehension, especially in the presence of an anteriorly directed force. Increased anterior translation and apprehension with external rotation at 45° to 60° of abdution are characteristic of anterior-superior or SLAC (superior labral anterior capsule) instability (G.C. Terry, MD, unpublished data, 1999), in which an anterior superior labral tear has caused detachment of the middle glenohumeral ligament. At 90° or greater, pathologic anterior translation becomes characteristic of anterior-inferior instability and a possible Bankart lesion. Often with the patient in this position, a labral click suggestive of tearing of the glenoid labrum can be detected and localized. This can be confirmed with the clunk test, as described by Andrews and Gillogly. Abduct the arm to 180°, and apply an anterior compressive force while rotating the humeral head in an attempt to capture the torn piece of labrum. Applying an anteriorly directed force on the humerus aids in the capture of an anterior labral tear. A painful clunk is believed to represent the capture of a detached labral fragment.

Apprehension may also be elicited with the fulcrum test in the supine position. We combine this with a relocation test, as described by Jobe and Bradley, when there is a strong suspicion of recurrent anterior instability (Figure 6). Abduct the arm to 90°, and then gradually increase external rotation until the patient becomes apprehensive. Apply a posterior stress to the proximal humerus, relocating the humeral head. With the posterior stress applied, further external rotation should be possible without exaggerating the patient’s feeling of apprehension.

Superior glenoid impingement, recently described by Jobe and others, is occasionally a cause of shoulder pain in throwing athletes. This is a secondary impingement felt to be caused by excessive translation of the humeral head, commonly present in throwers. We use the internal rotation resistance strength test to assess for impingement of the infraspinatus tendon on the posterior-superior glenoid. With the patient in the supine position, abduct the shoulder to 90° and externally rotate to 90°. Perform resisted active internal and external rotation. Pain and weakness on external rotation that are absent on internal rotation may reflect this internal impingement.

The final segment of a complete shoulder examination consists of neurovascular testing. Cervical radiculopathy commonly presents as a shoulder complaint. Pain posteriorly, especially if it radiates past the elbow, is suggestive of cervical
pathology. Injuries to the axillary, suprascapular, or long thoracic nerves may initially present as a painful shoulder. Stingers are traction injuries to the brachial plexus, commonly seen in athletes participating in contact sports. When there is suspicion of neurologic involvement, perform a complete assessment of upper extremity strength and deep tendon reflexes at the biceps, triceps, and brachioradialis. Athletes with stingers should not return to contact sports until upper extremity strength is symmetric.

Among the vascular causes of shoulder pain are thoracic outlet syndrome (the most common) and an aneurysm of the axillary or brachial artery (rare). These conditions are most often seen in throwing athletes and are usually diagnoses of exclusion. Patients complain of numbness and tingling related to activity. The physical examination is usually unremarkable, and radiographic studies are negative. When vascular compression is suspected, the Adson and Wright maneuvers may be beneficial. To perform the Adson maneuver, have the patient seated with the shoulder extended and the neck rotated toward you. Evaluate the radial pulse as the patient holds a deep breath. (A modification has been described with the head rotated away from the examiner.) For the Wright maneuver, the patient is seated with the arm abducted, extended, and externally rotated. Assess the radial pulse as the neck is rotated away from the side being examined. These tests are only considered positive if they reproduce the patient’s pain or paresthesias. Vascular assessment is critical in patients with shoulder trauma; be sure to evaluate distal pulses.

CONCLUSIONS

The shoulder is the most complex joint of the body, which is reflected by the number of test and maneuvers that have been described for the evaluation of shoulder complaints. The key to making timely, accurate diagnoses rests in taking a systematic approach to the history and physical examination. Only then can the appropriate diagnostic tests and treatment be prescribed.

REFERENCES

Acromioclavicular Joint Injuries

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Objective: To discuss the anatomy and biomechanics of the acromioclavicular (AC) joint, along with the clinical evaluation and treatment of an athlete with an AC joint injury.

Data Sources: I searched MEDLINE from 1970 through 1999 under the key words “acromioclavicular joint,” “clavicle,” “acromioclavicular separation,” and “acromioclavicular dislocation.” Knowledge base was an additional source.

Data Synthesis: AC joint injury is common in athletes and a source of significant morbidity, particularly for athletes in overhead sports. Because this injury can masquerade as other shoulder conditions, the examiner must understand the anatomy and biomechanics of the shoulder in order to perform a systematic clinical evaluation and identify the injury.

Conclusions/Recommendations: Careful attention to the clinical evaluation allows the clinician to categorize the athlete’s AC joint injury and institute appropriate treatment in a timely fashion, thus permitting the athlete to return to sport as quickly and safely as possible.

Key Words: acromioclavicular ligaments, coracoclavicular ligaments, acromioclavicular joint separation, clavicle fracture, sternoclavicular dislocation, distal clavicle osteolysis, acromioclavicular joint degenerative disease

The acromioclavicular (AC) joint is a diarthrodial joint, only 1 of the 5 joints that make up the complex arrangement of the shoulder. Together with the sternoclavicular joint, the AC joint provides the upper extremity with a connection to the axial skeleton. Injuries to the AC joint are very common in athletes and a source of significant morbidity. AC pathology particularly affects athletes whose sport demands overhead upper limb activity. These problems are most frequently encountered in contact sports and are far more common in males; they may be responsible not only for aesthetically unpleasant deformities of the clavicle but also for pain, fatigue, and muscle weakness.

The treatment of injuries to the AC joint has been controversial since the time of Hippocrates (460 to 377 bc). Rockwood’s modern classification includes 6 types. Many treatment options have been proposed in the literature, targeted toward the different types of injuries, but it is difficult to compare the different series. An understanding of the anatomy and an accurate clinical diagnosis are critical for the development of a successful treatment plan to address the injuries and degenerative changes that can affect the AC joint. AC joint pain may masquerade as other conditions in the shoulder; therefore, the pathology must be thoughtfully sought. Careful clinical examination and basic radiographic imaging help to direct a clinically effective approach to these problems.

ANATOMY

The AC joint, which is approximately 9 mm by 19 mm, is a diarthrodial joint with various angles of inclination in both the sagittal and coronal planes. The articular surface of the acromial end of the clavicle is hyaline cartilage until 17 years of age, at which time it acquires the structure of fibrocartilage. Similarly, the articular surface of the clavicular surface of the acromion becomes fibrocartilage at approximately 23 years of age. Viewed anteriorly, the inclination of the joint may be almost vertical or downward medially, the clavicle overriding the acromion by an angle of as much as 50°. Moseley suggested an underriding type of inclination with the clavicle facet under the acromion process, and in his experience, the vertical and underriding types of facets appeared to be most prone to prolonged disability after injury. Urist studied 100 random radiographs of the shoulder and found that the articular surface of the clavicle overrode the articular surface of the acromion approximately 50% of the time.

The meniscus of the AC joint is poorly understood, and little is known of its biomechanical role. The AC joint has similar morphology to the sternoclavicular joint but more commonly has an incomplete fibrocartilaginous disc. This may be one of the reasons why degenerative changes affect this joint more frequently than they do the sternoclavicular joint. Because of the small area of the AC joint and the high compressive loads transmitted from the humerus to the chest by muscles such as the pectoralis major, the stresses on the AC joint can be very high. As a result, the distal clavicle articular surface is prone to compressive failure, as seen in osteolysis of the distal clavicle in weightlifters. Degenerative changes in the disc increase in frequency with patient age, and the disc undergoes rapid degeneration, until it is essentially no longer functional beyond the fourth decade.

The AC joint and the entire shoulder girdle are stabilized by the ligaments that surround the joint (Figure 1). The AC joint is surrounded by a thin capsule that is reinforced above and below by the superior and inferior AC ligaments and the anterior and posterior AC ligaments. Acromioclavicular stability is maintained by the coracoclavicular ligaments (conoid and trapezoid) in addition to the AC capsule and ligaments. The superior and inferior AC ligaments provide the joint with horizontal stability. Codman observed that AC joint motion was minimal and generally equivalent to the pliability of the ligaments. He noted that the AC joint “swings a little, rocks a little, twists a little, slides a little, and acts like a hinge.”

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Figure 1. Ligamentous structures surrounding the acromioclavicular (AC) joint: acromioclavicular, trapezoid, conoid, and coracoacromial. The trapezoid and conoid ligaments make up the coracoclavicular ligament complex.

Rockwood and others have found little relative motion between the acromion and the clavicle during studies with percutaneous implanted pins in volunteers. Rockwood described a synchronous, 3-dimensional linkage of clavicular and scapular rotation: the clavicle does rotate, but the scapula rotates with it, so that there is very little relative motion of the clavicle and scapula. Thus, most scapulothoracic motion occurs through the sternoclavicular joint. The clinical significance of this is that AC fixation may be rigid without necessarily producing an obligate loss of shoulder motion.

Fukuda et al performed a cadaver study of the ligamentous structures of the AC joint, carrying out load-displacement tests along with sequential sectioning of the ligaments. They found that the AC ligament acted as a primary constraint for posterior displacement of the clavicle and posterior axial rotation. The conoid ligament appeared to be more important than has been previously described, in that it played a primary role in constraining anterior and superior rotation as well as anterior and superior displacement of the clavicle.

The fibers of the superior AC ligament blend with the fibers of the deltoid and trapezius muscles, which are attached to the superior aspect of the clavicle and the acromion process. These muscle attachments are important in strengthening the AC ligaments and adding stability to the AC joint.

CLINICAL EVALUATION

Mechanism of Injury

Injury to the AC joint most commonly occurs as a result of direct force produced by the patient falling on the point of the shoulder onto the ground or firm object with the arm at the side in the adducted position (Figure 2). The most common events associated with AC injuries include contact sports such as hockey, rugby, and football. Webb and Bannister noted a 45% incidence of AC injuries in first-class rugby players, and most did well with conservative treatment. The direct force of striking the point of the shoulder drives the acromion downward. Beam has shown that the downward displacement of the clavicle is primarily resisted through an interlocking of the sternoclavicular ligaments. The clavicle remains in its normal anatomic position, and the scapula and shoulder girdle are driven inferiorly. The result, then, of a downward force being applied to the superior aspect of the acromion is either give-way of the AC and coracoclavicular ligaments or clavicle fracture. There may be an additional anteroposterior direction to the force. AC joint injuries consist of a continuum of ligament injuries, beginning with a mild sprain of the AC ligaments. Then the AC ligaments tear, followed by stresses to the coracoclavicular ligament. Finally, if the downward force continues, tears of the deltoid and trapezius muscle attachments occur from the clavicle, as well as ruptures of the coracoclavicular ligament (Figure 3). When these structures tear, the upper extremity has lost its ligamentous support from the distal end of the clavicle, and it droops downward. With severe force, the skin overlying the AC joint can also be disrupted. In the rare type VI injury to the AC joint (see below), a different mechanism of injury is responsible (Figure 3G). A severe direct force onto the superior surface of the distal clavicle along with abduction of the arm and retraction of the scapula has been described. The clavicle is driven inferiorly, where it lodges beneath either the acromion or the coracoid.

Indirect forces to the AC joint may also be responsible for injury. An upward force to the AC joint can occur from a fall
History and Physical Examination

The history should be focused toward the age of the patient and the mechanism of injury. In addition, postinjury performance, as well as a history of prior injury, patient occupation, and type of sporting activities performed in the past, is important to understand. The patient’s level of activity may play a role in treatment decision, and is, therefore, a crucial component of the history.

The physical examination should begin with careful observation of the patient’s shoulder without any obstruction from clothing or improper gowning. Inspect the shoulder contour with the patient in the seated position in order to accentuate any deformity that may be present at the AC joint (Figure 3). View the shoulder from both superior and anterior positions in order to note any subtle anteroposterior displacements of the AC joint. Carefully palpate the sternoclavicular joint, clavicle, and AC joint to appreciate any subtle deformities and to elicit focal areas of tenderness. In addition, palpate for soft tissue defects. If there is obvious subluxation or dislocation of the AC joint, attempt a gentle reduction by supporting the ipsilateral arm and depressing the distal clavicle in order to establish the type of AC injury (see below). Finally, identify and record the neurovascular status of the extremity.

Classification of AC Separations

The classification scheme for AC separation described by Rockwood and Young is well accepted. Six types of injury are classified according to the degree of displacement of the distal clavicle, the involvement of the AC and coracoclavicular ligaments, and the integrity of the fascia overlying the deltoid and trapezius musculature (Figure 3).

Type I. Type I AC separations occur secondary to a mild force to the point of the shoulder, which produces a minor strain to the fibers of the AC ligaments. The AC joint remains stable, and the ligaments are intact. On physical examination, AC joint tenderness is minimal to moderate without palpable deformity.

Type II. Type II AC separations result from a moderate force to the point of the shoulder, yet severe enough to rupture the AC ligaments. The distal end of the clavicle is unstable, but the coracoclavicular ligaments are intact. The scapula may rotate medially, widening the AC joint. If the coracoclavicular ligament is mildly stretched, slight downward displacement of the scapula from the distal end of the clavicle may be apparent. On physical examination, pain at the AC joint can be moderate to severe. The outer end of the clavicle may be slightly superior to the acromion. Shoulder motion produces pain in the joint, and the coracoclavicular space is tender to palpation. Manipulation of the clavicle in the horizontal plane may result in subtle motion detectable with palpation of the AC joint.

Type III. Disruption of the AC and coracoclavicular ligaments occurs after a severe force is applied to the point of the shoulder. In children, the AC and coracoclavicular ligaments may remain intact to the periosteal tube of the clavicle, and the clavicle is displaced out of the periosteal tube, secondary to a longitudinal split in the periosteal sleeve (Figure 3D). The mechanism for this injury is similar to that described above. The deltoid and trapezius muscles are disrupted from the distal end of the clavicle, or the periosteal sleeve with muscle attachments may be separated from the outer end of the clavicle. On physical examination, a type III injury may be less painful than a type II injury, in which the distal clavicle is unstable, yet is still contained in the region of the acromion by the intact coracoclavicular ligaments, allowing abnormal movement between the 2 bones and resulting in irritation and pain. The patient often presents with a depressed upper extremity compared with the normal shoulder, and the distal
end of the clavicle may be prominent enough to tent the skin. Abduction generally causes the most severe pain in this injury. In type III AC separations, the distal clavicle can be manually reduced into its anatomical location; however, it will remain unstable when the pressure is removed. (Figure 4).

**Type IV.** This injury is similar to a type III AC separation except that the distal clavicle is displaced posteriorly and may even be locked within the fibers of the trapezius muscle. The physical examination is similar to that in type III injuries, although the patient will present with significantly more pain with shoulder motion. Observation of the shoulder superiorly may reveal that the outline of the involved clavicle is posteriorly inclined when compared with the uninvolved shoulder. Significant posterior displacement of the clavicle may tent the skin on the posterior aspect of the shoulder. A manual reduction maneuver is not possible in this type of injury, and thus, helps to distinguish it from a type III injury.

**Type V.** This is a very severe type III injury with disruption of the AC and coracoclavicular ligaments, as well as detachment of the deltoid and trapezius muscles from the distal third of the clavicle. As a result, the entire upper extremity droops inferiorly, making the clavicle appear very prominent. In addition to the tenderness noted in a type III injury, the patient also has pain over the distal half of the clavicle secondary to the extensive muscle and soft tissue disruption from the clavicle.

**Type VI.** This is a very rare injury resulting from a significant traumatic abduction force to the upper extremity. The distal end of the clavicle is dislocated under the coracoid process and is posterior to the conjoined tendons (coracobrachialis and short head of the biceps). On physical examination, the shoulder has a flattened appearance, as opposed to the rounded contour of the normal shoulder. The acromion is prominent, and the superior surface of the coracoid process can be palpated easily. Associated fractures of the clavicle and upper ribs and injury to the brachial plexus must be carefully sought due to the significant amount of trauma required to cause a type VI injury.

**RADIOGRAPHIC EVALUATION**

Routine radiographic projections of the AC joint have traditionally been taken using a horizontal-beam technique. This may lead to superimposition of the AC joint on the spine of the scapula, which can result in missed pathology. In addition, if the AC joint radiographs are taken by the technician with the same x-ray exposure setting used to penetrate the heavier and thicker glenohumeral joint, the resulting dark and overpenetrated x-ray of the AC joint will be difficult to interpret for AC pathology. The exposure must be reduced approximately 50% from an ordinary glenohumeral joint radiograph to maximally visualize the AC joint.

The Zanca view of the AC joint was developed to address the superimposition of the AC joint on the scapular spine.17 The patient is positioned standing, with both AC joints projected onto a single large cassette, and a true anteroposterior view (45° angulation from the thoracic plane) with a 10° to 15° cephalic tilt is performed (Figure 5). The cephalic tilt maximizes visualization of the joint and helps to identify small fractures that may be present.

**Figure 4.** Type V acromioclavicular (AC) joint injury with obvious deformity of the shoulder contour.

**Figure 5.** The Zanca view of the acromioclavicular (AC) joint. A standing, true anteroposterior view of both AC joints is performed with or without weights suspended on the forearms. A 10° to 15° cephalic tilt maximizes visualization of the joint and helps to identify small fractures that may be present.
The axillary lateral view of the shoulder is important to identify any posterior displacement of the clavicle, and it may also reveal small fractures not visible on the anteroposterior x-ray. The axillary lateral view is taken with the arm abducted 70° to 90° and the radiographic beam directed cranially. Although this view can be obtained in almost any patient, an occasional patient may be unable to abduct the arm enough for this view. Several techniques are useful in this situation. The arm can usually be carefully passively abducted to allow this film to be taken. In other patients, a curved cassette can be placed in the axilla and the beam directed inferiorly onto the cassette. Alternately, the arm can be forward flexed rather than abducted. Finally, the Velpeau axillary lateral view can be obtained without even removing the injured extremity from its immobilized position. The patient is simply asked to lean backward over the edge of the radiography table where the x-ray cassette is placed, and the beam is directed from superior to inferior.

The technique for a stress radiograph of the AC joint is similar to that in the anteroposterior view with the addition of a 10- to 15-lb (4.54- to 6.80-kg) weight suspended from the forearm. Care must be taken not to allow the patient to hold the weights because proximal muscular contraction may reduce the degree of the AC joint dislocation. The average distance between the superior aspect of the coracoid process and the inferior aspect of the clavicle varies from 1.1 cm to 1.3 cm. However, the coracoclavicular distance varies in normal subjects, depending on how far the patient is from the x-ray tube and cassette. Therefore, the most important measurement is the side-to-side comparison with the uninjured side. Bearden et al recommended comparing the 2 sides: an increase in the coracoclavicular distance of the injured shoulder over the normal shoulder by 40% to 50% can be considered a complete coracoclavicular ligament disruption. Rockwood and Young have documented that a side-to-side difference of 25% of the coracoclavicular distance is diagnostic of a complete disruption of the coracoclavicular ligaments. Vanarthos et al performed a cadaver study to establish whether an anterior/posterior (AP) x-ray with the arm in internal rotation could replace the weightbearing view to diagnose type III AC dislocations. On the basis of their model and analysis, a routine AP view obtained with the shoulder in internal rotation and without weights is sometimes sufficient for diagnosing type III separations of the AC joint. They proposed that this protocol eliminates a potentially painful procedure for the patient and saves time and film.

Bossett and colleagues reviewed the stress x-rays of 82 patients who did not have an obvious type III injury of the AC joint. They only diagnosed 5 patients with type III injuries, and therefore, did not recommend routine use of stress x-rays of the AC joint.

Treatment of AC Separations

**Type I.** Type I AC separations are minor injuries and are generally treated conservatively with a sling for 5 to 7 days to reduce the stress on the AC joint. Ice is applied for the first 48 to 72 hours, and nonsteroidal anti-inflammatory drugs (NSAIDs) may be recommended. Immediate isometric and gentle range-of-motion exercises are encouraged. A more structured strengthening program is initiated as soon as the patient’s symptoms begin to resolve. Most athletes with type I AC separations return to full activities within 1 to 2 weeks.

**Type II.** Soft tissue trauma in type II injuries is more extensive than in type I injuries. Treatment for type II injuries is essentially the same as for type I injuries, although the time frame is prolonged due to the greater trauma sustained. A sling is generally used for 1 to 2 weeks. Ice and NSAIDs are recommended early, and strengthening exercises may begin once symptoms have abated. The patient is informed that a mild cosmetic deformity may be present once the injury is healed. Most athletes with type II AC separations return to full activities within 2 to 3 weeks. These injuries may lead to posttraumatic degenerative joint disease. If these patients develop symptoms unresponsive to conservative management, they may do quite well with an arthroscopic or open distal clavicle resection.

**Type III.** Type III injuries are commonly treated nonoperatively. One exception is in the elite throwing athlete, in whom the extremes of motion and biomechanical loads placed on the shoulder at a high level of activity may be affected enough to cause a noticeable difference in performance. Acute conservative treatment is similar to that recommended for type I and II injuries, including ice, NSAIDs, and sling immobilization. The sling can be discontinued once the major symptoms have subsided, within 1 to 4 weeks. Isometric and gentle range-of-motion exercises are encouraged as soon as the patient can tolerate them, usually within the first week. Devices designed to reduce the AC joint are very uncomfortable and can often lead to skin breakdown or necrosis. These devices have not been shown to lead to better functional results than "skillful neglect." Hughston and colleagues (J.C. Hughston, MD, unpublished data, 1999) have advocated early operative repair of type III AC dislocations. They have had excellent clinical results with this form of treatment and feel that restoration of normal anatomy is essential for a good functional result, especially in the contact athlete.

**Types IV, V, and VI.** Most surgeons recommend early surgical treatment for type IV, V, and VI AC dislocations. A wide variety of operative procedures has been recommended for the open treatment of both acute and chronic complete AC dislocations and is beyond the scope of this article.

ASSOCIATED INJURIES

Fractures

Fractures of the acromial process, clavicle, and ribs can be associated with AC dislocations. Type VI injuries are generally caused by severe trauma and are more likely to be associated with other injuries. Distal clavicle fractures can occur in association with AC joint injuries. Neer classified these fractures according to their location in relation to the coracoacromial ligaments (Figure 6). Type I injuries occur lateral to the coracoaclovacular ligament complex and are quite stable (Figure 6A). Type II injuries are complex, unstable fractures-dislocations that leave the distal clavicle and the AC joint intact but separate the clavicle from the underlying coracoaclovacular ligament complex through an oblique or vertical fracture (Figures 6B, 6C). Type III injuries are intra-articular fractures of the distal clavicle at the AC joint and may be an occult source of posttraumatic arthritis and pain (Figure 6D). Some more unusual associated fractures have been reported in the literature. Wurtz reported on 4 patients with combined...
AC dislocations and midshaft clavicle fractures: 3 had a type IV injury, and 1 had a type II injury. They recommended treatment directed at the injuries of the AC joint. Only 3 patients with type III AC separations associated with midshaft clavicle fractures have been reported in the world literature to date. All 3 patients did well, 2 AC joints being treated surgically\(^30,31\) and 1 conservatively.\(^32\)

A coracoid process fracture associated with AC joint dislocation and with rupturing of the coracoclavicular ligaments in an adult has been reported only twice.\(^33\) Two separate mechanisms, direct trauma to the shoulder girdle and a sudden pull on the coracoid process by the conjoined tendons of the short head of the biceps and the coracobrachialis muscles, appear to be responsible for this unusual triple lesion.

**Sternoclavicular Dislocation**

Fewer than 20 cases of combined AC and sternoclavicular dislocations (panoclavicular dislocation) have been reported in the literature.\(^34\) Nearly all of the cases reported consisted of an anterior sternoclavicular dislocation combined with a posterior type IV AC dislocation. The sternoclavicular joint should be palpated for tenderness in every routine shoulder examination. If tenderness is elicited, a serendipity view\(^35\) of the sternoclavicular joints (AP x-ray with a 40° cephalic tilt) should be performed or a computed tomographic scan should be obtained.

**Pulmonary Injury**

Barber\(^36\) described a patient with a type IV AC dislocation, an ipsilateral pulmonary contusion, and a contralateral pneumothorax. The mechanism of injury was a direct blow to the posterior aspect of the scapula. Diagnosis of this rare but serious injury, which may be associated with an AC dislocation, requires an attentive physical examination not limited to the shoulder, as well as a high index of suspicion.

**OTHER AC JOINT PATHOLOGY**

**Distal Clavicle Osteolysis**

Distal clavicle osteolysis is common in weightlifters and can follow traumatic injuries. Osteolysis is thought to be caused by repetitive microtrauma leading to subchondral stress fractures, which induce hyperemia and bone resorption as in normal healing. However, in the presence of ongoing stress, bone formation and remodeling do not occur. Flato et al\(^37\) described 12 patients, with an average age of 27 years, who had osteolysis of the distal clavicle. Nine of these patients were involved in weight training. Osteolysis can also occur subsequent to a type III intra-articular fracture of the distal clavicle, but this is rare.\(^38\) Patients complain of localized pain, aching, and weakness exacerbated by weight lifting. Examination may demonstrate pain with flexion and cross-chest adduction. The classic radiographic appearance demonstrates resorption of the superior aspect of the distal clavicle with joint space widening (Figure 7).\(^39\) Local injections into the AC joint may at least temporarily relieve the pain.

**Degenerative Joint Disease of the AC Joint**

AC degenerative joint disease can be isolated or may occur in conjunction with subacromial impingement syndrome. Examination most often reveals pain with cross-chest adduction, as well as localized tenderness at the AC joint with palpation. Injection of the joint with local anesthetic often relieves this pain. Clinical symptoms may not correlate with the radiographic evidence of degenerative joint disease. Therefore, the decision to intervene surgically (once nonsurgical treatment has failed) must be based on clinical findings of pain and relief with a selective local anesthetic block.

**CONCLUSIONS**

AC joint injuries are very common in athletes, especially those engaged in contact sports. As part of the history and physical examination, plain radiographs are very useful and
cost effective in evaluating and classifying these injuries. The currently accepted classification system describes 6 types of AC dislocations. The type of injury dictates the treatment, whether operative or conservative, which may depend on the activity level to which the patient would like to return. A high index of suspicion for the presence of associated injuries must be present, particularly in the higher-grade injuries. Injuries to the AC joint can lead to degenerative changes and instability ranging from subtle subluxations to gross dislocations. Patients may report activity-related pain, weakness, and cosmetic deformity. A thorough understanding of the anatomy and the pathomechanics of the shoulder is vital to making appropriate treatment decisions.

REFERENCES

Pathophysiology of Anterior Shoulder Instability

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Objective: To review some of the important biomechanical factors that provide glenohumeral stability, along with the pathologic mechanisms involved in glenohumeral instability of the shoulder.

Data Sources: Current English medical literature concerning the multiple pathologic factors involved in glenohumeral instability was reviewed.

Data Synthesis: Multiple dynamic and static factors control glenohumeral stability. Knowledge of normal shoulder anatomy and biomechanics is necessary to interpret pathologic events.

Conclusions/Recommendations: Dynamic and static factors collectively provide stability to the glenohumeral joint. Disruption or malfunction of these factors causes dysfunction in the shoulder.

Key Words: anatomy, biomechanics, glenohumeral

The minimally constrained shoulder is designed for function and mobility at the expense of stability. Excessive translation of the humeral head on the glenoid is prevented during work and athletic activities by dynamic and static stabilizing mechanisms. Dynamic factors that maintain joint stability include the rotator cuff, biceps tendon, scapulo-humeral and scapulothoracic motion, and negative intra-articular pressure. Important static stabilizers include articular geometry and congruence, the glenoid labrum, and the capsular ligamentous structures. Each individual presents with variations in shoulder anatomy, overall conditioning and fitness, and degrees of shoulder laxity that make the precise evaluation of pathologic lesions difficult. A spectrum of instability exists that includes the degree of instability (microsubluxation, subluxation, dislocation), the direction of instability (unidirectional, bidirectional, multidirectional), the timing of instability (acute, recurrent, chronic), the etiology of instability (traumatic, atraumatic, repetitive microtrauma), and patient volitional factors (voluntary, involuntary).

An important distinction must be made between asymptomatic laxity and clinical symptomatic instability. Laxity represents the normal translation in the shoulder joint that is not associated with pain or apprehension. Laxity may seem excessive to the point that the shoulder may dislocate, but the patient does not experience pain. Caution should be exercised in the interpretation of the passive examination of the shoulder, as an excessive amount of translation of the humeral head relative to the glenoid may not represent a pathologic condition. It should be emphasized that all loose shoulders do not represent instability and may not require surgical repair.

Many pathologic lesions are associated with glenohumeral instability, and the etiology of instability is generally multifactorial. Successful evaluation and treatment of patients within this spectrum of instability requires knowledge of normal and abnormal anatomy and shoulder biomechanics.

STATIC RESTRAINTS

Articular Geometry

The bony architecture of the shoulder joint provides little inherent stability to the shoulder. Unlike the hip joint, the humeral head has a surface area approximately 3 to 4 times larger than the glenoid, and the glenoid does not enclose the head. Only 30% of the humeral head is in contact with the glenoid in various shoulder positions.

The orientation of the proximal humerus and glenoid allows for the exaggerated range of motion of the shoulder compared with other joints. The scapula is oriented 30° anteriorly on the chest wall, and the glenoid is tilted superiorly 5° (Figure 2).

Version of the glenoid is more variable and ranges from an average of 5° to 7° of retroversion in most cases to 10° of anteversion in fewer specimens. Patients with glenoid
dysplasia or degenerative posterior erosion in the arthritic shoulder have the highest likelihood of symptomatic posterior instability as a result of altered glenoid version. The average retroversion for the humeral head is 25° to 30° as related to the distal humeral transepicondylar axis (Figure 3). Reliable measurements from various radiographic studies that define the normal glenohumeral articular geometry are difficult to reproduce and have questionable clinical applicability.

Glenoid Labrum

The labrum is a fibrocartilaginous structure that consists of a confluence of ligament and capsular attachments inserting onto the glenoid rim. The appearance of the labrum is variable, with the superior attachment loose and likened to the meniscus in the knee, while the inferior labrum is firmly attached to the glenoid rim. The labrum also increases the depth of the glenoid, as well as increasing the surface area of the glenoid cavity with which the humeral head articulates (Figure 4). The labrum works with the tensed capsular ligamentous complex and rotator cuff tendons in extending the functional load-bearing surface of the glenoid.

Bankart considered detachment of the anterior inferior labrum from the glenoid to be the essential lesion in producing anterior instability (Figure 5). However, many authors have demonstrated that labral detachment alone does not cause...
anterior instability unless accompanied by a disruption or injury to the capsular mechanism. Concomitant labral avulsion and capsular injury are often associated with periosteal stripping away from the glenoid neck, which potentiates the instability problem.\(^2\)\(^3\)\(^4\)\(^5\) Clinical subluxation and dislocation is often seen in patients with atraumatic and repetitive microtraumatic causes of instability without a labral injury.

**Capsule and Glenohumeral Ligaments**

The shoulder capsule is large and redundant, allowing for a generous range of motion. The capsule has about twice the surface area of the humeral head. Distinct thickenings in the anterior capsule are called glenohumeral ligaments and play an important role in shoulder stability.\(^2\)\(^6\)\(^3\)\(^5\) With rotation of the arm, these ligaments tighten and loosen reciprocally.\(^1\)\(^4\) Different ligaments provide static support depending on the position of the arm and the translation forces that are applied.\(^7\)\(^2\)\(^9\)\(^3\)\(^7\) In routine positions of the arm (mid ranges of motion), the capsular ligaments are generally lax, and the dynamic restraints (particularly the rotator cuff) produce most of the glenohumeral joint stability by compressing the humeral head into the glenoid. However, at more extreme positions, such as cocking in a thrower, the capsular ligamentous structures control excessive translations in the joint.\(^3\)\(^8\)

The anterior capsule is much thicker than the posterior capsule, which has no defined glenohumeral ligaments. The posterior capsule begins superior to the posterior band of the inferior glenohumeral ligament and is extremely thin.

Three glenohumeral ligaments have been described in the anterior capsule. The superior glenohumeral ligament (SGHL) originates from the anterior superior glenoid just inferior to the biceps tendon and inserts above the lesser tuberosity (Figure 5).\(^2\)\(^4\)\(^5\)\(^6\)\(^3\)\(^6\)\(^3\)\(^9\) It runs parallel to the coracohumeral ligament in the rotator interval and functions together with the coracohumeral ligament to limit inferior translation and external rotation in the adducted arm and posterior translation with the arm in flexion, adduction, and internal rotation.\(^4\)\(^0\) The rotator interval identifies the space between the supraspinatus and the subscapularis tendons. When this interval is pathologically stretched or torn, it allows inferior subluxation of the head, which leads to bidirectional and multidirectional instability. Contracture of the coracohumeral ligament and SGHL limits external rotation and forward elevation of the arm.

The middle glenohumeral ligament (MGHL) is variable in structure and absent in 30% of patients.\(^1\)\(^2\)\(^4\)\(^5\) When present, it usually originates at the superior glenoid and labrum adjacent to the SGHL and blends with the subscapularis tendon at its insertion medial to the lesser tuberosity. The MGHL primarily limits anterior translation with the arm abducted to 45° and externally rotated. When the arm is adducted, the MGHL limits external rotation and inferior translation.\(^4\)\(^5\)\(^4\)\(^1\)\(^4\)\(^2\)

The inferior glenohumeral ligament complex (IGHLC) is the primary static stabilizer when the arm is abducted to 45° to 90° and externally rotated (the provocative position for anterior instability).\(^4\)\(^2\)\(^4\)\(^3\) The inferior glenohumeral ligament originates along the anterior glenoid rim and labrum and inserts inferior to the MGHL along the inferior margin of the humeral articular surface and anatomic neck. The IGHLC has been described as including 3 main structural components: a thick anterior band, a less prominent posterior band, and a thin interposed pouch (Figure 6).\(^3\)\(^6\) This complex resembles a hammock that supports the humeral head during abduction and external rotation of the arm. Global shoulder stability requires that all 3 portions of the IGHLC function properly when the arm is abducted. With maximum abduction and external rotation of the arm, the IGHLC tightens or winds up and compresses the humeral head into the glenoid, limiting anterior translation. With abduction and internal rotation, the IGHLC prevents posterior translation. With abduction and extension, the anterior band prevents excessive anterior and posterior translation; with abduction and flexion, the posterior band is the primary stabilizer.\(^4\)\(^4\)

Bigliani and coauthors\(^3\)\(^3\) studied the size and tensile properties of the IGHLC and found the anterior band to be thickest (2.8 mm) and the posterior portion of the capsule to be thinnest (1.7 mm). They were unable to identify a distinct posterior band in their specimens. When the IGHLC in their cadaveric specimens was loaded to tensile failure, failure occurred at the glenoid insertion in 40% and at the humeral insertion in 25% of the specimens. Midsubstance failure occurred in 35% of the cases. Most important, however, was the finding of plastic deformation and strain in the midsubstance of the IGHLC before failure at the glenoid, humeral, or middle portions of the ligament. This suggests that repetitive microtrauma may cause significant stretching and laxity of this important stabilizer before complete failure and disruption of the ligament. A supportive study\(^4\)\(^5\) has demonstrated that application of subfailure, repetitive loads to the IGHLC caused persistent elongation and deformation of the ligament and capsule, with
permanent changes in the mechanical properties of these structures.

**DYNAMIC STABILIZERS**

**Negative Intra-Articular Pressure**

The shoulder joint is generally a closed compartment that allows a negative intra-articular pressure or suction effect to occur when the articular surfaces of the humeral head and glenoid are displaced from each other. When the arm is adducted at the side, the inferior translation of the humeral head caused by gravity and the weight of the arm are negated by this negative intra-articular pressure. In the shoulder with a patulous capsule and larger joint volume, or in a shoulder with a rotator interval tear or capsular vent, the vacuum effect of the joint is lost and some inferior translation will occur until other static restraints come into play.

**Rotator Cuff and Biceps Tendon**

The primary function of the rotator cuff is to guide and stabilize the glenohumeral joint. This stabilizing function occurs through the interaction of several mechanisms. The coordinated contraction of the rotator cuff and biceps engages and centers the humeral head in the glenoid at a fixed point and compresses the articular surfaces together. This concavity-compression mechanism enhances joint stability. An injury to the glenoid labrum that interrupts this mechanism adversely affects joint stability. The compression force generated by the rotator cuff and biceps muscles is sufficient to contain the humeral head in the glenoid, even when large portions of the joint capsule are sectioned. Studies have demonstrated the protective mechanism of the rotator cuff and biceps on the anterior capsule by reducing strain when the arm is placed in an abducted and externally rotated position and stress applied. Weak or fatigued rotator cuff muscles increase the risk for stretching injury to the anterior capsule during repetitive overhead activities such as pitching. Thus, rotator cuff strengthening must be a mainstay in the prevention and nonoperative treatment of instability in overhead workers and athletes. Abnormal electromyographic rotator cuff activity and strength patterns have been documented in patients with anterior instability.

The rotator cuff also functions to "dynamize" the capsular ligamentous complex during active motion of the shoulder, particularly at the extremes of rotation. The cuff tendons blend in with the capsule at the humeral attachment sites. Contraction of the rotator cuff creates tension in the capsule and glenohumeral ligaments to enhance stability. Terry and associates felt that tension in the cuff musculature is activated by stretch receptors within the capsular ligaments. Repetitive stretch injury or traumatic injury to the capsular ligaments may adversely affect this mechanism of dynamization and increase the risk of further instability to the joint. The rotator cuff muscles are generally inactive at rest but may function minimally as static stabilizers. The subscapularis may limit anterior translation with the arm in adduction, and the supraspinatus may assist in resistance against inferior translation.

A smooth scapulohumeral rhythm is important to maintain joint stability. The scapular rotators must be coordinated and balanced to provide a stable and mobile glenoid platform on which the humeral head can rotate. Additionally, disruption of the normal scapulothoracic movement may allow scapular winging. Secondary functional impingement may occur as the scapula fails to allow the tuberosity to clear the acromion during abduction and external rotation of the arm. The serratus anterior, rhomboids, and trapezius must be included in a rehabilitation program for instability.

**SUMMARY**

In conclusion, the glenohumeral joint enjoys a global range of motion at the expense of inherent joint stability. A delicate balance between dynamic and static stabilizing factors allows the arm to be placed in extreme positions for athletic and work-related activities. Instability that arises from minor or major disruptions in this coordinated system requires careful analysis and properly guided treatment for full return to activity. Surgery, when indicated, should attempt to restore normal anatomy, range of motion, and strength to the joint.

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Glenohumeral stability plays an integral role in shoulder function and kinematics. Thus, recurrent anterior glenohumeral instability may be quite disabling, particularly in its later phases when compensatory mechanisms are incompetent. Early accurate diagnosis of this instability pattern is paramount if surgical treatment is to be avoided. In the recent past, anterior shoulder pain was dismissed as bicipital tendinitis or a rotator cuff strain. Research has demonstrated, however, that the causative pathology is more commonly labral or capsular ligament injuries, or both. Although these injuries are occasionally difficult to assess clinically, practiced repetition of examination techniques leads to improved reproducibility in establishing the correct diagnosis. When the patient’s pain and apprehension prohibit a dependable examination, diagnostic studies such as magnetic resonance imaging are helpful. Once recurrent anterior instability is confirmed, an algorithm for treatment should be tailored to the individual athlete and must, in order to be complete, address proper biomechanics, flexibility, and strength and conditioning, in addition to all the standard approaches that encourage the healing of disrupted tissues.

IDENTIFICATION OF INSTABILITY

The classification of shoulder instability is based on frequency, etiology, direction, and degree as shown in the Table. A complete history and clinical examination provide most of this information. Our discussion will focus on recurrent involuntary traumatic and microtraumatic anterior glenohumeral subluxation and dislocation. The clinical history should establish the athlete’s age, hand dominance, number of years of sports activity, and the preinjury, current, and desired future levels of competition. Next, determine whether the initial onset of any shoulder complaints corresponded with or followed a traumatic event or developed insidiously with no identifiable causation. For example, in recurrent traumatic instability, a football linemen may recall a 1-arm tackle in which his shoulder “popped out of place” and was reduced by the team physician. On return to sport later in the season, while tackling, he sustains another frank dislocation or perhaps feels his shoulder “almost slide out.” In recurrent microtraumatic instability, a baseball pitcher may note aching pain in the shoulder posteriorly, coinciding with a decrease in ball velocity and control as he advances in the pitch count. In a subsequent game while in the cocking position, he may experience anterior and posterior shoulder discomfort; on throwing a pitch, he experiences “dead-arm” syndrome. Dead-arm syndrome indicates pathologic anterior instability and occurs when the arm is in an abducted, externally rotated position (Figure 1). The athlete complains of a sharp anterior shoulder pain and tingling in the hand and drops the arm suddenly. This syndrome can be seen in overhead athletes in other sports, such as swimming, volleyball, tennis, and water polo.

In addition to glenohumeral joint pain, the presence of other complaints related to recurrent anterior instability must be recorded. These symptoms may include shoulder stiffness with difficulty warming up for the sport; rotator cuff weakness; sensations of popping, grinding, or catching deep in the shoulder joint; pain when reaching backward or above shoulder height; and apprehension when sleeping with the arm overhead in abduction and external rotation. Neurologic complaints consist of burning or tingling in the lower arm and hand or localized numbness of the skin overlying the deltoid muscle. Any comitantant neck pain must be noted due to the correlation of cervical spine disease with rotator cuff dysfunction and referred shoulder pain. The history is completed with a list of the athlete’s pertinent general medical history and prior treatment, operative and nonoperative, of shoulder and ipsilateral elbow injuries.
Table 1. Classification of Shoulder Instability*

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Acute</th>
<th>Recurrent</th>
<th>Chronic (fixed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etiology</td>
<td>Traumatic (macrotrauma)</td>
<td>Atraumatic</td>
<td>Microtrauma (repetitive)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No trauma</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Voluntary</td>
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<td></td>
<td></td>
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<td>Involuntary</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Congenital</td>
</tr>
<tr>
<td>Direction</td>
<td>Anterior</td>
<td>Posterior</td>
<td>Inferior</td>
</tr>
<tr>
<td></td>
<td>Multidirectional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree</td>
<td>Dislocation</td>
<td>Subluxation</td>
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PHYSICAL EXAMINATION OF THE SHOULDER

Physical examination of the shoulder should be performed in an organized, thorough manner that is reproducible for the examiner and as comfortable as possible for the athlete. I recommend beginning with the athlete in the seated position with the neck and shoulders exposed. Observe the resting appearance, and note any swelling, bruising, trapezius spasm, deltoid or rotator cuff muscle atrophy, or scapular winging. Ask the athlete to fully abduct both arms overhead and check for symmetric scapular glide (Figure 2). A delay or skip in scapular glide with concomitant winging has been associated with a tight posterior shoulder capsule or tight posterior musculature and a loss of internal rotation.\(^3\) In some cases, this may be associated with anterior instability or rotator cuff impingement. A wall push-up test may augment scapular winging. Palpation of the shoulder includes the sternoclavicular and acromioclavicular joints, clavicle, glenohumeral joint, scapula, and associated capsuloligamentous and musculotendinous soft tissue structures. A finding suggestive of anterior instability is tenderness of the anterior glenohumeral joint line and the posterior rotator cuff.

Shoulder range of motion is assessed next. Active range of motion provides information on positions that are painful and cautiously avoided, usually abduction with external rotation beyond 90°. Passive range of motion (abduction, adduction, forward flexion, and internal and external rotation) is measured bilaterally. In throwing athletes, expect the dominant shoulder to have less internal rotation and greater external rotation than the nondominant shoulder; however, the total arc of motion should be similar side to side (Figure 3). Excessive external rotation or overrotation of the thrower’s shoulder is purportedly associated with the development of internal impingement syndrome, a potential precursor to anterior instability. Internal impingement occurs when the shoulder is maximally externally rotated and the intra-articular side of the supraspinatus tendon impinges on the adjacent posterior superior glenoid and glenoid labrum. This can cause posterior superior shoulder pain. Also, partial tears of the supraspinatus may result, leading to rotator cuff dysfunction and loss of the stabilizing effect of the rotator cuff. Furthermore, secondary rotator cuff (subacromial) impingement may result.\(^4\) Posterior superior labral tears can occur, further contributing to the loss of inherent glenohumeral stability provided by the labrum. Subsequent increased stress to the anterior inferior and middle glenohumeral ligament complex may develop. Eventually, frank anterior instability and complaints of anterior shoulder pain ensue.

Before performing the instability tests, which may be painful for the athlete, assess neurovascular function of the upper extremities. Hiking of the shoulder during resisted abduction may indicate supraspinatus or deltoid weakness. Axillary nerve palsy, associated with anterior dislocations, can result in loss of deltoid function. This is best demonstrated by an inability to place the ipsilateral hand into the front pants’ pocket when beginning with the arm resting at the side. Loss of sensation over the deltoid also indicates an axillary neurapraxia. Rotator cuff weakness, particularly in external rotation and “empty-can” abduction, is common in athletes with anterior instability.

Instability testing is performed bilaterally and begins with an assessment of overall laxity, ie, elbow hyperextension, index metacarpophalangeal hyperextension, thumb hyperabduction, and knee hyperextension. With the athlete seated, determine the amount of inferior glenohumeral instability by the sulcus sign test: stabilize the scapula with 1 hand while pulling directly downward on the arm with the other. The amount of inferior translation created is measured in fingerbreadths, or centimeters, between the lateral edge of the acromion and the humeral head. In the absence of multidirectional instability or significant inferior instability, the distance should be less than 1 cm or fingerbreadth. Anterior and posterior translation are initially assessed with the athlete’s arm at the side; the examiner stabilizes the scapula with 1 hand while the other hand grasps the humeral head, thumb posterior and index and
Figure 2. To check for symmetric scapular glide, ask the athlete to fully abduct both arms overhead.

Figure 3. In a throwing athlete, the dominant shoulder may have less internal rotation and greater external rotation than the non-dominant shoulder, but the total side-to-side arcs of motion should be similar.

long fingers anterior, and shifts the humeral head anteriorly and posteriorly. Concomitant compressive loading of the humeral head into the glenoid can also be performed, but labral pathology may cause this additional maneuver to be too painful. Translation is gauged as 1+ when the humeral head slides to the glenoid edge, 2+ for subluxation, and 3+ for dislocation with no spontaneous reduction. Next, use 1 hand to

Figure 4. For the anterior apprehension test, use 1 hand to grasp the athlete’s wrist, then place the shoulder in 90° of external rotation and vertical abduction and increase the amount of external rotation while using the other hand to push the humeral head anteriorly.5 This anterior apprehension test is positive when the athlete experiences pain and a sense of the shoulder slipping out of place (Figure 4). Pain alone may indicate rotator cuff disease. Posterior instability is suggested when the athlete complains of pain as the shoulder is brought passively into internal rotation and cross-chest adduction while a posteriorly directed force is applied to the humeral head.

The supine examination follows the same order as the seated examination and is often better tolerated; thus, the examiner may be more creative. The Lachman maneuver for the shoulder is performed by first grasping the athlete’s elbow below the epicondyles and the shoulder at the humeral neck (Figure 5).6 The humeral head is then translated anteriorly and posteriorly while abduction and external rotation are varied to stress different segments of the joint capsule. For instance, with the shoulder in 90° of abduction, the anterior inferior glenohumeral ligament contributes more to shoulder instability than the middle glenohumeral ligament, which is a significant stabilizer at 45° of abduction. The apprehension-relocation test is positive when no instability is appreciated by the athlete with the shoulder in abduction and full external rotation as long as the examiner applies a posteriorly directed force to the humeral head, eliminating stress to the anterior capsule (Figure 6). When this force is released and the humeral head shifts suddenly anteriorly, complaints of pain and the shoulder “slipping out” are consistent with anterior instability.

Labral tears are often present in athletes with glenohumeral instability. Labral pathology may be detected with the “clunk”
Figure 5. The Lachman maneuver for the shoulder is performed by grasping the athlete’s elbow below the epicondyles and the shoulder at the humeral neck. The humeral head is translated anteriorly and posteriorly while abduction and external rotation are varied to stress different segments of the joint capsule.

test, which is similar to the McMurray test for knee meniscal tears. The humerus is manually compressed into the glenoid and the shoulder passively circumducted in an attempt to capture labral flaps and elicit pain and a click or clunk. Symptomatic rotator cuff tendinitis may be aggravated with this maneuver as well.

The prone position allows for easier palpation of the posterior glenohumeral joint line and overlying soft tissue structures. An apprehension test is performed by positioning the athlete’s chest at the edge of the examining table, with the injured upper extremity dangling to the side of the table. The examiner grasps the athlete’s forearm with 1 hand and places the other on the posterior aspect of the athlete’s humeral head (Figure 7). While the examiner pushes the humeral head anteriorly, the athlete’s shoulder is eased into abduction and external rotation. Complaints of pain and instability constitute a positive test.

DIAGNOSTIC TESTING FOR SHOULDER INSTABILITY

Diagnostic studies for the unstable shoulder include plain radiographs, computed axial tomography scans, magnetic resonance imaging scans with and without injected contrast, and arthroscopy. Findings of a humeral head impaction defect (Hill-Sachs lesion), glenoid labral avulsion (Bankart lesion), loose bodies, partial rotator cuff tear, and, of course, a patulous capsule are suggestive of shoulder instability. The studies ordered and the sequence in which they are ordered are based on physician preference, study availability, and the quality and reliability of the study.

TREATMENT OPTIONS FOR RECURRENT ANTERIOR INSTABILITY

Outcome studies comparing different modes of treatment can provide helpful guidance for effectively managing symptomatic glenohumeral instability. However, since the vast number of variables contributing to instability cannot all be controlled, published reports of the success rates for nonoperative, arthroscopic, and open surgical treatment should be interpreted carefully.

Three key factors that portend a poor result from nonoperative treatment are athletes less than 20 years of age, participation in a collision sport, and severe injury to the capsulolabral structures. Nonetheless, with few exceptions, athletes with instability will benefit from the following: avoidance of the inciting activity; performance of a physical therapy program; and, if needed, instruction in the correct biomechanics for the sport and identification and avoidance of any undesirable techniques. In nonthrowing athletes participating in collision sports, recurrent subluxation may respond to a short period of rest, strengthening of the scapulothoracic and rotator cuff musculature, and protective bracing on return to sport. In the collision athlete with recurrent dislocations and significant trauma to the static stabilizers, dynamic muscle recruitment and bracing may be inadequate to control residual instability. The throwing athlete who sustains a traumatic dislocation of the dominant shoulder and develops subsequent complaints of instability is less likely to regain the high level of function, (accuracy, velocity, and endurance) required for the sport. In contrast, the overhead athlete who has experienced a limited number of subluxations, primarily during
technique, such as splitting instead of elevating the subscapularis has been modified through the years. Now, an additional criterion This is attributable to a success rate of 91% to 96%, in which physician that arthroscopic surgery alone is warranted due to periods of fatigue or overtraining, may respond quite well to rest and therapy including proprioceptive neuromuscular facilitation. Unfortunately, the presence of generalized hyperlaxity may limit any promising results.

In the event that nonoperative techniques fail, surgical options may be discussed. The necessary radiologic diagnostic studies should be performed, if they have not already been done, to identify as much of the underlying pathology as possible. No diagnostic studies are 100% specific, sensitive, or accurate. The additional information provided, however, may suggest to the physician that arthroscopic surgery alone is warranted due to minimal joint injury or that open surgery is appropriate because of an abundance of trauma. Routinely, the athlete is informed of the overall success rate, risks and consequences, and recovery time for each procedure option and consents to a diagnostic and operative arthroscopy and a possible open procedure. Historically, open surgical stabilization of the shoulder has been the gold standard against which all other techniques have been compared. This is attributable to a success rate of 91% to 96%, in which success is defined as the absence of further complaints of subluxation or dislocation. However, the definition of success has been modified through the years. Now, an additional criterion is a return to the previous sport or, even more stringently, a return to the previous level of function for more than 1 season. In sports requiring full motion, a postoperative loss of external rotation is disconcerting. In early publications on open procedures, the postsurgical loss of shoulder external rotation or forward flexion measured as much as 20°. Recent modifications of the open technique, such as splitting instead of elevating the subscapularis tendon and a limited imbrication of the joint capsule, have helped alleviate this problem.

Although initial reports on arthroscopic stabilization touted minimal loss of external rotation, they were not without their own challenges, as the rate of recurrent instability was as high as 49%. Arthroscopic techniques have undergone a significant evolution since their inception by Johnson in 1982. Screws, tacks, and sutures, both absorbable and nonabsorbable, have replaced the use of staples. Abnormalities of the capsule, labrum, and rotator cuff are being addressed more aggressively and more thoroughly. As a result, arthroscopic success rates have improved. On the forefront of arthroscopic surgery is thermal capsular shrinkage. This technique involves applying the tip of a thermal probe to the attenuated joint capsuloligamentous structures and shrinking the collagen tissue via thermal modification. The capsular tissue stiffness is decreased initially, thus necessitating a period of immobilization postoperatively before a gentle, progressive range-of-motion program is instituted. Too rapid an increase in motion in the first 6 weeks can lead to stretching of the shrunken capsule. Purportedly, after 1 year, the thermally modified capsule appears as normal collagen microscopically. Early reports are promising, but certainly thermal capsulorraphy is not the panacea for shoulder instability. Athletes who are not “ideal candidates” for arthroscopic treatment include those who participate in a collision sport; have a history of multiple dislocations; have a humeral avulsion of or tear through the glenohumeral ligaments or a poorly defined capsulolabral complex; and have failed to improve after previous arthroscopic techniques or are noncompliant. Most athletes experience less pain after arthroscopy than after open surgery. However, minimally invasive is not synonymous with rapid recovery, nor does it imply a lack of need for a supervised postoperative rehabilitation program. Furthermore, an aggressive arthroscopic stabilization may be complicated by a loss of return of full motion, similar to that seen after some of the former open procedures, unless the postoperative course is monitored closely.

The goals of surgical reconstruction are to correct the pathology and stabilize the shoulder without eliminating critical motion and with minimal morbidity to the normal adjacent soft tissue structures. With the advent of new technology and a better understanding of all the closely integrated essential lesions of instability, the success rates of arthroscopic and open procedures have improved. Surgeon preference and training often dictate the specifics of the operative treatment plan.

REFERENCES
Understanding Multidirectional Instability of the Shoulder

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Objective: To provide an overview of the evaluation and treatment of the patient with multidirectional shoulder instability.

Data Sources: I searched MEDLINE for the years from 1980 to 2000 using the key words “shoulder joint,” “instability,” “dislocation,” “multidirectional shoulder instability,” and “inferior capsular shift.”

Data Synthesis: Multidirectional instability is symptomatic glenohumeral subluxation or dislocation in more than 1 direction: anterior, inferior, or posterior. The primary pathology is a loose and patulous capsule, and the entity is more common than previously recognized. Multidirectional instability affects young, sedentary patients with generalized ligamentous laxity, often with bilateral symptoms and an atraumatic history, but it also affects athletes, many of whom have sustained injuries. Patients with multidirectional instability may also have Bankart lesions and humeral head impression defects.

Conclusions/Recommendations: Patients with multidirectional instability must be identified before appropriate treatment can be initiated. If a course of rehabilitation fails to improve the patient’s symptoms, an inferior capsular shift procedure has been demonstrated to be an effective surgical option.

Key Words: shoulder instability, shoulder joint, multidirectional shoulder instability, inferior capsular shift

Nee and Foster1 introduced the inferior capsular shift for the treatment of involuntary and multidirectional instability of the shoulder in 1980. They noted a relative dearth of information regarding the management of this problem and little consensus concerning the operative treatment of choice. Before the publication of this landmark article, several authors2–6 had recognized the importance of distinguishing this disorder from the more common unidirectional form of instability and recommended a comprehensive trial of strengthening exercises before considering surgical intervention. Neer7–10 has emphasized that when standard procedures used to correct unidirectional anterior or posterior instability are performed in patients with multidirectional instability, they may fail because they do not reduce the excessive inferior capsular redundancy. Additionally, excessive tightness created on 1 side of a hypermobile joint may result in a fixed subluxation or dislocation in the opposite direction, possibly leading to severe glenohumeral arthritis.10–28

For these reasons, it is important to identify patients with multidirectional instability before initiating treatment. Patients with shoulder instability do not always easily separate into clear categories (unidirectional versus multidirectional). This applies to athletes in particular, often lax to begin with, who subject their shoulders to repetitive microtrauma on a daily basis and who may also suffer a superimposed injury. Athletes with anterior instability constitute a spectrum from unidirectional anterior instability to frank multidirectional instability with pronounced inferior capsular laxity, rather than simple discrete groups.29–32

CLINICAL PRESENTATION

Multidirectional instability may be manifested in a variety of ways. The patient is often athletic, and gymnasts, swimmers, and weight trainers may be particularly predisposed. The instability episode may have occurred without significant injury and spontaneously reduced or been self-reduced. Hypermobile shoulders can become symptomatic without unusual trauma and possibly even from the activities of daily living.

A family history of hypermobility is present in a subgroup of patients. While associations between connective tissue disorders, such as Ehlers-Danlos syndrome, biochemical abnormalities, and ligamentous laxity syndromes, have been investigated, no definitive relationships have been demonstrated.4,33–37

The patient’s symptom complex may provide a clue to the direction of instability. With inferior instability, the patient may describe pain associated with carrying heavy suitcases or shopping bags. Occasionally these symptoms are accompanied by traction paresthesias. Pain associated with pushing open a heavy or revolving door, or use of the arm in a forward-flexed and internally rotated position usually suggests a component of posterior instability, and discomfort in the overhead, abducted, and externally rotated position generally suggests anterior instability. However, symptoms can be complex, vague, and difficult to sort out.

Generalized ligamentous laxity may be demonstrated on physical examination. Hyperextension at the elbows (Figure 1), the ability to approximate the thumbs to the forearms, hyperextension of the metacarpophalangeal joints, or patellofemoral subluxation may be evident. In some of these patients, hypermobile acromioclavicular and sternoclavicular joints can be sources of symptoms. Therefore, it is important to examine these joints for tenderness. A significant finding is the sulcus sign (Figure 2), documenting inferior laxity. Additionally, the scapulothoracic articulation should be closely inspected.
because concomitant scapulothoracic instability may occasionally be present.\textsuperscript{7,38} Multiple positive findings may occur with the following maneuvers: anterior and posterior load-and-shift tests, anterior and posterior apprehension tests, fulcrum test, relocation test, Fukuda test, and push-pull or supine stress test.\textsuperscript{1,7,38,39} The aim is to produce humeral translations anteriorly, posteriorly, or inferiorly (relative to the glenoid) at 0°, 45°, and 90° of abduction. It is important to document that these translations are reliably accompanied by the patient’s report of the usual pain and discomfort. Laxity in and of itself is not an indication for surgical stabilization procedures; therefore, it is important that symptoms be reproduced with such maneuvers.\textsuperscript{7,40} Biomechanical studies have demonstrated that normal asymptomatic shoulders may show substantial translation on clinical testing.\textsuperscript{41} In addition, joint laxity may be remarkable enough to distract the examiner from the primary source of pain, such as a painful acromioclavicular joint or a cervical radiculopathy. Conversely, laxity may be hard to demonstrate, even in a shoulder with multidirectional instability; if pain, muscle spasm, and guarding prevent subluxation. It is helpful to examine the contralateral, asymptomatic shoulder for laxity. An extremely loose shoulder may be a clue to the multidirectional nature of the affected side.\textsuperscript{7,42}

Determining the primary direction of instability can be difficult on physical examination. Whether the shoulder is moving from a dislocated to a reduced position or from a reduced to a dislocated position can be challenging to ascertain. Maintaining the fingers of 1 hand on the coracoid anteriorly and the posterolateral acromion can aid in this determination. For this reason, repeated physical examinations are helpful in assessing these patients.

Plain radiographs are typically normal but should be evaluated for the presence of humeral head defects and glenoid lesions such as osseous Bankart fragments, reactive bone, or wear. Double-contrast computed tomography arthrograms may demonstrate an increased capsular volume. Magnetic resonance imaging enhanced with an intra-articular mixture of saline and gadolinium may distend the joint sufficiently to permit evaluation of the capsular volume and the uncommon labral or capsular detachments. Inferior subluxation can be demonstrated by stress radiographs; however, this technique is generally not needed.\textsuperscript{43} Cine magnetic resonance imaging is currently under investigation but has the potential to dynamically demonstrate capsular and labral defects in varying positions.\textsuperscript{44}

**TREATMENT**

When the diagnosis of multidirectional instability has been established, a prolonged course of rehabilitation is instituted, with emphasis on strengthening the deltoid and rotator cuff muscles with the arm below the horizontal.\textsuperscript{45-47} The scapulothoracic-stabilizing muscles are equally important and are strengthened as well. Patients with multidirectional instability may have an associated synovitis and occasionally develop a secondary impingement syndrome. Nonsteroidal anti-inflammatory drugs are helpful in these patients. At times, a subacromial injection of a corticosteroid preparation provides sufficient relief for the patient to resume his or her exercise regimen.

Lephart et al\textsuperscript{48} demonstrated that athletic individuals with chronic shoulder instability have significant deficits in proprioception and that surgical stabilization normalizes proprioceptive sensibility. These findings have supported proprioception’s role in shoulder stability. Because mechanoreceptors must be deformed or loaded to function, they may not be sufficiently stimulated in a lax or injured capsule.\textsuperscript{48} Alteration of the normal state of negative intra-articular pressure may also affect the function of the mechanoreceptors and contribute to shoulder instability.\textsuperscript{49-51} Muscle coordination abnormalities have been noted in studies of patients with generalized laxity as well.\textsuperscript{52} These studies support the need for a rehabilitation program that includes neuromuscular adaptation and focuses on improving muscle tone and general coordination.\textsuperscript{47,53}

Motivation should be carefully assessed during the rehabilitation program, both to be sure that the patient is mature enough to cooperate in the rehabilitation effort required postoperatively and to screen out those manipulating their disease for secondary gain.\textsuperscript{5,7} Patients with acquired instability (often
athletes) may have developed the ability to dislocate the shoulder at will or on command. This is especially true if certain positions reliably result in a dislocation (e.g., the humeral head falls out posteriorly whenever the arm is raised in the forward plane). Such positional dislocators may demonstrate this for the examiner, if requested, but otherwise will do their best to avoid such positions. These patients must be differentiated from true voluntary dislocators, who have underlying psychiatric problems and often use asymmetric muscle pull to dislocate their shoulder, or even to hold it out, to great dramatic effect. To complicate things further, a small group of patients has developed the habitual initiation of improper muscle-firing patterns that also produce dislocations by asymmetric muscle pull. These patients may be unaware of this pattern and without psychiatric disturbance. Nevertheless, both groups of muscular dislocators are poor candidates for stabilization procedures. Those with psychiatric disturbances need counseling and, with respect to the shoulder, skillful neglect. The group with habitually improper muscle use may be successfully treated with muscle retraining and biofeedback.

Surgery is recommended if the patient has prolonged symptoms that have not responded to conservative treatment, including an extensive exercise regimen, as well as the occasional use of nonsteroidal anti-inflammatory drugs. Surgery may be considered sooner if, for example, glenohumeral ligament avulsion on double-contrast computed tomography arthrogram or magnetic resonance imaging is documented.

**OPERATIVE TECHNIQUE**

A loose, redundant capsule is the primary pathology in multidirectional instability. This pathologic capsular laxity is directly addressed by the inferior capsular shift procedure, which reduces the volume of the glenohumeral joint anteriorly, inferiorly, and posteriorly. The inferior capsular shift is designed to reduce capsular volume on all sides by thickening and overlapping the capsule on the side of greatest instability and tensioning the capsule on the inferior and opposite sides.

An interscalene regional block is the anesthesia of choice when possible. The examination under anesthesia is then performed. Biomechanical studies have contributed to the fund of knowledge regarding the static stabilizers of the glenohumeral joint and aided in the performance of the examination under anesthesia. Because different portions of the capsule and ligament system are brought into play in different arm positions, the glenohumeral joint is stressed anteriorly, posteriorly, and inferiorly in adduction, 45° of abduction, 90° of abduction, and internal and external rotation.

This technique is usually performed from 1 surgical approach, anterior or posterior, but it is sometimes difficult to decide on the best side for the approach. Essentially, the side that dislocates takes precedence over lesser degrees of instability. Shoulders that dislocate both anteriorly and posteriorly should be approached from the anterior side. Cooper and Brems have preferred to approach all cases from the anterior aspect of the shoulder. An axillary skin incision (Figure 3) as described by Leslie and Ryan is made within the anterior axillary skin crease. The importance of the subscapularis muscle cannot be overemphasized, and meticulous care throughout the approach and repair is imperative. The subscapularis tendon is generally incised approximately 1 cm medial to its insertion on the lesser tuberosity. The incision is oriented from superior to inferior, perpendicular to the tendon fibers, and extends from the rotator interval superiorly to the lower border of the subscapularis inferiorly (Figure 4).

The capsular approach to the joint may be lateral (humeral) as described by Neer and Foster, intermediate (middle) as advocated by Wirth et al, or medial (glenoid) as described by Altchek et al. The lateral capsular incision offers several advantages. The capsule is shaped like a cone or funnel, with a broader insertion and surface area on the humeral side. For this reason, more capsule can be shifted, as the tissue can be shifted a greater distance and reattached to a broader insertion. This is particularly important in patients whose shoulders have

![Figure 3. The skin incision begins at a point midway between the tip of the coracoid and the inferior border of the pectoralis major and extends to the inferior border of the pectoralis major, concealed within the anterior axillary skin crease.](image)

![Figure 4. Subscapularis tendon identification begins superiorly at the level of the rotator interval and inferiorly in the region of the anterior humeral circumflex vessels. The incision starts 1 cm medial to the lesser tuberosity.](image)
significant inferior redundancy or a patulous capsule. The lateral capsular incision also affords relative protection to the axillary nerve if the shoulder is maintained in a position of external rotation and adduction during the dissection (Figure 5), as the nerve is more medial in this shoulder position. Additionally, in the unusual instance of capsular tears at the humeral insertion, a lateral approach facilitates diagnosis and repair. The intermediate (middle) incision in the capsule has been recommended because it is thought to be technically easier than a medial approach, improves medial visualization of the glenoid rim, and allows “double breasting” of the glenohumeral ligaments. A primary disadvantage is that inferior dissection must be done with great care, as injury to the axillary nerve is quite possible. The medial (glenoid) approach to the capsule has the advantage of facilitating repair of the capsule and labrum to bone when a concomitant Bankart lesion is present.

The lateral (humeral) approach to the capsule begins 5 mm medial to its humeral insertion. The incision starts at the level of the rotator interval. As the inferior aspect is approached, the arm is maintained in external rotation to avoid injury to the axillary nerve. Stay sutures are placed in the capsule as it is mobilized (Figure 6). As the humerus is externally rotated and flexed, the capsule is incised around the neck of the humerus, extending as far posteriorly as necessary depending on the degree of instability. A ring retractor is placed, and the joint is inspected carefully. Intra-articular pathology, loose bodies, and articular cartilage defects are noted. Special steps are added at this stage as the pathology indicates. If the glenohumeral ligament complex is detached (Broca-Perthes-Bankart lesion), it is repaired. Although less frequently observed, glenohumeral ligament detachments do occur in patients with multidirectional instability. Sutures through drill holes in the bone or suture anchors, or both, may be used for fixation. Both ends of the suture are passed through the medial capsule and tied down to secure the capsule, labrum, and ligaments to the roughened anterior glenoid neck (Figure 7). Bone grafting is rarely required for patients with multidirectional shoulder instability. If anterior glenoid bone deficiency involves more than 25% of the glenoid articular surface (secondary to erosion from multiple previous dislocations or from prior fracture), a bone graft may be performed.

Figure 6. Stay sutures are placed in the capsule as it is incised, and progressive external rotation facilitates inferior dissection.

Figure 7. A capsulolabral avulsion from the bony neck of the glenoid should be repaired before any attempt at capsulorrhaphy or shifting of the anterior capsule. Bone sutures or suture anchors can be used.

After carefully evaluating the joint, the surgeon incises the capsule horizontally in a T fashion, generally between the middle and inferior glenohumeral ligaments (Figure 8). The superior flap, thus, contains the superior and middle glenohumeral ligaments, whereas the inferior flap consists of the 3 portions of the inferior glenohumeral ligament. At this time, the inferior capsular flap is mobilized superiorly. Shifting the inferior capsular flap should effectively eliminate the redundant inferior pouch and tension the posterior capsule. The capsule is usually repaired with the arm in approximately 25° of external rotation and 20° of abduction, although the position is modified based on the individual patient. I repair the dominant shoulders in throwers in relatively more external rotation and abduction. The repair begins with the inferior flap, which is shifted superiorly (Figure 9). The sutures are placed in a simple, interrupted manner, progressing superiorly, repairing the inferior flap to the lateral stump of capsular insertion. Occasionally, when the quality of the capsular tissue remaining on the humerus is poor, sutures through humeral bone or suture anchors, or both, are used. Next, the superior cleft is repaired.
Figure 8. The capsule is incised horizontally in a T fashion between the middle and inferior glenohumeral ligaments.

Figure 9. The capsular shift begins as the inferior flap of the capsule is shifted superiorly and repaired to the lateral cuff of capsule. After repair of the superior cleft, the superior capsular flap is then shifted inferiorly and repaired.

in a simple, interrupted manner, closing the enlarged rotator interval. The superior capsular flap is then shifted inferiorly and repaired (Figure 9). The subscapularis muscle is reattached to its insertion in an anatomic manner; it is not transferred laterally.

Neer and Foster believed that the rotator interval between the supraspinatus and subscapularis and the deeper cleft between the superior and middle glenohumeral ligaments was widened in patients with multidirectional instability. They described closing it before shifting the superior flap inferiorly “to act as a sling against inferior subluxation.” Recent studies of the rotator interval confirm its important role in instability and substantiate the need to address this area at the time of reconstructive surgery, as described by Neer. The inferior capsular shift corrects the redundant inferior pouch associated with inferior instability in the abducted arm and the widened rotator interval responsible for inferior instability in the adducted arm. This concept has been supported by subsequent biomechanical and clinical studies. Thus, the soft tissues are balanced in a systematic way to address the pathology.

Several investigational techniques are being evaluated. Arthroscopy has been advocated as a diagnostic aid, and arthroscopic medial-based capsular shift has demonstrated satisfactory preliminary results. The effect of thermal heating on the glenohumeral joint capsule is being investigated, and arthroscopic laser contraction of the capsule has been described. A recent preliminary study evaluating thermal capsulorrhaphy for patients with multidirectional instability yielded a high early failure rate. This technique requires careful assessment in this particular patient population before any meaningful recommendations can be made. The indications for these procedures have yet to be established, and long-term follow-up is unavailable at this time.

REHABILITATION

Patients with multidirectional instability without a significant posterior component are protected in a sling for 6 weeks, but after 10 days, the arm is removed from the sling for exercises, including isometrics and external rotation to 10° and forward elevation to 90°. From 2 to 4 weeks, external rotation is increased to 30° and forward elevation to 140°, and isometric strengthening is added. From 4 to 6 weeks, external rotation is increased to 40° and forward elevation to approximately 160°, and resistive exercises are begun. After 6 weeks, external rotation is increased to 60° and forward elevation to 180°. After 3 months, external rotation may be progressed. Strengthening begins with the arm in neutral below 90°. As the rehabilitation progresses, more dynamic strengthening exercises are introduced, including the use of medicine balls in various sizes and weights, as well as plyometric exercises.

Patients with classic multidirectional instability and a significant degree of posterior instability are placed in a special brace that holds the arm in a slightly abducted position with neutral rotation (Figure 10). The arm is immobilized in this brace for 6 weeks; only gentle isometric exercises and supervised elbow range of motion are allowed during that time. At 6 weeks, the brace is discontinued, and range-of-motion exercises are gradually introduced. At 12 weeks, progressive strengthening is instituted on an individualized basis.

Figure 10. Brace used in the early postoperative period in patients with multidirectional instability and associated posterior dislocations.
These general protocols are modified on an individual basis as indicated. For example, the dominant shoulder of throwers is progressed more quickly, particularly with reference to external rotation. The objective is to regain motion over several months, because progression that is too quick may lead to recurrent instability. This is especially true in patients with some degree of generalized ligamentous laxity and in younger, late adolescent patients. Careful and frequent postoperative follow-up is necessary, because patients who are not progressing quickly enough may need an accelerated program, whereas those who are regaining motion too quickly may need to be slowed down. Return to contact sports is generally restricted until 9 to 12 months have elapsed.

RESULTS

Several investigators have reported on the treatment of patients with multidirectional instability since 1980. Operative management using the inferior capsular shift has been quite successful. In the initial report by Neer and Foster of 32 patients, only 1 had an unsatisfactory result. One decade later, they reported, “more than 100 additional inferior capsular shifts have been done with similar satisfactory results.” Cooper and Brems reviewed their series of 43 shoulders in 38 patients with a minimum 2-year follow-up after inferior capsular shift. Thirty-nine of 43 shoulders (91%) were rated by the patient as satisfactory, with no recurrent instability. Postoperatively, recurrent symptomatic instability developed in 4 patients (9%). Two of these patients required subsequent revision inferior capsular shifts, and 1 of those later underwent humeral head replacement for arthritis. The latter patient had a prior Bristow procedure. They concluded that the inferior capsular shift procedure provided satisfactory objective and subjective results. Failures and recurrences of symptomatic instability generally occurred in the early postoperative period, less than 2 years after surgery. Their findings did not demonstrate a deterioration of the results with follow-up to 6 years. Bigliani et al reported the results after inferior capsular shift for classic multidirectional instability in 52 shoulders. Average follow-up was 5 years, and all patients were immobilized in a brace for 6 weeks. Satisfactory results were noted in 94% of patients. Hawkins et al reported less favorable results in 31 patients followed for 2 to 5 years. Fewer than 40% of the patients went on to failure.

Altchek et al reported their results following a T-plasty modification of the Bankart procedure for multidirectional instability in 42 shoulders. The patient population differed somewhat in that 38 of the 42 subjects had a Bankart lesion or detachment of the labrum and glenohumeral ligament complex. Patient satisfaction was rated excellent for 40 (95%) of the shoulders, although throwing athletes found they were unable to throw a ball with as much speed as before the operation, and the average loss of external rotation was 5°. Additionally, 7 of 42 shoulders (16%) demonstrated 2+ or greater posterior instability postoperatively. Four patients had symptomatic recurrent instability, 1 anterior and 3 posterior, and 1 patient required a posterior stabilization 2 years postoperatively. Capsular shift procedures in patients with anteroinferior instability have produced satisfactory results as well. Bigliani et al have published preliminary results after performing 75 inferior capsular shifts in young athletes. Eighty-nine percent were able to return to their major sport, whereas 73% maintained the same level of competitiveness. Seven patients (9.3%) reported a single episode of probable subluxation that was not followed by recurrent instability and did not affect the final result, while 2 patients (2.7%) had dislocations postoperatively, both associated with a traumatic episode. The average loss of external rotation was 7°. In the experience of Pollock et al with the inferior capsular shift in 171 anterior repairs, the cause was primarily traumatic in 122 shoulders (71%), repetitive microtrauma in 22 (13%), and atraumatic in 27 (16%). The direction of instability was unidirectional (anterior) in 50 (29%), bidirectional (anterior and inferior) in 87 (51%), and multidirectional (anterior, inferior, and posterior) in 34 (20%). At follow-up averaging 5 years (range, 2 to 13 years), 97 (57%) were rated excellent, 61 (36%) good, 4 (2%) fair, and 8 (5%) poor. Seven shoulders (4%) had recurrent instability. The cause (traumatic, atraumatic, or acquired) and direction (anterior versus anteroinferior versus multidirectional) of the instability did influence the rate of success.

Turkel et al demonstrated that anterior glenohumeral stability is provided by varying regions of the capsule, depending on arm position. Similarly, Warner et al demonstrated that inferior humeral translation is restrained by the anterosuperior capsule and ligaments with the arm at the side and by the inferior capsule and ligaments with the arm in abduction. This is consistent with the clinical findings of Neer and Foster, who described inferior humeral translation with the arm at the side and abducted in patients with multidirectional instability and emphasized reducing redundant capsular volume on all sides during surgical reconstruction. Isolated tensioning of the anterosuperior capsular structures and rotator interval has been proposed to treat the inferior component of instability. While preliminary results are favorable, the role for these variations in technique has not yet been established.

The capsular shift procedure eliminates laxity in the rotator interval, anterosuperior capsule, and anteroinferior capsule and can be continued around the humeral neck to reduce laxity in the posterosuperior and posterior capsule. Thus, it is a highly versatile procedure allowing precise soft tissue balancing on several sides of the joint. Because of the shifting of load between different capsular regions as shown by Turkel et al, the capsular shift affords stability in varying functional positions while preserving motion and is especially useful in the reconstruction of the unstable athletic shoulder.

A versatile surgical approach to shoulder instability is advantageous in that the surgeon is not committed to any 1 technique at the start. Varying degrees of instability can be addressed precisely using a utility approach. Overlap syndromes are especially common in overhead athletes, given their associated repetitive stress and injury. Thus, rather than 2 discrete groups, unidirectional and multidirectional, there is a spectrum of varying amounts of inferior and posterior laxity on which, for example, a traumatic anterior stress may be superimposed. I have found the inferior capsular shift approach very valuable, allowing precise takedown of as much inferior capsule as needed on an individual basis to eliminate a redundant pouch. Thus, one can perform only a modified shift, essentially an anterior capsulorrhaphy, if anterior instability is found, or a full inferior capsular shift for classic multidirectional instability. Additionally, a labral or ligamentous detachment can be repaired to the medial glenoid rim to anchor the capsule before shifting the capsular flaps. In this way, both elements of capsular damage can be addressed.

The inferior capsular shift has become the operative treatment of choice for patients with multidirectional instability.
since the landmark article by Neer and Foster in 1980. Anatomy-deforming procedures, bony procedures, muscle transfers, and procedures designed for unidirectional instability have fallen into disfavor. The inferior capsular shift procedure is a versatile and reliable treatment for patients with multidirectional shoulder instability.

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Superior Labral Lesions: Diagnosis and Management

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Objectives: To review the pathoanatomy, classification, and etiologies of lesions of the superior labrum and biceps anchor (SLAP lesions) and to discuss the clinical presentation, with emphasis on physical examination findings and current treatment recommendations.

Data Sources: We searched MEDLINE for English-language articles published from 1985 to 1999 using the key words "superior labral lesion," "SLAP lesion," "labral tear," and "biceps tendon." Additional information was obtained from cross-referencing pertinent articles and personal communications with experts in the field of shoulder arthroscopy.

Data Synthesis: The clinical presentation of superior labral lesions often includes a history of trauma or repetitive overuse in athletes associated with complaints of pain and clicking or popping in the shoulder. The diagnosis can be difficult, as clinical findings may overlap with those of acromioclavicular or rotator cuff problems and exist concomitantly with glenohumeral instability.

Conclusions/Recommendations: Superior labral lesions are a relatively newly defined cause of shoulder pain and disability. Knowledge about these lesions and a high index of suspicion are essential to identifying this important cause of shoulder pain. Superior labral lesions are usually confirmed and successfully managed arthroscopically.

Key Words: shoulder arthroscopy, SLAP lesion, labral tear, biceps tendon

Our knowledge of the superior labrum and biceps anchor has benefited from the excellent visibility and accessibility provided by the arthroscope, as this area was previously difficult to assess through standard open approaches. Arthroscopy has now allowed us to define normal in vivo anatomy and to begin to understand the variety of labral pathologies that can occur.1

Over the past decade, a number of nonpathologic anatomic variants have been recognized that must be distinguished from labral pathology. Injuries to the superior glenoid labrum are relatively uncommon, found in only 6% of a large series of patients with symptomatic shoulders evaluated arthroscopically.2 These injuries were initially classified and named SLAP lesions (superior labral anterior and posterior lesions) by Snyder et al3 in 1990. It is important to understand that these lesions not only involve the superior glenoid labrum but the biceps and glenohumeral ligament attachments as well.

Anatomy

The anterosuperior labrum extending from the biceps anchor to the midglenoid notch (the 3 o'clock position on the glenoid rim) is one of the most confusing and variable areas of glenohumeral anatomy (Figure 1). Cooper et al4 described the gross anatomy, histology, and vascularity of the glenoid labrum in a cadaver study. The biceps tendon was found to consistently insert directly into the most superior portion of the labrum. At the 12 o'clock position on the glenoid rim, the hyaline cartilage extended over the superior edge, where the attachment of the undersurface of the superior labrum consisted of thin connective tissue. A small recess or synovial reflection just below the biceps insertion on the supraglenoid tubercle was usually present. The anterosuperior labrum was loosely attached to the glenoid, and its configuration and histology resembled that of the meniscus in the knee. Thus, the glenoid labrum is commonly triangular in cross-section, with its free edge pointing toward the glenohumeral articulation. The superior and anterosuperior portions of the labrum are less vascular than the remainder of the labrum, a fact that may have important clinical implications regarding the healing potential of the superior labrum.

The superior and middle glenohumeral ligaments usually attach to the anterior-superior labrum, which in turn attaches to the glenoid rim (Figure 1). However, normal variants of this anatomy must be recognized as nonpathologic. The sublabral foramen is a normal opening or hole between the labrum and glenoid rim. Its size can vary from only a few millimeters to spanning the entire anterior-superior quadrant (Figure 2A). In normal variants, the edges of both the labrum and glenoid are smooth, without the fraying or hemorrhage that would be more suggestive of a pathologic detachment.

In a review of 200 shoulder arthroscopies, Williams et al5 found 24 (12%) such normal sublabral foramina. Seventy-five percent of patients with sublabral foramina also exhibited a cord-like middle glenohumeral ligament (MGHL) that inserted...
directly into the superior labrum at about the 1 o’clock position on the glenoid (Figure 2B). They also defined another uncom­mon (1.5%) normal variant in this area termed the Buford complex, consisting of a cord-like MGHL inserting at the base of the biceps tendon, with a complete lack of anterosuperior labral tissue (Figure 2C). The importance of these variants is emphasized by a case report in which a cord-like MGHL was misinterpreted as a labral detachment and stapled down.6 Severe restriction of external rotation resulted, which required manipulation under anesthesia and capsular release.

CLASSIFICATION OF SUPERIOR GLENOID LESIONS

Snyder et al,3 in 1990, divided superior labral lesions into 4 distinct types according to the pathoanatomy noted at the time of surgery. A type I SLAP lesion has degenerative fraying of the superior labral edge, which remains firmly attached to the glenoid (Figure 3A). In type II lesions, the superior labrum and attached biceps tendon are stripped off the superior glenoid, destabilizing the biceps anchor (Figure 3B). Type III lesions involve a bucket-handle tear of the superior labrum, which may or may not displace into the joint. The peripheral edge of the labrum and biceps anchor remains intact (Figure 3C). In type IV lesions, a bucket-handle tear is present as in type III but with extension into the biceps tendon itself (Figure 3D).

Most superior labrum-biceps tendon complex tears fall into 1 of the above categories. In a large series of 140 superior labrum injuries reviewed by Snyder et al,2 type II lesions were the most common, representing 55% of all lesions, followed by type I lesions (21%), type III lesions (9%), and type IV lesions, (10%). Although other authors have labeled additional types of SLAP lesion, the pathologic findings can usually be described in terms of a combination of the above standard types. Of the 140 lesions reviewed by Snyder et al,2 5% were complex and represented combinations of type II and III or type II and IV lesions.

There is, however, 1 additional labral injury pattern that warrants a designation as type V. Maffet et al7 described 14 cases of a type V SLAP lesion characterized by an anteroinferior Bankart lesion that continued superriorly to include a separation of the anterosuperior labrum and biceps tendon. Warner et al8 reported this identical lesion in 7 cases of arthroscopic repair of the combined Bankart and SLAP lesion in patients with instability.

Reinhart et al9 proposed an alternative approach using clinical criteria as a means of categorizing lesions. They reviewed 52 patients with injuries to the structures of the superior glenoid. Patients were grouped according to clinical presentation, considering history, physical examination, and all the pathologic findings identified at arthroscopy, not just those specific to the glenoid labrum. Understanding that SLAP lesions can be isolated or associated with rotator cuff disease and glenohumeral instability is essential to making the appropriate therapeutic recommendations.

ETIOLOGY

To understand the etiology of superior labral injuries, it is useful to first consider the 2 discretely different mechanisms of injury that have been proposed in the literature: superior compression and inferior traction.

An acute traumatic superior compression force to the shoulder, usually due to a fall onto an outstretched arm with the shoulder positioned in an abducted and slightly forward-flexed position at the time of impact, was the most common mechanism of injury described in the initial series of Snyder et al.3 In a subsequent series, Snyder et al2 again found that the most common mechanism of injury was a fall or direct blow to the shoulder, occurring in 31% of patients.

A significant number of patients with superior glenoid lesions and concomitant impingement or rotator cuff disease in the absence of trauma have also been identified.7 Indeed,
Snyder et al.² found partial-thickness or full-thickness rotator cuff disease in 55 (40%) of 140 patients with SLAP lesions. Superior migration of the humeral head can result from a rotator cuff that is not effectively performing its role as a humeral head depressor. The superior labrum and biceps anchor could theoretically be gradually lifted off the glenoid as a result of chronic repetitive superior translation of the humeral head on the glenoid rim.

Other authors⁷,⁹-¹⁷ supported the theory of an inferior traction mechanism on the basis of a sudden, traumatic, inferior pull on the arm or repetitive microtrauma from overhead sports activity with associated instability. In the series reported by Maffet et al.,⁷ two thirds of patients had an acute traumatic mechanism of injury, 9 of whom had sustained traumatic dislocations. In the series by Snyder et al.², 19% had an episode of glenohumeral subluxation or dislocation, and 16% noted the onset of pain after lifting a heavy object. Bankart lesions were identified in 22% (31/140) of these patients at the time of arthroscopy.

The throwing athlete appears to be prone to this injury.⁷,⁹,¹⁶,¹⁸ Both biomechanical and clinical explanations exist for the occurrence of SLAP lesions in overhead athletes. In a 1985 review of 73 throwing athletes with superior labral injuries, Andrews et al.¹⁰ hypothesized that large forces in the biceps tendon during the deceleration phase of the throwing motion may create SLAP lesions. Electromyographic studies showing increased activity in the biceps after ball release support this theory.¹⁶,²⁰

Underlying instability should always be considered the potential cause for shoulder pain in the athlete, even in the presence of more overt impingement findings. Biomechanical studies have shown that lesions destabilizing the biceps anchor may lead to increased translation of the glenohumeral joint.¹¹,¹⁵,¹⁷ Rodosky et al.¹⁷ in a cadaveric study, found that a superior labral lesion contributed to anterior shoulder instability as it decreased the shoulder’s resistance to torsion and placed greater strain on the inferior glenohumeral ligament. In another cadaveric study, Pagnani et al.¹¹ noted that lesions of the superior labrum that destabilized the insertion of the biceps resulted in significant increases in anteroposterior and superoinferior translation in the lower and middle ranges of shoulder elevation. Furthermore, most clinical series of SLAP lesions contain a subset of patients with concomitant subtle instability.⁷,⁹,¹²-¹⁴,¹⁸,²¹,²²

**CLINICAL PRESENTATION**

The clinical presentation of superior glenoid lesions is quite variable. A review of the literature does not identify a specific constellation of historical or physical findings that are pathognomonic for superior glenoid lesions. In the series of Snyder et al.², lesions were most often found in males (91%). The average patient age was 38 years, and the dominant shoulder was twice as likely as the nondominant shoulder to be involved. In terms of occupation, 31% were heavy laborers, 18% were business personnel, 15% were sedentary, 11% were professionals, 8% were students, 15% had other occupations, and only 2% were professional athletes.

**HISTORY**

The patient may or may not relate a specific event to the onset of symptoms. As previously outlined, various mechanisms of injury have been described, such as falling on an outstretched arm or sustaining a direct blow to the shoulder or a sudden pull on the arm. Many patients do not have a history of a single acute traumatic event but describe an insidious onset of symptoms. In their original article on SLAP lesions, Snyder et al.³ could identify no specific cause in 22% (6/27) of their patients. In the more recent series by Snyder et al.² which included a diverse patient population, 14% of patients (19/140) had an insidious onset of symptoms. Reinhart et al.⁹ attributed the onset of symptoms to an acute event in only 52% of the patients, whereas a gradual onset of symptoms occurred in 48%. Interestingly, most of their patients (75%) were athletes, and repetitive throwing or overhead activity was considered to be the most likely mechanism of injury.

The most common complaint is deep shoulder pain localized to the anterosuperior shoulder between the acromioclavicular (AC) joint and the coracoid, associated with overhead use of the extremity. In addition to deep shoulder pain, symptoms of clicking, catching, or popping are commonly described. In the large series of Snyder et al.², 69/140 (49%) complained of

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*References 2, 3, 6, 7, 9, 10, 14, 16, 18, 23-25.
mechanical symptoms. These mechanical symptoms should raise the clinician’s suspicion for the presence of a SLAP lesion.

**PHYSICAL EXAMINATION**

The physical examination findings in patients with superior glenoid lesions are also variable, but a number of provocative tests can suggest the diagnosis. A complete and careful physical examination can help to distinguish patients with an isolated SLAP lesion from those who have both a SLAP lesion and associated or concomitant problems. In general, the patient with an isolated labral tear exhibits full range of motion and has good rotator cuff strength.

A maneuver referred to as the clunk, or compression rotation, test may be the most specific test for identifying labral mechanical symptoms. These mechanical symptoms should raise the clinician’s suspicion for the presence of a SLAP lesion.

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significant superior glenoid lesion is less likely. If the patient’s symptoms are not improved or are only partially diminished after a subacromial injection, then a superior glenoid lesion should be considered.

RADIOPHASIC EVALUATION

With the clinical presentation often unclear, radiographic and imaging studies are frequently used to aid in the diagnosis. Plain radiographs cannot identify a SLAP lesion, but assessment of the acromial morphology and the AC joint are useful in considering associated disorders. The utility of magnetic resonance imaging (MRI) or computed tomography arthrograms for diagnosing this lesion is touted in the radiology literature.32-41 Chandnani et al 39 prospectively compared MRI, magnetic resonance arthrography (intra-articular gadolinium used with MRI), and computed tomography arthrography in the detection of glenoid labral tears, reporting sensitivities of 93%, 96%, and 73%, respectively.

MRI appears to be somewhat less sensitive in the diagnosis of tears in the superior portion of the labrum. In a prospective study by Gusmer et al,40 unenhanced MRI detected superior labral tears with a sensitivity of 86%. Recently, magnetic resonance arthrography has been applied in an attempt to improve the accuracy of SLAP lesion detection because it more clearly defines injuries to the labrum than conventional MR imaging. In a retrospective study by Chandnani et al,41 magnetic resonance arthrography identified superior labral tears with a sensitivity of 89%, specificity of 88%, and accuracy of 89%.

The value of imaging studies has been questioned in the orthopaedic literature, in which detection of superior glenoid disease has been reported in only 9% to 38% of cases.23,9,14,15 In the large series by Snyder et al,2 73 MRI studies were available for preoperative evaluation. Of these, only 26% suggested a superior glenoid lesion. Regardless of the imaging studies used, a good history and physical examination, combined with a high index of suspicion, are necessary to make the diagnosis preoperatively.27

TREATMENT

Most patients with a suspected superior labral lesion should undergo a period of conservative management, including rest, physical therapy, and nonsteroidal anti-inflammatory drugs. The natural history of superior glenoid lesions is unknown, and no data are available regarding the efficacy of conservative treatment for SLAP lesions. Despite efforts to make the diagnosis preoperatively, most lesions are discovered and treated surgically at the time of arthroscopic diagnosis. In fact, the surgeon may often have a different presumptive diagnosis in mind preoperatively. In the series reported by Maffet et al,7 75% of patients had a preoperative diagnosis of impingement based on history and physical examination. Superior glenoid lesions may also be found in association with shoulder instability. Thus, the surgeon must approach diagnostic arthroscopy with an open mind and be prepared to address all pathologic conditions encountered.42-44

TYPE I LESIONS

For isolated superior glenoid lesions without confounding instability or subacromial disease, management is relatively straightforward. Treatment of type I SLAP lesions is arthroscopic debridement (Figure 4A).2,3,13,23 A motorized shaver with a curved blade is particularly useful for debriding the frayed labral edge back to a stable rim, taking care to preserve the biceps anchor. Posterosuperior labral fraying can occur in young, overhead athletes as a result of abutment of the posterior undersurface of the rotator cuff and greater tuberosity during the late cocking phase of the throwing motion. This mechanism has been termed internal impingement and usually responds to simple debridement.9,19 Normal attritional degeneration of the superior glenoid labrum occurs with age, and in patients more than 40 years old, it is sometimes difficult to determine whether superior labral fraying is clinically significant or just part of the aging process. More likely than not, another primary pathologic process is responsible for the symptoms in this older age group.

TYPE II LESIONS

The critical feature of type II SLAP lesions is the pathologic instability of the biceps insertion. Debridement alone of the frayed labrum and biceps, leaving an unstable biceps anchor, does not provide reliable results.13,23 With the development of operative arthroscopic techniques, the recommended treatment of type II lesions is debridement of the frayed tissue and repair of the detached biceps-labral complex back to the superior glenoid. Various methods of fixation have been proposed, including staples,25 screws and washers,24 multiple transglenoid sutures,14 suture anchors,2,3,14 and absorbable tacks.8,16,24,45 Currently, the use of either suture anchors or absorbable tacks is favored by most surgeons. The biodegradable tack (Suretac, Acufex and Microsurgical Inc, Norwood, MA) is available in both 6-mm and 8-mm sizes and is preferred by the senior author (D.F.D.) because no knot tying is necessary and no metal is retained in the shoulder (Figure 4B).
The surgeon may sometimes find it difficult to decide whether the degree of mobility of the biceps anchor identified at arthroscopy is truly pathologic. It is important to remember that the superior articular surface of the glenoid fossa extends directly to the synovial recess and into the undersurface of the biceps anchor. No bone should be exposed in this location. It is usually necessary to debride labral fraying back to a firm labral edge to allow complete inspection of the biceps anchor. The presence of a hypermobile biceps anchor in association with undersurface fraying or hemorrhage, or both, and exposed bone are suggestive of a type II SLAP lesion.

**TYPE III LESIONS**

Type III lesions represent bucket-handle tears of the labrum with an intact biceps anchor. Resection of the bucket-handle portion of the labrum, again confirming that the biceps origin is intact, is the recommended treatment and should yield satisfactory results (Figure 4C).2,3,13,23

**TYPE IV LESIONS**

The management of type IV SLAP lesions depends on the amount of biceps tendon involved, as well as the stability of its insertion. In most cases, the lesion includes a bucket-handle tear of the labrum and a tear involving a small portion of the biceps tendon. If less than approximately 30% of the width of the biceps is involved, arthroscopic excision of the torn tissue is adequate treatment (Figure 4D).14 If the lesion involves a larger portion of the biceps and superior labrum and the tissue is of adequate quality, repair is indicated.14,16,42–44 Suture anchors are useful in treating this lesion because the labrum and biceps both should be repaired and anchored.14,42,46 If the biceps tear involves more than 50% of the tendon, particularly in an older person with symptoms referable to the biceps tendon and a normal rotator cuff, consideration should be given to primary biceps tenodesis.2,3

**RESULTS OF ARTHROSCOPIC TREATMENT OF SLAP LESIONS**

Grauer et al23 treated 13 patients with superior labral lesions (4 type I, 6 type II, 3 type III) with debridement only and noted satisfactory results in 12 of the patients at an average follow-up of 18 months. However, all patients noted occasional pain after heavy activity or sports. Cordasco et al13 reviewed the results of arthroscopic debridement of 27 SLAP lesions (7 type I, 17 type II, 2 type III, 1 type IV). Initially, 78% of patients had excellent pain relief and 52% were able to return to their sports at the same level. However, these results deteriorated over time such that only 63% of patients still had excellent pain relief and only 45% of patients were capable of returning to their previous athletic performance at 2-year follow-up. These authors treated all types of SLAP lesions with debridement only, leaving the biceps anchor unstable in many cases.

Yoneca et al42 treated 10 type II SLAP lesions with arthroscopic stapling and noted excellent or good results in 8 patients at follow-up at over 24 months. However, because of concerns about possible staple loosening, all patients underwent a second arthroscopy for staple removal at 3 to 6 months. Resch et al24 reported on 14 patients with type II SLAP lesions repaired with screws (6 patients) or absorbable tacks (8 patients). At mean follow-up of 18 months, an excellent result was noted in 8 patients, who were able to return to their previous level of athletic performance. Field and Savoie14 repaired type II and IV SLAP lesions with multiple sutures and reported 100% good results at an average follow-up of 21 months. Pagnani et al16 reported 22 superior glenoid lesions with unstable biceps anchors (16 type II, 6 type IV), which were stabilized with absorbable tacks. At 2-year follow-up, 86% of the patients had satisfactory results, and no complications were related to use of the tack.

Two recent reports on the long-term results of arthroscopically treated superior glenoid lesions are noteworthy. Samani et al47 presented the results of 25 patients with type II SLAP lesions that were stabilized arthroscopically using a bioabsorbable tack. At average follow-up of 35 months, 24 (96%) of the patients had good or excellent results (using the UCLA rating scale) and returned to their preinjury level of work and athletic participation. Asymptomatic tack osteolysis was noted on postoperative radiographs in 2 patients.

Stetson et al48 presented the long-term results of 140 SLAP lesions with follow-up available on 130 patients at an average of 3.2 years. Type I lesions were identified in 30 patients (23%) and were treated with debridement. Type II lesions were found in 61 patients (47%) and were stabilized with suture anchors in most patients. Type III lesions in 14 patients (11%) and type IV lesions in 17 patients (13%) were debrided. Finally, complex SLAP lesions were identified in 8 patients (6%) and treated with debridement and reattachment with a suture anchor. Using the UCLA rating scale, 103 (79%) had a good or excellent result, 22 (17%) had a fair result, and 5 (4%) had a poor result. Complications included fragmentation of a bioabsorbable tack in 5 patients, requiring surgical removal. Because of this finding, the authors switched from the absorbable tack to a removable screw-in suture anchor for stabilization of type II SLAP lesions. These results suggest that the arthroscopic treatment of SLAP lesions provides reliable long-term results.

**SUMMARY**

Superior glenoid lesions or SLAP lesions are an infrequent but important cause of shoulder pain and disability. Extremely variable presentations with nonspecific clinical and radiographic findings make preoperative diagnosis of superior glenoid lesions difficult. In a patient with shoulder pain and mechanical symptoms such as clicking, catching, or popping, a high index of suspicion for labral lesions is necessary.

These lesions can usually be diagnosed and managed arthroscopically. Type I lesions require only debridement of the frayed labral edge. Type II lesions are most common and are best treated with suture anchor or biodegradable-tack fixation of the unstable biceps anchor. Type III lesions should be treated with debridement of the bucket-handle portion of the superior labrum. Finally, type IV lesions may require debridement of the torn portion of labrum and biceps tendon, arthroscopic repair and stabilization, or biceps tenodesis, depending on the amount of biceps tendon involvement. Associated pathology, including instability, impingement syndrome, and rotator cuff tears are common. It is essential that these concomitant problems be recognized and treated appropriately at the time of surgery to optimize the patient’s outcome.

Additional clinical experience and further studies are necessary to gain a better understanding of the underlying causes of these lesions and to improve our ability to diagnose them preoperatively. As our knowledge of superior glenoid pathol-
ogy improves, so will our ability to manage these lesions as we strive for reliable and successful clinical results.

REFERENCES

Evaluation of Impingement Syndromes in the Overhead-Throwing Athlete

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*Loma Linda University, School of Medicine, Loma Linda, CA; †Dodger Stadium, Los Angeles, CA

Objective: We outline impingement entities, describe the history and physical examination, and provide an overview of treatment beyond that routinely used in glenohumeral and scapulothoracic dysfunction.

Background: In the athlete, pain and dysfunction due to excessive overhead use or abnormal positioning of the shoulder is common and can result from multiple etiologies, including impingement syndromes. Primary, secondary, internal, and coracoid impingement syndromes have all been described. The treatment of shoulder problems must be carefully considered and then patiently and diligently undertaken to return the shoulder to its preinjury form. Primary impingement is due to abnormal excursion of the supraspinatus tendon under the subacromial arch during repetitive overhead throwing motions. This was the original impingement entity as described by Neer. Primary impingement has been attributed to abnormalities of the shape of the acromion and other static and dynamic causes. While controversies still exist with regard to primary impingement, we have a reasonable understanding of this entity. Existing controversies include which structures are involved and the role of physical contact in the overall scheme of supraspinatus tendinosis and degeneration.

Secondary impingement is a similar entity but in this case is due to an occult dynamic instability (usually anterior), which leads to symptoms similar to those seen in primary impingement. The fact that an underlying instability could cause similar impingement symptoms became evident as traditional conservative and operative interventional approaches for what was assumed to be primary impingement were unsuccessful. It became evident that the instability needed to be addressed first as the primary pathology, with subsequent resolution of the impingement condition. Other, more recent impingement entities include internal impingement and coracoid impingement. Internal impingement denotes contact between the posterior glenoid rim and the posterior aspect of the insertion of the supraspinatus and the superior aspect of the infraspinatus tendon insertion into the posterior greater tuberosity (Figure 1). This condition also has been related to arm position, especially in pitchers. Coracoid impingement is usually associated with anterior shoulder pain at the extremes of internal rotation.

Figure 2 attempts to organize these impingement entities in a systematic fashion with respect to static and dynamic components and contributing factors. The listed causes are not necessarily mutually exclusive, but an attempt should be made to identify a main etiologic factor for focused treatment. Static causes may be age related. Table 1 lists the elements of the history, physical examination, and imaging with regard to these entities. Table 2 lists specific treatments in addition to a general glenohumeral and scapulothoracic program, while the patient avoids overhead or cross-body motions.

New treatment plans are evolving for primary, secondary, and internal impingement. In this fairly new area of interest, questions often beget more questions instead of answers. Primary impingement knowledge is in a relatively advanced stage, and secondary impingement due to instability is an established entity. However, our understanding of internal impingement and coracoid impingement due to instability or pathomechanics is in its scientific infancy. Our purpose is to present current concepts for primary, secondary, and internal impingement. This will include an overview of the history and physical examination for each, followed by an in-depth review of current treatment strategies beyond those routinely used for glenohumeral and scapulothoracic dysfunction.

We intend to organize the clinician's thought process toward treatment-plan design and implementation. An overview of the individual tests as discussed is beyond the scope of this article but has been previously reported. Treatment will be summarized, with additions to the basic glenohumeral and scapulothoracic rehabilitation for range of motion, strengthening, proprioception, and functional training.

Soft tissue mobilization may include contract-relax and massage. Joint mobilization may include oscillation, hold-stretch, and scapular side-lying distraction. Therapeutic exercises involve the scapula (retraction, elevation, and depres-
the Neer sign, the supraspinatus is well past the acromion. The full elevation and internal rotation. Note that in this position, that of structures at risk are (1) greater tuberosity, (2) rotator cuff tendon, (3) labrum and biceps origin, (4) inferior glenohumeral ligament and labrum, and (5) the bony glenoid. (Reprinted with permission from Figure 1. Anatomic cross-section. The cadaver’s arm was placed in full elevation and internal rotation. Note that in this position, that of the Neer sign, the supraspinatus is well past the acromion. The structures at risk are (1) greater tuberosity, (2) rotator cuff tendon, (3) labrum and biceps origin, (4) inferior glenohumeral ligament and labrum, and (5) the bony glenoid. (Reprinted with permission from Orthopedic Clinics of North America.)

Compensatory abnormalities and dysfunction of the shoulder girdle are becoming better understood. These include muscular fatigue due to overuse, with related sequelae, and mechanical disadvantages as the scapulothoracic portion of the upper extremity attempts to compensate for decreased glenohumeral function. Parascapular and paracervical muscles develop tightness and spasm with upper medial scapular border trigger points and decreased scapulothoracic range of motion. These areas of involvement need to be treated with stretching and strengthening to bring the shoulder to a state of normalcy.

Impingement (Symptoms) Acromioclavicular degenerative joint disease Hooked acromion Ossification of ligament Os acromiale Coracoid change

Against arch Weak muscles Tight posterior capsule

Coracoid Glenoid Abduction, external rotation (Internal) Flexion, internal rotation?

Figure 2. Impingement entities: biomechanical causes, static and dynamic.

PRIMARY IMPINGEMENT

Pathology

Primary impingement has been identified as a pathologic involvement of the subacromial bursa and supraspinatus tendon, leading to inflammatory changes of the bursa. Morphologic or age-related changes are often involved (Figure 2), resulting in pain with overhead or repetitive arm motions. Secondary impingement presents similarly but is a result of glenohumeral instability from joint laxity and stressful demands. Secondary impingement is often due to repetitive abduction and external rotation positioning and loading of the arm during sports or occupational activities. “Impingement” of the supraspinatus tendon in the subacromial space has been described and examined in depth, including the contribution of acromion shape, acromioclavicular joint deformity or spurs, coracocromial ligament contact, and decreased subacromial volume. All of these can lead to contact and inflammatory changes of the subacromial bursa and the tendon itself. The innervation of the subacromial bursa with a higher percentage of pain fibers has been shown. Acromion type has been implicated in compromising the subacromial space. Bigliani et al described 3 commonly seen types: flat, curved, and hooked, with a correlated incidence of rotator cuff involvement. Degenerative changes with spurring of the acromioclavicular joint are common with increased age and can impinge on the tendon. The 5 stages of tendon involvement, as described by Neer, have been simplified and probably include a greater spectrum of disease and aging pathology.

In addition to the bony boundaries of the path of the supraspinatus tendon, other factors such as soft tissue changes also contribute. These include any abnormalities in the normal biomechanics of the rotator cuff musculature. Capsular tightness, especially at the posterior aspect, has been implicated as a significant factor for abnormal position and motion of the humeral head, especially in abduction and external rotation (Figure 3). Significant changes in the range of motion of the overhead athlete can often be elicited compared with the contralateral side. These often include increased external rotation and decreased internal rotation. Muscular timing and firing in different phases of sport-related motion also contribute to the development of an abnormal or unbalanced shoulder. Acute, relatively minor injuries may be enough to literally “throw” the shoulder out of synchrony in such a way that compensation leads to abnormal motion. In a downward cyclic fashion, this can lead to further deterioration of the overall function of the shoulder. The development of scapulothoracic dysfunction has also been elucidated; this condition is often a sequel of impingement. Therefore, rehabilitation of the entire shoulder girdle to achieve normal shoulder mechanics is necessary. Range of motion, strengthening, proprioception, and conditioning are all important and are often addressed in that order or concurrently. Regaining the extremes of range of motion allows full use of muscle length, and therefore, tension curves and moment arm advantages. Nonoptimal muscle function and fatigue, which makes cowards of us all and also may lead to physiologic decompensation, can be improved with strengthening and conditioning. The importance of proprioception is just beginning to be appreciated, but like the fine timing of a gyroscope, it allows a careful balance of the involved kinetic and potential energies with direct and indirect feedback mechanisms from neural structures.
Table 1. History and Physical Examination Findings for Etiologies of Impingement-Type Shoulder Pain

<table>
<thead>
<tr>
<th>Entities</th>
<th>Activity</th>
<th>Pain Location</th>
<th>Association</th>
<th>Impingement Signs</th>
<th>Palpation Tenderness</th>
<th>Relocation Test</th>
<th>Apprehension Test</th>
<th>Internal Rotation</th>
<th>Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromioclavicular joint degenerative disease</td>
<td>Cross-body abduction/overhead</td>
<td>Acromioclavicular joint</td>
<td>History of acromioclavicular separation, older age</td>
<td>-/+</td>
<td>Acromioclavicular joint</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X-ray</td>
</tr>
<tr>
<td>Hooked acromion</td>
<td>Overhead</td>
<td>Lateral</td>
<td>Older</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X-ray supraspinatus outlet</td>
</tr>
<tr>
<td>Ossification of coracoacromial ligament</td>
<td>Overhead</td>
<td>Anterolateral</td>
<td>Older</td>
<td>+/-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X-ray</td>
</tr>
<tr>
<td>Os acromiale</td>
<td>Overhead</td>
<td>Fibrous union</td>
<td>Impingement secondary to undersurface enlargement</td>
<td>+/-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Auxillary lateral CT MRI</td>
</tr>
<tr>
<td>Coracoid</td>
<td>Internal rotation/adduction</td>
<td>Coracoid/anterior</td>
<td>Internal rotation</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MRI</td>
</tr>
<tr>
<td>Weak muscles/anterior laxity</td>
<td>Overhead fatigue</td>
<td>Anterior/posterior</td>
<td>Overhead throwing, repetitive</td>
<td>+</td>
<td>Anterior/posterior</td>
<td>+/-</td>
<td>?/?</td>
<td>Usually</td>
<td>MRI</td>
</tr>
<tr>
<td>Tight posterior capsule</td>
<td>Throw</td>
<td>Posterior/anterior</td>
<td>Long history of throwing, decreased internal rotation</td>
<td>+/-</td>
<td>-</td>
<td>-/+</td>
<td>+/-</td>
<td>§§</td>
<td>MRI</td>
</tr>
<tr>
<td>Glenoid (internal) impingement</td>
<td>Abduction, external rotation, throwing</td>
<td>Posterior</td>
<td>Throwing fatigue</td>
<td>-</td>
<td>Posterior</td>
<td>+</td>
<td>Extreme of external rotation</td>
<td>+/-</td>
<td>MRI in abduction/external rotation</td>
</tr>
</tbody>
</table>

Evaluation, Diagnosis, and Treatment

Primary impingement may be seen in the weakened or ill-conditioned athlete who develops acute pain after a sudden increase in overhead activities. Pain is often localized to the lateral aspect of the shoulder. Positive impingement signs include those described by Hawkins and Kennedy and Neer and Welsh. Isolated supraspinatus testing reveals muscle strength that is not appreciably decreased but with guarding. This short-duration condition is often without significant weakness, abnormal range of motion, or other findings. It usually responds well to a few days of rest until pain is eliminated and then a progressive stretching and rotator cuff strengthening program is begun. Overhead and cross-body activities should be avoided, as the extremes of position (or repetitive excursion to near these extremes) place the glenohumeral structures at risk for abnormal contact. This may lead to inflammation secondary to tissue damage and possibly impede a normal healing process. The Hawkins and Kennedy and Neer and Welsh tests for impingement are prime examples of motions that physiologically narrow the subacromial space and cause possible contact between the greater tuberosity structures and the lateral acromion. Patients with primary impingement often do not have posterior capsular tightness or other instability leading to their symptoms. The impingement was due to a failure of muscular restraints by the untrained (and therefore fatiguing) rotator cuff soft tissue envelope when faced with a dynamic challenge. If any range of motion has been lost, stretching to regain a normal range is important. Strengthening,

Figure 3. Stiffness of the posterior glenohumeral capsule is commonly associated with signs of impingement. A, A normally lax posterior capsule allows the humeral head to remain centered in the glenoid with shoulder flexion. B, Stiffness of the posterior glenohumeral capsule will aggravate the impingement process by forcing the humeral head upward against the anteroinferior acromion as the shoulder is flexed. This upward translation in association with rotation is analogous to the action of a spinning yo-yo climbing a string. (Reprinted with permission from The Shoulder. Vol 2. 2nd ed. Copyright 1990, WB Saunders.)

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Table 2. Treatment Variations in Addition to a General Glenohumeral and Scapulothoracic Program (Avoiding Overhead and Cross-Body Motions)

<table>
<thead>
<tr>
<th>Entity</th>
<th>Conservative Treatment</th>
<th>Operative Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromioclavicular joint degenerative disease</td>
<td>Corticosteroid injection</td>
<td>Arthroscopic subacromial decompression, distal clavicle resection</td>
</tr>
<tr>
<td>Hooked acromion</td>
<td>Rotator cuff strengthening</td>
<td>Arthroscopic subacromial decompression, distal clavicle resection</td>
</tr>
<tr>
<td>Ossification of coracoacromial ligament</td>
<td></td>
<td>Release, arthroscopic subacromial decompression</td>
</tr>
<tr>
<td>Os acromiale</td>
<td></td>
<td>Resection/open reduction, internal fixation</td>
</tr>
<tr>
<td>Coracoid spurs</td>
<td>Rotator cuff strengthening</td>
<td>Resection?</td>
</tr>
<tr>
<td>Weak muscles</td>
<td>Stretching</td>
<td></td>
</tr>
<tr>
<td>Tight posterior capsule</td>
<td>Rotator cuff strengthening</td>
<td>Anterior capsular ligament repair, osteotomy with subscapularis shortening</td>
</tr>
<tr>
<td>Glenoid (internal) impingement</td>
<td>Rotator cuff strengthening</td>
<td></td>
</tr>
</tbody>
</table>

including the subscapular, supraspinatus, infraspinatus, and scapulothoracic musculature, reestablishes a balanced rotator cuff envelope (Figure 4, group I). This readily allows not only normal but gradually increased repetitive motion. A fall on an outstretched hand may contuse the supraspinatus tendon between the humeral head and the acromion and produce a similar inflammatory state, which usually resolves in like fashion.

Failure to improve with rehabilitation may indicate morphologic factors that decrease the subacromial space, and occasionally open or arthroscopic subacromial decompression may be needed for recalcitrant cases. A preoperative magnetic resonance imaging scan is often helpful to elucidate mechanical factors and evaluate rotator cuff tendon integrity for possible tears. Primary impingement is not the only commonly seen cause of lateral shoulder pain with overhead use; the overhead throwing athlete also must be carefully screened for secondary or internal impingement.

SECONDARY IMPINGEMENT

Pathology

Secondary impingement denotes a similar pathologic situation but is due to underlying instability of the shoulder. Abnormal glenohumeral translational motion, usually anterior, involving either anterior structures (with irritation or injury to the subscapularis and the anterior capsular structures) or superiorly (with involvement of the supraspinatus tendon) is seen. This condition was first identified in patients with subtle underlying instability who did not recover as expected after subacromial decompression to alter the subacromial morphology by increasing the available space traversed by the supraspinatus tendon. It became evident that correction of the instability as a primary pathology was needed, with increasing subacromial space being a secondary concern. Patient history is often similar to

Figure 4. Classification of shoulder pain. Group 1, Primary impingement. Group 2, Secondary impingement. Group 3, Global instability with secondary impingement. Group 4, Anterior instability. (Modified with permission from The Shoulder. Vol 2. 2nd ed. Copyright 1990, WB Saunders.)

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that in primary impingement, with the onset after prolonged, aggressive, high-speed, overhead use. The result is gradual onset of activity-related pain that is recalcitrant to conservative or operative interventions aimed at the subacromial space. This injury often occurs during the late cocking or early acceleration phase of throwing (Figure 5). A SLAP lesion, or disruption of the superior labrum at the origin of the biceps tendon, may cause articular symptoms. This can occur as a primary problem or possibly as a result of instability. The clinical picture of a painful SLAP lesion may be confounding, so intra-articular biceps tendon symptoms must be elicited. An in-depth discussion of SLAP pathology is beyond the scope of this article, but a thorough understanding of this entity is necessary. The modified Speed test (done in the scapular plane) may be positive, but this test can also be painful with supraspinatus inflammation. A recently described SLAP provocation test seems useful.11

Evaluation, Diagnosis, and Treatment

The physical examination shows positive impingement signs and may show subtle instability, including a mild sulcus sign (possible underlying global ligamentous laxity), a mild anterior shift, and pain elicited in the late cocking or early acceleration phase of pitching. The apprehension and relocation tests are usually positive.9 Examination under anesthesia shows increased translational motion. Arthroscopic findings include evidence of the increased translational motion with forward pressure and labral fraying consistent with mild instability, as well as possible partial rotator cuff tear.

Rehabilitation again emphasizes strengthening of the rotator cuff and scapulothoracic musculature to reestablish a balanced rotator cuff envelope (Figure 4, groups 2 and 3). A partial rotator cuff tear may also cause calcific symptoms. Failure to improve with rehabilitation may indicate a degree of instability that requires operative intervention, possibly anterior capsular labral reconstruction.9 Always remember that the throwing athlete may develop a subtle instability that mimics primary impingement but responds to treatment of the instability. In addition, careful screening for impingement is important in the throwing athlete.

INTERNAL IMPINGEMENT

Pathology

Internal impingement is due to contact between the posterior superior glenoid labrum and the posterior aspect of the supraspinatus tendon or the superior aspect of the infraspinatus tendon, or both, at the insertion in the greater tuberosity (Figure 1). It is usually seen with arm use that involves abduction and the extremes of external rotation, such as those seen in the late cocking stage of pitching. It has been implicated in athletic throwing injuries and positional shoulder pain. This diagnosis is relatively new, and the pathomechanics are being elucidated. Some experts feel that an underlying instability of the shoulder leads to this glenoid impingement. Others feel that the impingement is a result of abnormal biomechanics and that the resulting injury to the superior labral complex may contribute to the development of an instability pattern.

Evaluation, Diagnosis, and Treatment

With early internal impingement, the thrower (the incidence of glenoid impingement in throwers, especially pitchers, is high) or involved patient reports the shoulder is stiff and not loosening up as it normally would. Three stages of internal impingement have been described (Table 3). A decrease in pitching ability and quality should be observed carefully. At this early point, the pitcher should be removed from participation, and rehabilitation should be undertaken. If the thrower is allowed to pitch past the point of stiffness until pain is reported, then it is much harder to resolve this entity satisfactorily with conservative care. Pain is usually reported in the late cocking phase of pitching. It is important, before treatment is undertaken, to rule out other anterior instability pathology, including SLAP lesions, labral tears, and partial rotator cuff tears. The apprehension sign (at the extreme of external rotation) is positive as contact is made between the superior labrum and the supraspinatus insertion. The relocation test may also be positive as this pressure is relieved.12 If the patient has unidirectional instability, slight anterior laxity may be evident. With multidirectional instability, care must be taken not to stretch aggressively, as ligamentous laxity is a component of the problem. Examination of the shoulder must include exam-
Table 3. Stages of Glenoid Impingement in Current Therapy*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Symptomatology</th>
<th>Therapy</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Stiffness</td>
<td>2 weeks of throwing</td>
</tr>
<tr>
<td></td>
<td>Slow warm-up</td>
<td>Strengthen cuff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strengthen scapular</td>
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<tr>
<td></td>
<td></td>
<td>rotators</td>
</tr>
<tr>
<td>II</td>
<td>Posterior pain</td>
<td>4–12 weeks of throwing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>plus rehabilitation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>program</td>
</tr>
<tr>
<td></td>
<td>Positive relocation test</td>
<td>Same as stage II plus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>failure of rehabilitation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>program</td>
</tr>
<tr>
<td>III</td>
<td>Same as stage II plus</td>
<td>Anterior capsulolabral</td>
</tr>
<tr>
<td></td>
<td>failure of rehabilitation</td>
<td>reconstruction</td>
</tr>
</tbody>
</table>

*Reprinted with permission from Orthopedic Clinics of North America.3

ination for tightness of the posterior capsule, which, if left uncorrected, probably dooms the treatment plan to failure. The normal shoulder should have a mild degree of posterior translation with pressure in that direction. Loss of this normal motion, as well as markedly decreased internal rotation with the arm in 90° of abduction, indicates tight or restrictive posterior soft tissue, which is usually the posterior capsule.

Treatment Considerations

A strengthening program targeting the humeral and scapular rotators to treat the 3 stages of internal impingement has been proposed (Table 3).3 The key is to identify internal impingement early and stretch to improve range of motion and decrease posterior capsular tightness, while strengthening to improve the soft tissue envelope restraint and retraining to avoid recurrence.

Stretching of both the posterior capsule and posterior musculature is important.5 Both the capsule and the musculature can be stretched passively with the arm in 45° of abduction. The patient lies supine on the table to stabilize the scapula. The patient with internal impingement often has very tight posterior soft tissue structures. Posterior pressure can be applied to the anterior humeral head area and held to stretch these posterior structures. This is done by the athletic trainer or caregiver, who may feel improvement of posterior mobility with gradual constant pressure and repeated stretching treatments, leading to a gradual increase in shoulder mobility. A component of posterior stiffness may be reflexive guarding in the injured shoulder. Care should be taken to decrease and relieve this protective mechanism by appropriate techniques, such as massage, relaxation, and low-energy, high-repetition kinetic training. Emphasis on internal rotation and stretching of the posterior capsule is also important. Selective stretching of the tight capsular structure while protecting any area of laxity is necessary.

An advanced and dedicated program of glenohumeral rotator cuff and scapulothoracic musculature strengthening and stabilization is crucial. Subscapular strengthening to resist overan- gulation at the end of the late cocking phase is helpful. Weight training may be more effective than plyometric training, as it is difficult to mimic actual throwing physiology and biomechanics using a weighted ball. Current research includes proprioceptive guidance of rotator cuff muscle firing by immediate neuromusculature feedback to control glenohumeral positioning in different arm orientations. Mechanically, this is similar to balancing a stick on the palm of your hand, and the hope is that optimized, controlled, small-muscle firing can be used to train and help the pitcher optimize glenohumeral stability.

Surgical intervention may occasionally be indicated and can include anterior capsular labral reconstruction. Derotational humeral osteotomy and subscapular shortening has been proposed.13 This procedure may be appropriate in the patient with low humeral retroversion and no hyperlaxity whose symptoms are not improving. Careful screening for primary, secondary, and internal impingement using history and activity correlation, pain location, selected physical examination, and imaging should allow identification of the pathomechanical etiology of lateral shoulder pain in most throwing athletes.

CORACOID IMPINGEMENT

Coracoid impingement is a newly examined entity causing anterior shoulder pain that usually occurs with forward flexion and internal rotation.14 It has been related to decreased distance between the coracoid and the anterior humeral structures in anatomic studies.15,16 Current understanding in this area is in its infancy, and the pathomechanics remain to be elucidated.

SUMMARY

Shoulder pain is common in the overhead athlete.17–21 Optimizing range of motion,22 strength,23 and biomechanics is

Figure 6. Hypothetical pathogenesis of secondary and internal impingement.
important in preventing shoulder pain. Careful observation and communication with the athlete is needed to identify problems early. Treatment of the painful throwing shoulder requires a systematic thought process and a treatment plan that is centered on the shoulder, much as the entire function of the body to throw is centered at this point. A poorly thought-out approach to treatment is doomed to failure. The treatment regimen and its basis must be thoroughly understood by the physician, athletic trainer, and patient.

Evaluation must include a carefully elicited history, with attention paid to the onset of symptoms, phase of activity involved, and location of pain. Physical examination must include active and passive range of motion, strength testing, and localizing tests particularly suited to the shoulder. The localizing tests should be those that the examiner feels are reliable and with which he or she feels comfortable. Videos outlining these tests are available and helpful. Recorded observation of pitching technique is invaluable in assessing biomechanical changes and compensatory mechanisms. Radiographic examination is often not helpful, except for possibly contrast-enhanced magnetic resonance imaging. Cessation of the aggravating activity as early as possible in the developing stage is important, and identifying the etiology is the key.

A systematic approach to diagnosis and treatment is crucial. The caregiver must feel comfortable gaining enough information to guide diagnosis and treatment and be able to elicit subtle nuances between the different syndromes. Primary impingement is often a 1-time occurrence in the overhead “weekend warrior.” Secondary impingement and internal impingement are more likely in the overhead athlete. Posterior pain at 90° of abduction and the extreme of external rotation may indicate internal impingement if the apprehension sign (not at the extreme of external rotation) is not as remarkable. Internal impingement pathogenesis is currently an area of discussion, and Riand et al did not feel that laxity was a factor in their reported cases. The pathogenesis shown in Figure 6 may be 1 hypothetical model, but this is still to be elucidated. The involvement of SLAP lesions in this mechanism is also a possibility.

Rehabilitation must include regaining range of motion, strength, and dynamic stabilization (D. Caborn, personal communication, 1996), including trunk, scapulothoracic, and glenohumeral muscles, as well as dynamic functional rehabilitation with endurance. The role of proprioception in rehabilitation is currently under investigation but holds promise. Training the rotator cuff musculature to fine-tuned control may be a key factor in optimization. Conservative care is often successful if the injury is diagnosed early and appropriate treatment is undertaken. Removing the athlete from the pitching rotation early may avoid soft tissue changes that can be recalcitrant to rest and rehabilitation. If rehabilitation alone is unsuccessful, then surgical options need to be discussed, but postoperative rehabilitation again is key. Surgical treatment consists of possible debridement of posterior labral lesions or partial rotator cuff tears. Laxity procedures include capsulolabral reconstructions, thermocapsular shrinkage, and rotator interval closure or plication. Treatment of the painful shoulder in the overhead-throwing athlete is, and will remain, a challenge.

REFERENCES


Management of Rotator Cuff and Impingement Injuries in the Athlete

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Objective: To review current concepts of the pathophysiology, diagnosis, and treatment of rotator cuff and impingement injuries in the athlete.

Data Sources: The information we present was compiled from a review of classic and recently published material regarding rotator cuff and impingement injuries. These materials were identified through a search of the MEDLINE. In addition, much of the information presented represents observations and opinions of the authors developed over 8 to 10 years of treating shoulder injuries in athletes.

Data Synthesis: Biomechanics of the normal shoulder and pathophysiology of rotator cuff injuries in the athletic population are discussed, followed by a summary of the important diagnostic features of rotator cuff and impingement injuries. The principles of rehabilitation are extensively presented, along with indications and important technical aspects of selected surgical procedures. General principles and specific protocols of postoperative rehabilitation are also summarized.

Conclusions/Recommendations: Rotator cuff and impingement injuries in the athletic population are multifactorial in etiology, exhibiting significant overlap with glenohumeral instability. Nonoperative treatment is successful in most athletic patients with rotator cuff and impingement injuries. When nonoperative treatment fails, arthroscopic surgical techniques such as rotator cuff repair and subacromial decompression may be successful in returning the athlete to competition.

Key Words: impingement, rotator cuff tear, glenohumeral instability, arthroscopy

According to Neer, rotator cuff tears are usually the result of subacromial impingement, and they are most common in patients over 40 years of age. However, these observations apply primarily to patients who are not involved in regular athletic activity. Although primary impingement-related rotator cuff disease may also exist in the athletic population, other etiologic factors may be more important. These factors include repetitive overuse, glenohumeral ligamentous laxity, soft tissue contracture (especially of the posterior capsule), and poor scapular mechanics. As a result of these other mitigating factors, management of rotator cuff disease in the athletic population can be difficult.

Among athletic patients, overhead athletes are perhaps the most susceptible to rotator cuff injuries. They exhibit a high incidence of age-adjusted partial and small complete rotator cuff tears. In addition, they are often unwilling to modify their activities. Consequently, the persistently high demands on the rotator cuff may predispose them to recurrent episodes of anterior, rotator cuff-related shoulder pain. Successful management of these patients requires a thorough knowledge of the relevant pathoanatomy, as well as an accurate and complete diagnosis. Our purpose is to review the biomechanics, pathophysiology, diagnosis, management, postoperative rehabilitation, and treatment results of rotator cuff and impingement injuries in the athlete.

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BIOMECHANICS
Most athletic endeavors potentially place significant stress on the shoulder joint and surrounding structures. However, overhead sports such as swimming, tennis, and baseball are among the most demanding on the shoulder. The baseball pitching motion has been extensively studied and provides several principles that are applicable to other overhead sporting activities.

A baseball pitcher accelerates a 142-g baseball from 0 to 184.84 kph (90 mph) in 50 milliseconds. This results in an angular velocity of 6100°·s⁻¹ and a joint compressive load of approximately 860 N. Safe and efficient transfer of energy of this magnitude from the back and lower extremities to the pitching arm to the baseball requires highly complex and synchronous interactions among the trunk and lower extremity muscles, scapular rotators, extrinsic shoulder muscles (ie, latissimus dorsi and pectoralis major), intrinsic shoulder muscles (ie, rotator cuff), and static capsular restraints.

The baseball pitch has been divided into 5 stages for the purposes of discussion and ease of understanding (Figure 1). The 5 stages of the baseball pitch are wind-up (stage 1), early cocking (stage 2), late cocking (stage 3), acceleration (stage 4), and follow-through (stage 5). A detailed discussion of these 5 stages is beyond the scope of this article; however, certain points deserve emphasis.

During the wind-up, the rotator cuff muscles are relatively inactive. In the early cocking phase, the superior and posterior rotator cuff muscles (ie, supraspinatus, infraspinatus, and teres minor) contract concentrically to bring the arm into abduction and external rotation. During the late cocking phase, the trunk rolls forward, the posterior rotator cuff continues its vigorous
Stage 2
Stage 3
Stage 4
Stage 5

Figure 1. The five stages of the baseball pitch include wind-up (stage 1), early cocking (stage 2), late cocking (stage 3), acceleration (stage 4), and follow-through (stage 5). (Reprinted with permission. Tibone JE, McMahon PJ. Biomechanics and pathologic lesions in the overhead athlete. In: Iannotti JP, Williams GR Jr, eds. Disorders of the Shoulder: Diagnosis and Management. Lippincott Williams & Wilkins; 1999.)

PATHOPHYSIOLOGY

Rotator cuff injuries in overhead athletes are rarely the result of a single etiologic factor. The complex interaction among the rotator cuff, the static capsular restraints, and the scapular stabilizers can be disrupted by abnormalities of any of these component structures. Potential contributing factors to rotator cuff injuries in the athlete include tensile failure of the rotator cuff tendon fibers, poor scapular mechanics, rotator cuff imbalance, anterior capsular laxity, posterior capsular contracture, and traditional supraspinatus outlet narrowing. Rotator cuff and impingement injuries are usually the result of a number of these etiologic factors acting concurrently.

Tensile Failure

Except during the wind-up phase, the rotator cuff muscles are quite active during the pitching motion. They are primarily responsible for generating the glenohumeral compressive load that occurs during throwing. The superior and posterior rotator cuff muscles in particular (ie, the supraspinatus, infraspinatus, and teres minor) come under significant stress, because they contract maximally in the early, cocking phases as well as in the follow-through phase of throwing. During the follow-through, the arm must be gradually decelerated from its maximum velocity of 6100°s⁻¹. This requires a rapid and well-coordinated eccentric contraction from the superior and posterior rotator cuff. Moreover, the eccentric nature of this contraction creates the potential for tendon injury. In reality, the musculotendinous units of the superior and posterior rotator cuff are rapidly elongating at a rate and magnitude that are determined by the force of their contraction. If the timing and force of contraction are not adequate, continued rotation of the humerus may result in tensile failure of rotator cuff tendon fibers. When this occurs repeatedly, the tendon may become weakened or inflamed and more susceptible to recurrent injury.

Poor Scapular Mechanics

Overhead function requires a delicate balance between glenohumeral and scapulothoracic rotation. The reported normal ratio between glenohumeral and scapulothoracic rotation is approximately 2:1. This relationship has been referred to as scapulohumeral rhythm. Scapulothoracic rotation varies to some degree depending on the amount of elevation. However, in general, the 2:1 ratio between glenohumeral and scapulothoracic rotation is spread evenly across the entire arc of elevation. In addition to contributing to the overall range of elevation, scapular rotation allows the acromion to clear the greater tuberosity as the humerus is elevated. Therefore, alterations in this ratio may theoretically contribute to rotator cuff impingement against the coracocromial arch.

Long thoracic neuropathy is an extreme example of poor scapular rotation in which serratus anterior weakness prevents the scapula (ie, the acromion) from rotating. The range of active elevation is diminished, and the ratio of glenohumeral to scapulothoracic rotation is markedly increased. This results in rotator cuff impingement, as the acromion and coracocromial ligament are unable to clear the elevating greater tuberosity. Although long thoracic neuropathy is uncommon in overhead athletes, weak or asynchronous scapular rotation is often seen. When alterations of scapulothoracic rhythm are present, they are clearly potential contributing factors to rotator cuff and impingement injuries.

Rotator Cuff Imbalance

The ratio between internal rotation and external rotation strength depends on several factors, including training methods, dominant hand, and the presence of glenohumeral instability or subacromial impingement. Internal rotation strength has been reported to be 30% greater than external rotation strength in the dominant arm of asymptomatic volunteers. This ratio is altered in patients with subacromial impingement syndrome. However, it is unknown whether this alteration in strength ratio is a cause or an effect of subacromial impingement. At the very least, it may be a contributing factor and provides a rationale for rehabilitation of athletes with subacromial impingement syndrome.

Anterior Capsular Laxity

The inferior glenohumeral ligament, particularly its anterior band (AIGHL), is the prime static restraint against anterior...
translation of the humeral head when the arm is abducted, extended, and externally rotated. However, the AIGHL is also a checkrein for external rotation of the humerus with the arm abducted and extended. In the late cocking phase of throwing, the humerus is markedly externally rotated and the AIGHL comes under significant stress. Repeated stress on the AIGHL may cause elongation of the ligament and allow excessive humeral external rotation. Nonarticular contact between the superior rotator cuff (ie, supraspinatus tendon) and the posterosuperior glenoid is theoretically possible, even in the normal, asymptomatic shoulder. In the presence of AIGHL laxity, repeated external hyperrotation may traumatize the supraspinatus tendon and result in significant undersurface partial tears. This phenomenon has been referred to as internal glenoid impingement.

The relationship between excessive humeral external rotation and symptomatic internal glenoid impingement is not completely understood. Increased external rotation in the dominant arm of asymptomatic athletes is a common finding. Decreased humeral retrotorsion, when combined with AIGHL laxity and excessive external rotation, may be a contributing factor.

**Posterior Capsular Contracture**

Contracture of the posterior capsule results in a decrease in passive internal rotation. Posterior capsular tightness in overhead athletes is most pronounced inferiorly. Consequently, the internal rotation loss is most noticeable with the arm abducted to 90°, slightly anterior to the scapular plane. Obligate anterior humeral translation is known to occur when maximal passive internal rotation of the normal shoulder occurs. The mechanism of this anterior translation is progressive tightening of the posterior capsule, which forces the humeral head anteriorly. During active joint positioning, the compressive load of the rotator cuff limits the amount of passive rotation attainable in the normal shoulder. However, the amount of internal rotation that occurs in the follow-through phase of throwing would likely be enough to cause relative tightening of the posterior capsule. In the presence of significant posterior contracture, even greater capsular tightening may occur and produce anterior humeral translation. If this translation is significant enough, symptomatic impingement of the rotator cuff against the coracoacromial arch can occur.

Posterior capsular contracture can also interfere with normal scapular mechanics. When the posterior capsule becomes prematurely tight during adduction and internal rotation of the humerus, particularly when the arm is elevated to 90°, continued adduction and internal rotation may lead to elevation of the medial scapular border from the thorax. This places strain on the rhomboid, trapezius, and levator scapulae muscles that are attempting to stabilize the medial scapular border. The result of these altered scapular mechanics may be periscapular pain and muscular fatigue, which ultimately affect overall scapular rotation.

Loss of internal rotation associated with increased passive external rotation with the arm at 90° of elevation in the scapular plane has been reported frequently in pitchers. These changes may be asymptomatic and, in some cases, even a physiologic adaptation to the pitching motion. However, these findings are also documented in symptomatic pitchers with a high frequency. One potential explanation for this apparent contradiction is the possibility that symptoms and these changes in passive range of motion are unrelated. A more likely explanation is that the tolerance for increased passive external rotation (ie, increased length of the AIGHL) or decreased passive internal rotation (ie, decreased length of the posteroinferior capsule) with the arm at 90° of elevation, or both, varies among individuals. This individual variation is probably multifactorial. Potential etiologic factors include the degree of humeral retrotorsion, humeral head size, rotator cuff strength, and articular surface conformity. Clearly, more research is required to completely characterize the nature of the relationship between passive glenohumeral rotation (ie, capsular length or flexibility) and shoulder symptoms in the throwing athlete.

**Supraspinatus Outlet Narrowing**

Narrowing of the supraspinatus outlet is most often the result of anteroinferior acromial spurs or inferiorly projecting acromioclavicular osteophytes. The prevalence of subacromial and acromioclavicular spurs increases with age. Consequently, these causes of subacromial impingement are less common in athletes than in the standard impingement population, which is typically older. However, when present, subacromial spurs and acromioclavicular osteophytes may contribute to the development of rotator tears and impingement injuries.

The coracoacromial ligament, in the absence of subacromial spurring, may contribute to rotator cuff impingement in the young athlete. Although the anatomy of the coracoacromial ligament is somewhat variable, in general it is a Y-shaped ligament. Anterior and posterior bundles attach to the coracoid process and coalesce into a single ligamentous attachment at the anterior acromion (Figure 2). In young athletes without osseous outlet narrowing, hypertrophy of the leading edge of the anterior bundle of the coracoacromial ligament can reportedly lead to rotator cuff impingement.

**DIAGNOSIS**

Evaluation of primary and secondary impingement syndrome in the athlete is covered in another article in this issue.
Consequently, a detailed description of the clinical assessment of rotator cuff and impingement injuries in the athlete will not be repeated here. However, certain aspects of the diagnostic investigation of rotator cuff injuries in the athletic population are extremely important and deserve emphasis.

**History**

Most overhead athletes with rotator cuff injuries do not report a single, isolated traumatic event. More often, the onset of shoulder pain is gradual and progressive. Overhead athletes who do report a single traumatic episode usually convey the presence of preexisting shoulder pain of variable duration. Moreover, they may also recall previous episodes of shoulder pain that have resolved.

**Physical Examination**

Although many physical findings may be relevant, 3 of the most important aspects of physical examination of athletes with suspected rotator cuff and impingement injuries are scapular rotation, capsular laxity, and rotator cuff strength.

Scapular rotation is evaluated in the erect, disrobed patient so that scapular mechanics during overhead elevation can be observed bilaterally and compared. Neurologic scapular winging is uncommon. However, long thoracic neuropathy represents a potentially reversible cause of secondary rotator cuff impingement. Therefore, it should be sought carefully and verified with electromyography. More often, weak or asymmetric scapular rotation in the absence of a neurologic deficit is observed. Poor scapular mechanics contribute significantly to rotator cuff-related symptoms and must be corrected in order to return the athlete to competition.

The glenohumeral capsule controls both translation and rotation of the humerus at the extremes of motion. Consequently, excessive capsular laxity may be manifested not only by an increase in perceived translation but also by an increase in passive rotation when compared with the opposite, normal shoulder. Similarly, capsular contracture is evidenced by decreased humeral translation and passive rotation. Physical findings associated with glenohumeral instability or other alterations of capsular laxity have been described elsewhere in this issue. Yet the importance of an examination for excessive or diminished capsular laxity in athletes suspected of rotator cuff or impingement injuries cannot be overemphasized. Anterior, posterior, and inferior translation should be tested and compared with the opposite, normal side. Similarly, passive external rotation with the arm at the side, passive external rotation with the arm at 90° of elevation in the scapular plane, and passive internal rotation with the arm at 90° of elevation in the scapular plane should be quantitated and compared with the normal side.

Rotator cuff strength in athletes with rotator cuff and impingement injuries may be altered on the basis of an actual tendon defect, suprascapular neuropathy, or pain. The 4 rotator cuff muscles and their associated tendons act synergistically as a single functional unit. Consequently, isolated testing of individual rotator cuff muscles is difficult. However, strength testing in particular arm positions may provide relatively specific information about rotator cuff integrity, even if the information is not specific to the individual muscle. Weakness of abduction with the arm at 90° of elevation in the scapular plane, the humerus internally rotated, and the elbow extended is thought to be indicative of supraspinatus insufficiency. Weakness of external rotation with the arm at the side is representative of supraspinatus and infraspinatus (infraspinatus more than supraspinatus) deficiency. Teres minor loss is manifested by weakness of external rotation with the arm at 90° of elevation in the scapular plane. Inability to lift the back of the hand away from the lumbar spine with the arm behind the back (ie, the "lift-off" sign) indicates subscapularis rupture (Figure 3).

Suprascapular neuropathy may result in anterior impingement-like shoulder pain. This presumably occurs because of supraspinatus or infraspinatus weakness, or both. The most striking physical finding of suprascapular neuropathy, particularly when it has been chronic, is marked atrophy of the supraspinatus and infraspinatus muscles (Figure 4). In the young athletic population, rotator cuff tears large enough to result in atrophy of the supraspinatus and infraspinatus are very uncommon, especially if there is no history of severe trauma. Therefore, in the athletic population, atrophy of these muscles suggests suprascapular neuropathy rather than a rotator cuff tear. This can be verified by electromyography.
Figure 4. A, Significant supraspinatus and infraspinatus atrophy in young athletic patients is more often the result of suprascapular neuropathy than rotator cuff tear. B, This patient’s suprascapular neuropathy is secondary to compression from a large ganglion cyst associated with a labral tear40 (© 1997 American Academy of Orthopaedic Surgeons. Reprinted from the Journal of the American Academy of Orthopaedic Surgeons, Volume 5(2), pp. 97-108 with permission.)

Pain during rotator cuff strength testing may give the impression of rotator cuff weakness. Therefore, when severe pain is present, shortly after a traumatic injury for example, strength testing may be unreliable. The athlete should be re-examined in 7 to 10 days, when the severe pain has subsided and the examination is more reliable.

Radiography

Specialized radiographic views may be useful in the diagnosis of rotator cuff and impingement injuries in athletes. In addition to routine anteroposterior and axillary views, 30° caudal tilt and supraspinatus outlet views may reveal anterior acromial spurs.41-43 When attempting to differentiate between primary rotator cuff injury and anterior glenohumeral instability, apical oblique, West Point, and Stryker notch views may reveal anterior glenoid fracture or calcification, as well as small Hill-Sachs defects suggestive of recurrent anterior subluxation.44,45

Magnetic Resonance Imaging

Rotator cuff imaging is a useful adjunct to history, physical examination, and radiographic evaluation in the athlete with suspected rotator cuff injury. Ultrasonography, arthrography, and magnetic resonance imaging (MRI) are all valid methods of rotator cuff imaging. However, MRI is especially useful in the athlete with suspected rotator cuff injury because of its ability to provide complementary information regarding the glenoid labrum. MRI in combination with intra-articular gadolinium (ie, magnetic resonance arthrography) is thought to be even more accurate than routine MRI in identifying labral tears.46-49 As previously mentioned, there is significant overlap between subtle glenohumeral instability and rotator cuff pathology in young athletes with shoulder pain. Therefore, MRI or magnetic resonance arthrography is often indicated in patients who are considering surgery, especially if their x-ray films are normal.

Examination Under Anesthesia

The role of examination under anesthesia in clinical decision making has yet to be defined. It clearly is only 1 tool of many used in the evaluation of the athlete with shoulder pain and, as such, should not override the overall clinical impression derived from history taking, examination while the patient is awake, and diagnostic testing. However, examination under anesthesia may identify unsuspected or underappreciated posterior capsular contracture or excessive anterior capsular laxity in athletes suspected of having rotator cuff injuries.50 The surgical plan may be modified or completely changed on the basis of this information.

Diagnostic Arthroscopy

The documented prevalence of concomitant intra-articular pathology in patients undergoing arthroscopic acromioplasty for chronic subacromial impingement syndrome with a repairable, full-thickness rotator cuff tear is approximately 61%.51 Not all of these findings have clinical relevance. In patients over 40 years of age, intra-articular abnormalities such as labral tears may be a normal part of the aging process. However, in young athletes, these findings are presumably less common and more likely to be associated with symptoms. In addition, the characteristics of partial rotator cuff tears as seen arthroscopically may aid in diagnosis and treatment. For example, partial-thickness, joint-side supraspinatus tears that are in the posterior third of the tendon are characteristic of internal glenoid impingement rather than primary tendon failure. This is particularly true if the posterior superior glenoid labrum is frayed or torn and examination under anesthesia demonstrates a marked increase in passive external rotation with the arm at 90° of elevation. If, while the arthroscope is positioned to allow the surgeon to observe the posterosuperior glenoid, the arm is placed in 90° of elevation, slightly posterior to the scapular plane and the humerus is externally rotated, the partial supraspinatus tear can be seen to contact the frayed or torn posterosuperior labrum (Figure 5). Under these circumstances, treatment is directed at the excessive capsular laxity in addition to or instead of the partial rotator cuff tear.
Nonoperative Management

The rationale for nonoperative treatment methods for the athlete with rotator cuff or impingement injuries is based on the specific pathology, individual sport-specific demands, and known biomechanical, anatomical, and kinesiologic principles. Multiple authors have investigated normal and abnormal sport-specific electromyographic activity, information that can be helpful when one is developing the rehabilitation protocol.52-56

The speed with which the athlete progresses in rehabilitation depends on the level of symptoms as well as the severity of the injury. However, if we approach the treatment as phases of progression, based on reactivity and signs and symptoms, then a single scheme of progression can be followed (Table 1).

Phase I

Rest from irritating activities is always required when rehabilitation is initiated. Anti-inflammatory modalities such as phonophoresis, iontophoresis, ice massage, or ice may be used. Certain modalities (phonophoresis, iontophoresis) require correct arm positioning to optimize exposure of the targeted tissue. Oral nonsteroidal anti-inflammatory medications may also be helpful. Transverse friction massage (TFM) may be used on an inflamed tendon to promote scar tissue pliability and local blood flow. An evaluative TFM test can be used to identify the inflamed tendinous tissue and determine if the technique will be useful during treatment. The athlete is first examined for pain with resisted motions or elevation, or both. TFM is performed over the suspected involved tendon for 3 to 5 minutes. The shoulder is again examined and the percentage difference in pain on resisted motion testing or elevation is noted. If 80% of the pain dissipates after TFM, that tendon is treated with anti-inflammatory modalities or TFM, or both. This technique may be thought of as the noninvasive equivalent to the impingement test.

Collagen tissue tension produced by range-of-motion activities and submaximal strengthening exercises encourages collagen "healing." Consequently, passive or active-assisted range-of-motion exercises are initiated in pain-free ranges. Rotational exercises are commonly performed at 45° of scapular plane abduction because this is below the impingement zone. These exercises are then progressed toward positions of function based on symptom improvement. Pain-free submaxi-

Table 1. Phases of Shoulder Rehabilitation

<table>
<thead>
<tr>
<th>Phase I</th>
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<tbody>
<tr>
<td>Rest from painful activity</td>
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<tr>
<td>Anti-inflammatory therapy</td>
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<tr>
<td>Passive range-of-motion and active-assisted range-of-motion exercises</td>
</tr>
<tr>
<td>Joint mobilization</td>
</tr>
<tr>
<td>Strengthening (submaximal → maximal)</td>
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<tr>
<td>Scapulothoracic strengthening</td>
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<td>Aerobic conditioning</td>
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<tr>
<th>Phase II</th>
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<tr>
<td>Progress range of motion and flexibility</td>
</tr>
<tr>
<td>Strengthening (submaximal → maximal)</td>
</tr>
<tr>
<td>manual, elastic band, and isotonic</td>
</tr>
<tr>
<td>multangle isometrics</td>
</tr>
<tr>
<td>short-arc → full-arc excursion</td>
</tr>
<tr>
<td>Aggressive scapulothoracic strengthening and integration</td>
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<tr>
<td>Aerobic conditioning</td>
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<tr>
<th>Phase III</th>
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<tr>
<td>Prophylactic stretching</td>
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<tr>
<td>Strengthening and endurance (to full range and emphasize eccentrics, then progress to sport-specific positions)</td>
</tr>
<tr>
<td>Variable or free weight resistance, or both</td>
</tr>
<tr>
<td>Bodyblade (Hymanson Inc, Playa Del Ray, CA)</td>
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<tr>
<td>isokinetics</td>
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<td>plyometrics</td>
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<tr>
<th>Phase IV</th>
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<tr>
<td>Return to sport</td>
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Mal resistance exercises may be started at the shoulder or elbow, or both. Strengthening of the scapulothoracic muscles is initiated directly (eg, shrugs), as well as integrated (with the scapula “set,” or slightly retracted) into the strengthening exercises for the glenohumeral dynamic stabilizers. The athlete should continue with aerobic conditioning on the bicycle, stair-stepping machine, or equivalent device.

**Phase II**

As pain and inflammation resolve, modalities are discontinued and the intensity of stretching increased to approach the end range. If pain persists in provocative positions, those positions are avoided. Emphasis is placed on stretching the posterior capsule because tightness has been associated with anterior and superior humeral head migration, resulting in subacromial impingement. The strengthening program is also progressed according to information received through manual resistance. Feedback received from manual contact provides valuable information regarding choice of exercise position, direction, and resistance. Initially multangle isometrics are performed in various positions. For example, the arm may be moved from 30° to 90° of scapular plane abduction at 30° intervals (30°, 60°, 90°). At each position, the athlete is asked to push into a certain direction (eg, abduction and external rotation) as the clinician opposes the force. This is an excellent technique for regaining dynamic stabilization at different positions of elevation. If pain is encountered, the arm is moved down and the isometric performed again. The pain encountered at a higher degree of elevation may be due to abnormal superior translation causing mechanical impingement, as described by different investigators.

The functional strength of the scapular muscles must also be assessed. Scapular instability is commonly seen in throwing athletes when abduction and external rotation are isometrically resisted at 90°. The scapula moves into abduction (protraction), even though the humerus is stationary, because of the pull of the serratus anterior muscle (Figure 6). This is referred to as a serratus anterior-dominant shoulder. In this case, the ineffective medial scapular muscles (rhomboid, middle trapezius, and lower trapezius) permit scapular instability. This instability may result in increased tension across the anterior capsuloligamentous complex, potential impingement and overload to the rotator cuff and biceps, and perpetuation of scapular muscle dysfunction. Moreover, repetitive performance of this maneuver, as in pitching, could lead to subtle anterior instability and secondary internal glenoid impingement. Additionally, the rotator cuff muscles are less effective if their base (the scapula) is moving while they are attempting to control the glenohumeral joint. Therefore, strengthening of all the scapular muscles is emphasized, either in isolation or in combination with the glenohumeral muscles as each one is isolated.

Manual techniques are required to isolate muscles so that scapular instability can be corrected. Once the athlete is able to appropriately recruit the scapular and glenohumeral muscle patterns, the scapular muscles are incorporated into functional, sport-specific movements. Proprioceptive neuromuscular facilitation techniques are valuable in simultaneously strengthening all the upper extremity muscles. Proprioceptive neuromuscular facilitation uses diagonal patterns and specific techniques of applying and sequencing isometrics and concentric and eccentric muscle activity (Figure 7). Initially, only concentric activity is performed, until the patient is believed to have adequate voluntary isolation, at which time eccentric training is performed manually.

Closed-chain exercises can also be initiated. Progression to dynamic closed-chain activities, such as quadruped use of an unstable base or upper extremity walking or climbing, should be approached with caution until adequate strength is achieved to maintain scapular and glenohumeral fixation. Proper patient selection is required for these latter 2 exercises in order to maximize their usefulness and minimize symptom aggravation.
In conjunction with, and based on the feedback from, manual resistance, appropriate resistance equipment (ie, elastic bands or light free weights) can be used as part of the home and supervised rehabilitation program. Adequate strength of the rotator cuff, deltoid, and biceps muscles can be achieved using light resistance, and strength and endurance can be restored by increasing the number of repetitions to fatigue. Exercises commonly performed to improve strength of the rotator cuff and deltoid are internal and external rotation, abduction (coronal, scaption with internal rotation or external rotation), extension, and flexion.

To integrate scapular muscle activity, the athlete is asked to "set" (slightly retract) the scapula into good anatomical position, as opposed to the commonly seen position of protraction (Figure 8). Emphasis on scapulothoracic muscle function during all rotator cuff and deltoid strengthening exercises facilitates scapular muscle integration into sport-specific activities. Using a small bolster to slightly abduct the humerus can relieve pain when performing the rotational exercises. In the presence of a supraspinatus tendon lesion, placement of the arm in slight abduction slackens the tendon, thereby reducing passive, irritating tendon tension. Additionally, restricting external rotation to 30° past neutral rotation further minimizes passive supraspinatus tension created by the coracohumeral ligament through its intimate relationship with the supraspinatus.

Several investigators have provided electromyographic data to support the use of common glenohumeral and scapulothoracic strengthening exercises. However, these exercise programs must be applied on an individual basis and guided by the patient's symptoms. A frequently used exercise in rehabilitation programs for impingement is scaption in internal rotation. This exercise was found to isolate the supraspinatus and created the greatest muscle activity for the anterior and middle deltoid, supraspinatus, subscapularis, and upper trapezius. The higher levels of muscle activity reported were achieved above 90° of elevation in all muscles tested. Performance of scaption in internal rotation at or above 90° of elevation is contraindicated in the early phases of rehabilitation because of potential impingement (Figure 9). Although this exercise may be beneficial in the later stages of rehabilitation, performing it too early can result in further irritation of the rotator cuff due to increased shear forces and direct cuff compression.

The reader is encouraged to critically read literature reporting muscle activity based on electromyographic findings. Although these studies are valuable, direct application of study positions is not always clinically prudent, because their use may be contraindicated relative to the patient's symptoms and pathology. We believe strongly that the athlete must be moved from the commonly performed rotator cuff strengthening exercises, done with the arm in adduction or slight abduction, to functional sport-specific positions (Figure 10).

Phase III

In this phase, the athlete should have relatively pain-free end-range motion, and the strengthening program can be progressed to full range and maximal resistance. Eccentric activity is emphasized, particularly of the posterior cuff and medial scapular muscles, because these muscles are subjected to damaging forces in the deceleration (follow-through) phase of throwing.

Weight training using variable resistive devices or free weights is started with the same nonprovocative to provocative positioning philosophy. Certain exercises that require shoulder abduction and full external rotation may be avoided, particularly the military press, chest flys, and behind-the-neck latissimus pull-downs. These exercises may be modified to be performed in the scapular plane.

The upper body, or rowing, ergometer is used to further improve strength and endurance. Care is required when considering the athlete's position on the upper body ergometer. Placing the athlete in a sitting position, so that the machine's rotation axis is level with the glenohumeral joint, requires the athlete to repetitively cycle against resistance in the impingement zone. The prudent clinician has the athlete initially perform the exercise in the standing position to avoid potential rotator cuff trauma. However, the sitting position is used eventually if tolerated. Exercise in both the forward and backward directions is performed.

The Bodyblade has been extremely useful in rehabilitating athletes with rotator cuff tendinopathy or glenohumeral instability, or both. This device enhances strength, dynamic control, proprioception, and endurance training. Small to large oscillations of a fiberglass rod are performed in multiple positions...
(following the nonprovocative to provocative positioning philosophy) and various time intervals. Oscillating the blade requires short-excursion, high-speed cocontraction muscle activity of the rotator cuff, deltoid, and biceps complex, in addition to the scapular muscles. Therefore, dynamic stabilizing training is uniquely achieved when compared with other forms of exercise. An infinite number of static positions of movement patterns can be used. A progression program using the Bodyblade is seen in Figure 11.

Isokinetic exercise may be initiated for the glenohumeral rotators, elevators, and scapular muscles. Isokinetic dynamometers offer a constant speed, yet maximal resistance, throughout the exercised range. The fact that isokinetic dynamometers allow controlled high speeds reinforces their use as part of an exercise progression, because high velocities are required during sport activities. Adequate dynamic stabilization and negligible myotendinous reactivity are prerequisites to this mode of muscle strengthening. Initially, speeds of 120 to 240°·s⁻¹ are used. Lower speeds result in increased concentric torque. However, greater tensile loading and shear and compressive forces are created. Because of the potentially high torque produced, the athlete is initially placed in slight scapular plane abduction and progressed to the provocative sport-specific positions. Eccentric training can be performed submaximally, but prudence is required when increasing resistance. This is true in provocative positions because eccentric activity is associated with myotendinous injury. Caution is also required when increasing speed during isokinetic eccentric exercising, since torque increases (as does force translated across the soft tissues) as speed increases.

Plyometric training with weighted balls can be used to enhance strength and proprioception by reproducing the physiologic stretch-shortening cycle of muscle in sport-specific shoulder positions. By catching and throwing a weighted ball (0.91 to 4.5 kg [2 to 10 lb]), the adductors and internal rotators are eccentrically loaded, and thus stretched, followed by a concentric shortening phase. Catching the ball from a vertical drop while standing or lying on the side eccentrically loads the posterior cuff and scapular decelerators. These exercises appear to enhance muscle performance by neuromuscular control. Initially, concentric activity may be used in an activity simulating a chest pass. The athlete is gradually progressed into sport-specific positions (Figure 12). A trampoline or Plyoback (AliMed Inc, Dedham, MA) may be used. Alternatively, the ball may be thrown manually to the patient. In this way, the velocity can be varied (varying the force of impact),
yet positioning of the arm can be constant or variable, depending on where the rehabilitation specialist throws the ball.

Phase IV

During phase IV, the athlete gradually returns to sport. Regardless of the sport, the athlete is allowed a gradual return to the preinjury level of competition. The pitcher performs an interval throwing program; the tennis player begins with forehands and progresses to backhands; and the swimmer performs low-intensity interval training. The intensity of activity is gradually increased, as is the performance of provocative sport-specific activities. The athlete should continue with the outlined exercises to maintain strength and motion in addition to following an off-season program.

SURGICAL MANAGEMENT

Surgical techniques and indications for rotator cuff and impingement injuries in athletes are the same as those in nonathletes, with 2 major exceptions. First, traditional surgical techniques such as acromioplasty and cuff repair may need to be combined with procedures that address coexistent pathology more common in the athletic population. For example, subacromial decompression and labral repair are indicated in patients with supraspinatus outlet narrowing combined with a tear of the superior labrum from anterior to posterior (ie, SLAP lesion). Second, the athlete’s high activity level places significant demands on the postoperative shoulder and may influence the patient’s impression of the quality of the postoperative result. This is particularly true of overhead athletes. Loss of even 5° of external rotation may significantly influence throwing velocity and mechanics. Although rotator cuff and
impingement surgery can be performed using open or arthroscopic surgical techniques, arthroscopic surgery offers the potential advantages of decreased scarring and less deltoid morbidity, both of which may influence an athlete’s ability to return to competition after surgery.

Many factors influence surgical indications and the choice of surgical procedure. Among these factors, perhaps the most important is the degree of rotator cuff involvement. Consequently, the following discussion of indications and surgical techniques is organized according to the status of the rotator cuff: intact rotator cuff, partial rotator cuff tear, and complete rotator cuff tear.

**Intact Rotator Cuff**

According to Neer, anterior acromioplasty in patients with subacromial impingement syndrome with an intact rotator cuff is indicated after failure of 9 months of rehabilitation and activity modification. In general, these criteria also apply to athletes with subacromial impingement syndrome and an intact rotator cuff. In addition, surgical candidates should have radiographic evidence of supraspinatus outlet narrowing and temporary relief of pain with subacromial injection of local anesthesia or combined local anesthesia and corticosteroid injection. The surgeon must be as certain as possible that mechanical supraspinatus outlet narrowing is the cause of the patient’s symptoms. Glenohumeral instability and superior labral pathology are much more common causes of shoulder pain in the throwing athlete.

Anterior acromioplasty may be accomplished through open or arthroscopic means. We prefer arthroscopic acromioplasty because it is better tolerated in the early postoperative period, has the potential for less deltoid morbidity, and allows for management of concomitant, intra-articular pathology.

The technical goal of arthroscopic acromioplasty is to smooth the undersurface of the anterior acromion. Although complete flattening of the anterior acromion will relieve rotator cuff impingement, excessive bone removal may result in postoperative acromial stress fracture. Moreover, anatomical studies have shown that pathologic subacromial contact can be relieved without completely flattening the anterior acromion, so long as the undersurface of the anterior acromion is smooth and devoid of sharp inferior projections. Therefore, our aim is to preserve at least half of the anterior acromial thickness, even if that results in a resection margin that is less than flat. In many cases, however, the undersurface of the anterior acromion can be completely flattened without compromising acromial thickness.

Occasionally, rotator cuff impingement may result from hypertrophy of the anterior edge of the coracoacromial ligament, in the absence of anterior acromial spurring. Yet surgery must be carefully considered in this patient population. Isolated coracoacromial ligament impingement should be considered a diagnosis of exclusion after SLAP lesions and glenohumeral instability have been excluded. After failure of nonoperative management, temporary relief with subacromial injection, and exclusion of other potential sources of pain, presumed coracoacromial ligament impingement can be relieved by arthroscopic excision of the anterior leading edge of the coracoacromial ligament.

**Partial Rotator Cuff Tear**

The indications for surgery in athletes with partial rotator cuff tears are similar to those with an intact cuff. However, the duration of nonoperative treatment may be shortened if the preoperative MRI reveals an articular-side or bursal-side tear involving more than 50% of the tendon thickness. In our experience, bursal-side tears are more symptomatic than articular-side tears of the same size. Therefore, surgery may be considered more aggressively in athletes with bursal-side partial cuff tears.

Partial rotator cuff tears can be managed with arthroscopic, open, or arthroscopically assisted (ie, mini-open) techniques. We prefer the arthroscopic approach for the reasons mentioned above. Diagnostic arthroscopy is very helpful in verifying the depth of the partial tear as well as the quality of the remaining tendon. The rotator cuff insertion must be visualized both from the glenohumeral joint and from the subacromial bursa. High-grade partial tears may be present on the bursal surface of the rotator cuff with a normal-appearing articular cuff insertion (Figure 13). In patients with bony supraspinatus outlet impingement, diagnostic arthroscopy is followed by arthroscopic acromioplasty. Articular-side partial cuff tears of less than 50% of the tendon thickness and bursal-side tears of less than 25% of the tendon thickness are debrided. All other partial cuff tears are arthroscopically repaired (Figure 13).

**Complete Rotator Cuff Tear**

Complete rotator cuff tears in young athletes, particularly overhead athletes, often require operative repair in order to
Figure 13. High-grade partial tears may be present, A, on the bursal surface of the rotator cuff, and B, with a normal-appearing articular cuff insertion. C, This bursal-side partial tear was fixed arthroscopically by placing a suture anchor, and D, using arthroscopic suture passing and tying techniques.

allow a return to competition. However, a 6- to 12-week trial of rehabilitation and activity modification may be warranted. If this fails, surgical repair is indicated.

Most complete rotator cuff tears in overhead athletes are small (1 to 2 cm or 1 tendon) and minimally retracted. Therefore, they are frequently amenable to arthroscopic or mini-open repair. Conversely, rotator cuff injuries in contact athletes are occasionally larger than 2 cm or 1 tendon and retracted. Under these circumstances, we prefer open repair and may even use a postoperative abduction pillow or brace to protect the repair.

In small (2 cm or less), mobile rotator cuff tears, arthroscopic and mini-open techniques are indicated. Both techniques can be tedious but offer the potential of less deltoid morbidity than open repair. With experience, arthroscopic suture anchor placement, suture passing, rotator cuff mobilization, and arthroscopic knot tying can be performed with precision and accuracy. Theoretically, the purely arthroscopic approach should be the least invasive and associated with less subacromial and deltoid trauma. Therefore, in young athletes with good bone and tendon quality and small, mobile cuff tears, we prefer arthroscopic repair. This is combined with arthroscopic acromioplasty in cases of coexistent supraspinaus outlet narrowing.

In larger, less mobile tears (more than 2 cm or 1 tendon), we prefer open repair. Although these tears can be mobilized and repaired arthroscopically or with a mini-open technique, we find these techniques difficult and, in our hands, less reliable. Therefore, large tears are repaired through a superior, transdeltoid approach. Acromioplasty is only performed if a subacromial spur is present. Tears that are retracted medial to the midportion of the humeral head are protected in an abduction pillow or brace for 2 to 3 weeks postoperatively.

POSTOPERATIVE REHABILITATION

The progression of rehabilitation will vary depending on the surgical intervention. The exercises performed are similar to those mentioned for nonoperative treatment, except that soft tissue healing parameters are respected. When working with an athlete after surgery, the eventual goal is to return the individual to some level of sport participation, preferably the same level that existed before the injury and subsequent surgery. Rehabilitation after arthroscopic surgery that does not involve a rotator cuff repair is identical to the protocol outlined previously for nonoperative treatment. This protocol is modified slightly after rotator cuff repair. Table 2 outlines the phases of rehabilitation used in our practice after a traditional rotator cuff repair. This will be used for reference in the following discussion, but the variances resulting from other surgical interventions will be highlighted.

Phase I

The goals of this phase are patient education, control of pain and inflammation, tendon healing, and maintenance of subacromial gliding and capsuloligamentous complex and tendon pliability. The first step is to ensure protection of the surgical
repair and allow proper healing by educating the patient about shoulder-use precautions. Patients are also instructed to place a support, such as a pillow, under the arm to position it in slight abduction and neutral rotation. Pritchett found that 10% of patients undergoing a rotator cuff repair had an inferiorly subluxed humeral head within 2 weeks after surgery. Proper positioning of the shoulder helps to take the weight of the extremity off the repair site and discourages an internal rotation contracture. In addition, active exercises are performed at the elbow, wrist, and hand.

Because the subacromial space has been surgically manipulated, emphasis is placed on preventing subacromial space scarring. Immediate passive range-of-motion exercises are performed to maintain subacromial gliding and capsuloligamentous complex and tendon pliability. Phase I passive range-of-motion exercises are initiated. Exercises are performed with 20 repetitions, 3 to 6 times a day. Typically, the patient returns to the surgeon in 7 to 10 days to have the sutures removed and the shoulder assessed. The exercises are reinforced, as are the precautions. If the patient has excessive tightness or pain, referral to supervised therapy may be provided at that time. Supervised therapy consists of heat or ice (or both), joint mobilization, and passive stretching. In the absence of excessive stiffness or pain, the home exercise program is continued.

If an acromioplasty with an intact rotator cuff or a partial rotator cuff debridement was performed, active-assisted range-of-motion exercises, including extension, and phase II stretching (horizontal adduction and internal rotation) are started at 2 to 4 weeks. Phase I strengthening is also begun at 2 to 4 weeks, depending on the patient’s tolerance. If an arthroscopic repair was performed (ie, a partial-thickness or small full-thickness cuff tear was present), active-assisted range-of-motion exercises and isometrics are initiated at 4 weeks. Passive and active-assisted range-of-motion exercises into external rotation can be performed at 70° to 90° of scapular plane abduction after 4 weeks and if tolerated. If the rotator cuff tear was larger than 1 cm, isometric exercises are withheld until 6 weeks postoperatively.

Passive range of motion may be purposely restricted during this early rehabilitation phase in patients with large or massive cuff tears who required mobilization of the rotator cuff tissue and have been placed in an abduction pillow. Capsular releases and tendon mobilization allow repair of the tendon, but repairs of large tears are more likely to fail than repairs of small tears. Therefore, range-of-motion exercises must be individualized based on repair quality.

Phase II

This phase extends from 6 to 10 weeks and is the time when the patient adds phase II stretches (if not already started) and continues with phase I exercises. If stiffness persists, joint mobilizations and gentle, relatively pain-free, manual stretching is performed. An effective stretch to improve range of motion is to have the patient place the hands anywhere from the forehead to the back of the head (depending on comfort) and let the elbows slowly drop toward the floor. Stretches are maintained for 10 to 20 seconds, and the discomfort is relieved by raising the elbows for 5 seconds. This sequence is repeated 10 to 20 times. Progressive stretching into external rotation in multiple positions of elevation is emphasized in those patients having an acromioplasty, debridement, or arthroscopic rotator cuff repair. Posterior capsule stretching is also progressed.

If the patient had a large or massive tear repaired, restrictions are expected and respected. These patients are progressed slowly and monitored for excessive stiffness or capsulitis. Slow and gradual return of motion is allowed without attempts to instruct the patient in overstretching or disrupting the repair due to enthusiastic stretching by the rehabilitation specialist. The surgeon and rehabilitation specialist must discuss any decision to aggressively stretch the postoperative patient, particularly one who has undergone repair of a large or massive rotator cuff tear.

Patients initiate phase I strengthening exercises (external and internal rotation and extension) and progress to phase II (forward flexion and abduction) exercises during this phase. The decision to begin resisted exercise is based on the rotator cuff tear size, ease of repair, and quality of tissue. In general, however, we restrict resistive exercises for 6 weeks postoperatively in patients who have undergone repair of a full-thickness rotator cuff tear. The exercises performed are the same as those described for conservative treatment. Care is taken to minimize excessive loading of the rotator cuff by using a bolster when needed and choosing the appropriate resistance level. In our clinic, Thera-Band (Quality Health Products, Inc, Indiana, PA) is used, and yellow is the first band chosen. Patients perform the exercises in pain-free ranges. When active elevation is performed, appropriate scapulo-humeral rhythm is encouraged. Multigate isometrics begin at 45° in the scapular plane using manual resistance. Four directions of submaximal isometric resistance are performed by the patient in sequence; abduction and external rotation, adduction and internal rotation, elevation, and extension. This technique assesses the patient’s resistance and pain level. This also continues the process of neuromuscular training of the glenohumeral and scapular muscles. If pain is encountered, the position is modified, resistance level changed, or the exercise deferred until another session. The use of this manual resistance sequence helps to guide the patient’s elastic band and free weight program.

Depending on the patient’s response to resistive exercise and the time from surgery, the position of resistance is progressed toward 90° in the scapular plane. Individuals who had acromioplasty, rotator cuff debridement, or arthroscopic repair are progressed in motion more quickly. Strengthening may also be initiated 1 to 2 weeks earlier than in patients who underwent open repair of a large or massive defect. However, caution must be exercised in adding or progressing strengthening too quickly, even after arthroscopic repair of smaller tears. This progression continues to more provocative positions, as tolerated, in all patients regardless of the surgical intervention. The rationale for this exercise philosophy has already been described.

Strength in elevation can many times be compromised because of muscle atrophy, disuse, weakness or pain reflex inhibition. In the case of a chronic tear, it may have been 6 or 12 months since the supraspinatus last translated force from its origin to insertion. This muscle is not only lacking the cross-sectional mass to translate enough force to stabilize and elevate the humerus—it “forgot” how. The supraspinatus tendon is not providing its normal head-depressing force, and the humeral head is potentially migrating superiority, causing painful compression. This situation reinforces the concept of strengthening in all positions of elevation, starting with those that are less provocative and progressing to more provocative.
Table 2. Rehabilitation After Rotator Cuff Repair

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<th>Phase</th>
<th>Duration</th>
<th>Goals</th>
<th>Treatment</th>
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| I     | 0 to 6 weeks | 1. Patient education  
3. Control pain and inflammation  
4. Initiate range of motion exercises | 1. Patients may be immobilized in sling or abduction brace  
2. Pendulums  
3. Hand squeezes  
4. Elbow active range of motion |
| II    | 6 to 10 weeks | 1. Improve to full range of motion  
2. Improve neuromuscular control and strength | 1. Continue all stretches  
2. Resisted scapular strengthening  
4. Manual resistance for rotator cuff, deltoid, and biceps and proprioceptive neuromuscular facilitation |
| III   | 10 to 16 weeks | 1. Full, pain-free range of motion  
2. Optimize neuromuscular control  
3. Improve endurance  
4. Initiate return to functional activities | 1. Continue all stretches (to full end range) and strengthening progress rotator cuff exercises into elevation  
2. Manual resistance for rotator cuff and deltoid and proprioceptive neuromuscular facilitation in elevated positions  
3. Appropriate variable resistance and free weight exercises for upper extremity |
| IV    | 16 weeks to 6 months | 1. Return to sport  
2. Promote concept of prevention | 1. Continue with upper extremity strengthening and flexibility program  
2. Sport interval program  
3. Work- and sport-specific exercises |

To strengthen in the elevated positions, the supine patient is first treated with heat, joint mobilization, and stretching to maximize the elevation range. Multiangle isometrics are performed at different positions of elevation to improve the muscles’ ability to contract and centralize the humeral head on the glenoid. The arm is then placed at 90°, and the patient is asked to elevate through the pain-free range (90° to 130°). Scapular shrugging is discouraged via verbal and manual queues to reinforce appropriate synergistic scapular muscle activity as the glenohumeral muscles are activated. This sequence has proved very effective in safely strengthening the rotator cuff-deltoid-biceps complex in functional ranges while encouraging scapular muscle integration.

In selected patients, the Bodyblade may be used at 8 weeks in the nonprovocative positions (Figure 11). As the patient progresses, light free weights (2.27 to 4.54 kg [5 to 10 lb]) can be used for biceps curls. Triceps isolation exercises are performed on a variable resistance unit or with Thera-Band by placing the arm in a nonprovocative position. Shoulder extension exercises can usually progress without harm to the surgical repair.

Phase III

The patient should have at least 80% to 90% of the normal range of motion (full for those without a rotator cuff repair) in this phase, unless a large or massive rotator cuff repair required lateral mobilization of the tendon. Patients should be relatively pain free at this stage and should be able to actively elevate above shoulder level with good scapulohumeral rhythm. Many patients may continue to shrug with elevation, and one must determine the cause of the abnormal rhythm: weakness, capsuloligamentous complex tightness, pain, or learned behavior? Depending on the cause, the abnormal rhythm may be expected. However, if full passive range of motion is present and the rotator cuff is intact with good strength, further neuromuscular control training is required to improve synchronous recruitment of the glenohumeral dynamic stabilizers and scapulothoracic muscles. If pain continues to be an issue, a subacromial or acromioclavicular joint cortisone injection may be helpful to reduce local irritation.

The patient is progressed to further strengthening exercises and activity-related movements, depending on the level of symptoms. The nonprovocative to provocative philosophy is still used, with absolute respect for the rotator cuff repair and the deltoid. The patient may now be moved on to isolated triceps and biceps strengthening with the arm at the side or in slight abduction. Row-type pulls at chest level may be initiated, with progression to latissimus pull-downs (modified to be anterior to the scapular plane). Both of these exercises move the patient through the impingement zone. However, less rotator cuff stress is generated. The rotator cuff strengthening exercises are progressed into elevated, sport-specific positions based on signs and symptoms. Manual therapy is performed, attempting to maximize neuromuscular control and integrate scapular muscles in the elevated sport-specific positions. The athlete is progressed with the Bodyblade (Figure 11). In selected patients, the Plyoball (JumpUSA, Brooklyn, NY) progression may be initiated sometime after 10 to 12 weeks postoperatively (Figure 12). Isokinetics may be used in selected patients, but soft tissue healing parameters must be respected and weighed against the potentially injurious forces encountered during isokinetic exercise. Cardiovascular conditioning is unrestricted at this time.

Phase IV

This phase begins at 16 weeks and continues to 6 months. In this phase, most lower-demand patients (nonathletes) continue to gradually progress their home rotator cuff strengthening program and possibly their variable resistance program. Proper lifting is strongly emphasized to patients with 2- and 3-tendon rotator cuff tears. Isokinetics may be used in selected patients, but the tissue healing parameters must be respected and weighed against the potentially injurious forces encountered during isokinetic exercise. Cardiovascular conditioning is unrestricted at this time.
rotator cuff repairs because the literature demonstrates that these people are at great risk of retearing their rotator cuffs.91

The athlete is progressed in a manner similar to phase IV of the conservatively treated patient but with more consideration for soft tissue healing parameters and a slower reentry process. As with the conservatively treated athlete, the goal is return to the preinjury level of competition. However, this is often not possible with throwing athletes who have had rotator cuff surgery on their dominant arm.76,92–94 The use of a sports-specific interval program will be required to return the athlete to sport.

RESULTS

The reported results of anterior acromioplasty and rotator cuff repair in young (under the age of 45 years), athletic patients are inferior to the results in older patients.76,87,92–94 This probably occurs for 2 reasons. First, rotator cuff and impingement injuries in athletes are often not isolated. In fact, glenohumeral instability, labral tears, osteochondral defects, and other types of pathology are more common in the young, athletic population than primary or impingement-related rotator cuff disease. Therefore, subacromial impingement is often an incorrect or incomplete diagnosis. Second, the demands that athletes make on their postoperative shoulders are frequently greater than the demands of older, nonathletic patients. Therefore, athletes may be more likely to experience symptoms, even if the objective measure of their postoperative result is the same as their older, nonathletic counterparts.

Our ability to discern labral tears and subtle forms of glenohumeral instability from rotator cuff and impingement injuries has improved and will continue to improve as our knowledge of these diseases expands. Similarly, our surgical and rehabilitative techniques continue to evolve. Thus, it is reasonable to assume that the results of rotator cuff and impingement surgery will also continue to improve, so that we can return more athletes with rotator cuff and impingement injuries to their sports at their previous level of competition.

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Neurologic Injuries in the Athlete’s Shoulder

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Objective: To review the presentation, evaluation, treatment, and prognosis of various nerve injuries about the shoulder in the athletic population. Included are injuries to the axillary, suprascapular, musculocutaneous, long thoracic, and spinal accessory nerves.

Data Sources: This article represents a review of the literature regarding incidence, presentation, and results of treatment of these various nerve injuries. The clinically pertinent anatomy is also presented to better relate mechanism of injury to the occurrence of nerve injury. I searched MEDLINE from 1966 through 1999 for the key words “nerve” and “shoulder.”

Data Synthesis: A historical review of treatment results is presented as well as a review of treatment options and the results of studies using modern techniques in the management of nerve injuries.

Conclusions/Recommendations: Nerve injuries about the shoulder present as distinct clinical syndromes, although signs and symptoms can be subtle. The athletic trainer and team physician must be able to recognize the presentation of these injuries so that adequate evaluation and prompt treatment can be instituted to maximize the athlete’s chance for early return to sport.

Key Words: axillary nerve, suprascapular nerve, musculocutaneous nerve, long thoracic nerve, spinal accessory nerve, athletic nerve injury

Athletic injuries to the shoulder most commonly involve the rotator cuff, glenohumeral joint, and acromioclavicular joint. Although less common, peripheral nerve injuries about the shoulder during athletic competition have increased along with the general interest in recreational athletics. These injuries may be subtle and are often hard for the clinician to detect. Contact sports such as football and wrestling contribute to most of these injuries, although peripheral nerve injuries to the shoulder have been reported in almost every sport, including bowling, golf, backpacking, and rope skipping.

Injuries to the axillary, suprascapular, musculocutaneous, long thoracic, and spinal accessory nerves produce distinct clinical syndromes about the shoulder. Early recognition of these injuries by involved medical personnel is critical for the prompt treatment, rehabilitation, and return to sport in these athletes.

Nerve injuries can be seen after a forceful traumatic injury or as the result of chronic, repetitive stress. Patients most often present complaining of pain and weakness, followed in time by atrophy in the affected muscle groups.

The severity of nerve injuries increases from neurapraxia to axonotmesis to neurotmesis. Fortunately, most peripheral nerve injuries about the shoulder in sports are first-degree injuries, or neurapraxias, consisting of a conduction block in the presence of intact neural elements, including the axons and their connective tissue sheaths. The prognosis for complete recovery in these patients is excellent. Second-degree nerve injury, or axonotmesis, usually follows more severe trauma and results in axonal injury and distal axon degeneration without disruption of the connective tissue sheaths. The regenerating axon is guided back to its muscular endplates by the intact connective tissue sheath. Recovery in these patients occurs over a more extended time, depending on the length of the nerve, but the ultimate prognosis is good. Injuries to the shorter nerves around the shoulder, such as the axillary and suprascapular nerves, heal more quickly after second-degree injuries than injuries to the longer nerves to the forearm, such as the radial and ulnar nerves. This is because of the generally shorter distance from the lesion to the site of muscle innervation. Neurotmesis, or complete nerve disruption, carries a poor prognosis for regeneration but fortunately is rare in athletic competition. This third-degree injury occurs most commonly with high-energy trauma, fractures, and penetrating injuries.

ELECTRODIAGNOSTIC STUDIES

The electromyelogram (EMG) is a valuable tool in the diagnosis and management of peripheral nerve injuries about the shoulder in athletes. This study consists of 2 complementary parts: the needle electrode examination and the nerve conduction velocity study. The needle electrode examination records electrical potentials produced by muscle fibers and can detect characteristic patterns in normal, acutely denervated, and reinnervating fibers. Because a single nerve fiber innervates many muscle fibers, injury to 1 nerve fiber can be detected from abnormal depolarization in multiple muscle fibers, making this test very sensitive to partial denervation of a muscle. The nerve conduction velocity study records conduction velocity of nerve fiber action potentials by myelinated fibers. The nerve is stimulated proximally, and the response is measured distally, using either surface electrodes or needles.
Thoracic outlet syndrome has also been associated with exu­
ditant callus from a comminuted clavicle fracture in a college
brachial plexus at or above the level of the clavicle that
ners are the deltoid, biceps, spinati, and brachioradialis.15'18'19
The differential diagnosis in the evaluation of peripheral
nerve injuries about the shoulder, the clinical
tical examination reveals involvement of the medial forearm and hand.
THORACIC OUTLET SYNDROME
inserted into the affected muscle. This study is helpful in
localizing the site of nerve compression.
Despite its usefulness, the EMG has certain limitations in the
athletic setting. Characteristic degeneration of the muscle
surface membrane does not occur immediately after nerve
injury and cannot be detected by needle electrode examination
for approximately 2 to 3 weeks. Both the athlete and physician
must therefore wait several weeks after the injury before the
exact nature of the injury can be detected by EMG. Another
problem is that the EMG cannot adequately differentiate
between second-degree and third-degree nerve injuries (axonotmesis and neurotmesis, respectively), 2 lesions with mark­
edly different prognoses. Despite these limitations, however,
the EMG is an invaluable tool in the diagnosis and manage­
ment of athletes sustaining nerve injuries about the shoulder. It
can help an athletic trainer and physician to distinguish
between atrophy secondary to pain and that secondary to nerve
injury. It is also valuable in revealing associated nerve injuries,
as well as in monitoring subclinical healing.8'16'17
PROXIMAL NERVE INJURIES
The axillary nerve is the most commonly injured nerve
either to peripheral nerve injury, and the athlete must
tforthcoming.25'26 The axillary nerve originates from the posterior cord of the brachial
proximity to the coracoid and is composed of fibers from the
cord and sixth cervical nerve roots10 (Figure 1). The nerve passes
through the quadrilateral space close to the inferior shoulder joint
has also been advocated,18 although its efficacy has not been confirmed. When
spontaneous resolution does not occur, surgical exploration
with neurolysis, nerve repair, and muscle transfers may be
required if symptoms persist.
PREVENTIVE MEASURES
Proper conditioning and preventive measures in young
athletes are critical to avoiding peripheral nerve injuries around
the shoulder. Most of these injuries occur in inexperienced
athletes, and poor conditioning plays a large role in
their development.1'2'5'6'12'13'28 Preventing these types of injuries
includes the following: adequate preseason examination;
matching competitors for age, weight, and skill level; proper
conditioning; avoiding excessive training at too early an age;
the thorough rehabilitation of injuries before return to sports;
appropriate and properly maintained equipment and playing
fields; adequate supervision; and rule changes as necessary.
Although the highest injury rates are noted in the United States
in adolescents participating in football, basketball, gymnastics,
baseball, and roller skating, nerve injury in Japan occurs most
commonly from mountain climbing secondary to excessive
backpack weight.1'12'18 Rather than condemning certain sports
as unsafe because of a high incidence of injuries, proper
training techniques should be emphasized in all sports to
reduce the risk of these injuries.
PROGNOSIS
Most injuries to peripheral nerves about the shoulder in
sports have a good overall prognosis.1'13'18 Treatment consist­ing
of observation, physical therapy, and cross-training of the
athlete generally results in spontaneous resolution of the nerve
injury. Braces are sometimes required to decrease stress on the
nerve injury and cannot be detected by needle electrode examination
and are som­
times accompanied by momentary weakness. Burners are
caused by a forceful increase in the acromiomastoid distance
when the head is forced in the direction of the contralateral
shoulder, thereby stretching the brachial plexus. This can occur
during tackling in football, and the muscles most often affected
are the deltoid, biceps, spinati, and brachioradialis.15'18'19
Burners are characterized by a rapid return of sensation and
strength, and return to play can be allowed when the athlete’s
nerve injury must always include injuries
to the cervical roots and the brachial plexus. In the acute setting
on the playing field, one must maintain a high degree of
suspicion for cervical spine injuries, especially when nerve
injuries are identified. The cervical spine must be carefully
protected until injury is ruled out. Fortunately, cervical spinal
nerve injuries are much less common in sports than peripheral
nerve injuries about the shoulder.18
“Burners” are brief episodes of burning dysesthesias that
frequently involve the entire upper extremity and are some­
times accompanied by momentary weakness. Burners are
casually, a forceful increase in the acromiomastoid distance
when the head is forced in the direction of the contralateral
shoulder, thereby stretching the brachial plexus. This can occur
during tackling in football, and the muscles most often affected
are the deltoid, biceps, spinati, and brachioradialis.15'18'19
Burners are characterized by a rapid return of sensation and
strength, and return to play can be allowed when the athlete’s
nerve injury normalizes, which often occurs before the
sporting event has finished.18
True supraclavicular brachial plexus injuries are suspected
when multiple muscle groups innervated by different periph­
eral nerve roots are affected. This type of injury carries a much
worse prognosis than a peripheral nerve injury, and the athlete must
be thoroughly evaluated for possible associated vascular
injuries.16'17'20'22
Thoracic outlet syndrome represents a compression of the
brachial plexus at or above the level of the clavicle that
presents insidiously in the athlete. This is most often seen in
racquet sport athletes, who commonly develop unilateral
hypertrophy and the resultant abnormally low carriage of the
shoulder.17'23'26 These athletes complain of pain and
paresthesias with overhead activity. Neurologic examination
typically reveals involvement of the medial forearm and hand.
High radial nerve palsies with triceps weakness, however, have
been noted with increasing incidence in tennis players.25'27
Thoracic outlet syndrome has also been associated with exu­
teran callus from a comminuted clavicle fracture in a college
football player,22 as well as cervical ribs in adolescent ath­
elites.26 Postural training and specific exercises to strengthening
the scapular elevators and retractors usually lead to resolution
of symptoms,25'26 although cervical rib excision may be
required if symptoms persist.
AXILLARY NERVE
Anatomy
The axillary nerve is the most commonly injured nerve
around the shoulder in both athletes and nonathletes.1'7'8 The
axillary nerve originates from the posterior cord of the brachial
plexus near the coracoid and is composed of fibers from the
fifth and sixth cervical nerve roots10 (Figure 1). The nerve passes
through the quadrilateral space close to the inferior shoulder joint
capsule31 (Figure 2). The nerve then divides into anterior and
posterior branches, which supply the anterior and posterior por­
tions of the deltoid muscles. A small branch that arises posteriorly
innervates the teres minor and posterior deltoid muscles and
supplies the skin overlying the deltoid muscle insertion. The
anterior branch continues to wind around the surgical neck of the
humerus under the deltoid muscle and extends to the anterior
border of the deltoid. This nerve has relative fixation points at the
posterior cord of the brachial plexus, the quadrilateral space, and
the nerve’s insertion into the deltoid muscle.16 The short length of
the axillary nerve renders it vulnerable to stretch injuries, espe­
the triceps medially, the teres major inferiorly, and the humeral neck laterally, forms a potential site of compression for the axillary nerve as it passes from the anterior to the posterior aspects of the shoulder.34,35

**Mechanism of Injury**

Axillary nerve injuries most commonly occur after anterior shoulder dislocation, a common athletic injury.13,17,18,36-41 The exact incidence of nerve palsy after acute dislocations of the shoulder ranges from 9% to 18%.36,41 Inferior dislocations, luxatio erectae, have an even higher rate of axillary nerve palsy, reported as high as 60%.37 Blunt trauma to the anterior aspect of the shoulder without dislocation has been implicated in axillary nerve trauma in sports such as football, wrestling, and gymnastics.13,18,37,38,42 Acute axillary neuropathy has also been associated with backpacking, usually in inexperienced hikers.13 The cause of axillary nerve injury in "rucksack palsy" is thought to be traction caused by depression of the shoulder from the excessively weighted backpack.

Quadrilateral space syndrome represents a chronic compression syndrome of the axillary nerve in throwing athletes. Axillary nerve entrapment occurs insidiously in the quadrilateral space without history of trauma. Fibrous bands at the inferior edge of the teres minor have been implicated, as have randomly oriented fibrous bands found in the quadrilateral space. Both the axillary nerve and the posterior humeral circumflex artery are compressed in the quadrilateral space when the arm is placed in the abducted, externally rotated or throwing position.34,35 Acute entrapment of the axillary nerve in the quadrilateral space has been described in a wrestler secondary to violent contraction of the muscles surrounding the quadrilateral space.43

Surgery to correct athletic injuries about the shoulder also puts the axillary nerve at risk, especially in operations for repair of instability.31-33 The axillary nerve sits approximately 2 cm inferior to the usual posterior portal for arthroscopy, putting this nerve at risk during routine arthroscopic procedures and emphasizing the need for proper portal placement.32

**Clinical Presentation**

Acute axillary nerve palsy in the athletic setting often presents subtly, and careful physical examination and EMG evaluation are necessary to make an accurate diagnosis. Evaluation of strength is often hampered by pain. In the acute setting, the athlete classically presents with weakness in abduction, decreased sensation along the deltoid muscle insertion, progressive atrophy of the deltoid muscle, and subluxation of the glenohumeral joint. Pain is not a prominent complaint, and deltoid weakness is often masked by surrounding muscle groups that compensate for its function.16,44 The injured athlete can often elevate the arm using the pectoralis and supraspinatus muscles,17 and subluxation can be prevented by the supraspinatus and long head of the biceps muscles. Active arm elevation by compensatory muscles is seen in up to 60% of athletes after axillary nerve injury, and several reports have documented the unreliability of sensory changes after injury.36 Careful manual muscle testing is important in identifying gross weakness in abduction.

Chronic compression of the axillary nerve in quadrilateral space syndrome typically presents with tenderness in the posterior shoulder area in the quadrilateral space, which is
exacerbated by placing the arm in the throwing position and resisting internal rotation. Symptoms, however, are often vague, consisting of a dull ache in the shoulder with progressive use, and may be difficult to differentiate from the internal impingement also seen in the throwing athlete.

During physical examination, the examiner must carefully palpate the deltoid muscle to determine whether it is firing and contributing to active abduction. Normal sensory examination does not preclude the diagnosis of axillary nerve injury.

The athlete presenting with possible axillary nerve injury must be differentiated from those patients with a higher brachial plexus injury to the posterior cord or a cervical root injury involving C5 or C6. These higher neurologic lesions usually involve multiple muscle groups and can be differentiated from isolated axillary nerve lesions through careful physical examination and EMG evaluation.

**Treatment**

Conservative management consisting of observation and physical therapy is successful in managing most axillary nerve injuries in athletes. EMG evaluation confirms the diagnosis and degree of injury. When incomplete axillary nerve injury has been demonstrated by both clinical examination and EMG testing, the prognosis is favorable, and gradual improvement can be expected. Passive range-of-motion exercises maintain flexibility; electrical stimulation may help to maintain muscle bulk, although its efficacy has not been proved. Physical therapy may need to be modified for initial protection of the anterior labrum and capsule in the presence of axillary nerve palsy after shoulder dislocation.

When the EMG reveals a complete axillary nerve lesion, the athlete should be re-evaluated at monthly intervals for signs of regeneration. Because the nerve is relatively short, recovery should be seen in second-degree injury (axonotmesis) between the third and fourth month postinjury. Surgical exploration and possible nerve grafting are generally recommended if no return of function has occurred by 6 months after injury. The site of nerve injury is generally in the quadrilateral space, requiring both anterior and posterior surgical approaches. Cable grafts are commonly required if the axillary nerve ends cannot be repaired without tension, but despite this, the results of surgery are generally good, with restoration of 4–5/5 strength in the deltoid in more than 90% of patients.

Chronic axillary nerve compression in quadrilateral space syndrome generally responds to conservative management, including changing pitching mechanics, which has been reported to be successful in 75% to 90% of patients. Operative intervention in quadrilateral space syndrome is indicated for failures of conservative management and involves release of fibrous bands of the teres minor muscle and any aberrant bands crossing the quadrilateral space. This surgery is accomplished through a posterior approach to the shoulder.

**Prognosis**

The short length of the axillary nerve, which renders it susceptible to injury with shoulder dislocation, also gives the injured nerve a good prognosis for improvement because of the short distance between the site of injury and the muscle end-plates. The recovery rate for the axillary nerve after dislocation of the shoulder is near 80%. The prognosis in quadrilateral space syndrome is generally good, even when surgery is required. No consensus of opinion exists as to the exact point at which a return to sports should be allowed after axillary nerve injury; however, in general, improvement on the EMG, as well as recovery of at least 80% of deltoid muscle strength, is recommended.

**SUPRASCAPULAR NERVE**

**Anatomy**

The suprascapular nerve originates from the upper trunk of the brachial plexus and is formed from the spinal roots of C5 and C6, with variable contribution of the C4 nerve root. It branches from the upper trunk of the brachial plexus at the Erb point and runs laterally. The nerve passes through the suprascapular notch of the scapula, which is bridged by the thick transverse scapular ligament (Figure 3). After entering the supraspinatus fossa, the nerve gives off 2 motor branches to the supraspinatus muscle and then passes laterally within the fossa, providing sensory branches to the posterior capsule of the glenohumeral joint and acromioclavicular joint. It then passes around the lateral border of the base of the spinous process to the infraspinatus fossa, where the nerve terminates by supplying motor branches to the infraspinatus muscle. This unique anatomy renders this nerve susceptible to injury in athletic competition. The suprascapular nerve has no cutaneous distribution or innervation.

The suprascapular nerve has a short course and several sites of relative fixation, making it vulnerable to both traction and compression forces. The nerve is fixed at both its origin at the Erb point on the brachial plexus and at its terminal insertion on the scapular spine, it is in close proximity to the posterior glenohumeral joint line and is susceptible to compression by ganglion cysts in the joint.
the infraspinatus. The nerve is relatively fixed at the suprascapular notch, and anatomical studies have shown that motion does not occur at this point, even at the extremes of scapular and arm motion.

Mechanism of Injury

The supraspinal nerve is generally injured during sports by traction, which can occur from an increase in the acromiostoid distance and stretching of the nerve between the Erb point and the suprascapular notch (Table 1). Downward traction of the scapula, a common mechanism of acromioclavicular joint separation, can result in opposition of the supraspinal nerve against the sharp inferior border of the transverse scapular ligament. This injury, therefore, does not occur from friction of the nerve passing through the suprascapular foramen but from the so-called “sling effect.”50 Cross-body abduction or protraction with forward flexion, as seen in fencing, throwing sports, racquet sports, and weight lifting, have also been found to maximally stretch the supraspinal nerve.52 Supraspinal nerve entrapment syndrome can follow repetitive motions, prolonged positioning, or single acute events. Entrapment can also occur more distally at the spinoglenoid notch, which is more commonly seen in athletes whose sports require rapid forceful external rotation movements, such as volleyball.65 The cocking motion for the serve results in rapid external rotation of the shoulder; this rapid motion of the infraspinatus muscle is thought to pull the supraspinal nerve against the base of the scapular spine, resulting in nerve injury at this level. Injury to nerves in the spinoglenoid area has also been noted secondary to ganglion cysts1,3,35 (Figure 4). These ganglion cysts in the spinoglenoid area has also been noted secondary to ganglion cysts1,3,35 (Figure 4). These ganglion cysts in the spinoglenoid area, pain is an inconsistent finding.1,3,35 Because the spinoglenoid nerve has no denervation distribution, pain is poorly localized, commonly leading to a delay in diagnosis, on the average of 12 months.

Physical examination of the athlete with supraspinal neuropathy is characterized by atrophy of the supraspinatus and infraspinatus muscles. The supraspinatus muscle is often obscured by the trapezius, so wasting of the infraspinatus is the most likely diagnostic sign on physical examination. Depending on the level of nerve involvement, the athlete may have weakness in forward elevation or external rotation, or both. Proximal injury of the supraspinal nerve at the level of the supraspinal notch causes the weakness of both forward elevation and external rotation, while nerve injury at the level of the spinoglenoid notch affects only the infraspinatus and results in isolated weakness of external rotation. The teres minor muscle, which is innervated by the axillary nerve, usually allows some external rotation despite denervation of the infraspinatus.10 Full abduction is usually possible, although some loss of strength of abduction is present. Variable tenderness at the supraspinal notch has been reported, and if a large ganglion cyst is present, this can occasionally be palpated as well.57 Frozen shoulder and glenohumeral subluxation have also been reported in association with supraspinal nerve injury.58 Skin sensation is characteristically normal.

The EMG remains the most reliable test for making the diagnosis of supraspinal nerve entrapment and can readily distinguish compression at the supraspinal notch from compression at the spinoglenoid area. In cases of a suspected ganglion cyst, a computed tomographic or magnetic resonance imaging scan is helpful in visualizing the site and extent of the cyst.57,59 Computed tomography scans can also be beneficial in determining the degree of infraspinatus muscle atrophy, which significantly affects the prognosis.54 Because shoulder pain and weakness in external rotation and forward elevation are also characteristic findings of rotator cuff tears, an arthrogram or magnetic resonance imaging scan of the shoulder is helpful to exclude this diagnosis. Several authors have advocated the infiltration of local anesthetic under fluoroscopic guidance into the area of the supraspinal notch.51,63,65–73 Pain relief after this injection confirms the diagnosis of supraspinal nerve entrapment at this point, although this test can be difficult to perform, and its reliability has been questioned.74

The differential diagnosis for supraspinal nerve entrapment is extensive, and a variety of more common diagnoses should be excluded before an EMG is ordered. Rotator cuff tears are more common than supraspinal nerve entrapment and present similarly with weakness and atrophy of the spinati.38,39,65 Moreover, these 2 diagnoses can exist simultaneously.39,40 Cervical root lesions of C5 and brachial plexus lesions should be suspected if other muscle groups are involved.18,61

Glenohumeral arthritis typically presents with posterior joint line tenderness and weakness of external rotation secondary to intra-articular pathology. The vague pattern of pain seen in supraspinal nerve entrapment can also be confused with impingement syndrome and calcific bursitis.55 Supraspinal nerve entrapment has been reported in association with frozen shoulder and posterior instability, the latter secondary either to ganglion cyst formation from labral trauma or traction injury after posterior dislocation.

| Table 1. Sports Associated with Supraspinal Nerve Injury |
|----------------|----------------|----------------|
| Baseball | 32 | Basketball |
| Cycling | 68 | Weight lifting |
| Fencing | | Physical education |
| Surfing | 53 | Tennis |
| Throwing | 18 | Backpacking |
| Volleyball | 56 | Gymnastics |

Treatment

The initial management for supraspinal nerve entrapment includes a conservative regimen of observation, rest, and analgesics.28,56,58,61,63 Analgesics, cortisone injections into the supraspinal notch,55 and electrical stimulation have been
Figure 4. A ganglion cyst along the posterior labrum of the glenoid can compress the suprascapular nerve in the spinoglenoid area. Compression at this location is characterized by isolated involvement of the infraspinatus muscle. Magnetic resonance imaging can clearly define the ganglion cyst.
advocated, although variable success has been reported in the
literature using these techniques.56

Suprascapular nerve entrapment resistant to 3 to 6 months of
conservative management is an indication for surgical decom-
pression.18,55,63 Surgery is directed to the area of compression
as determined by the EMG. Involvement of both the supraspi-
natus and infraspinatus muscles with a conduction delay at the
suprascapular notch is an indication for transverse scapular
ligament release, whereas a conduction delay at the spinogleno-
noid ligament with isolated involvement of the infraspinatus
muscle is an indication for surgical release at this more distal
site. Suprascapular nerve entrapment associated with a gan-
glion cyst requires decompression of the cyst. Open excision of
the ganglion cyst through a posterior approach can be performed
with or without infraspinatus muscle take-down, and attention
must be paid to avoiding injury to the suprascapular nerve during
this dissection.11,57,58 Arthroscopic decompression of the gan-
glion cyst has recently been described.59 The ganglion cyst is
typically associated with a labral injury, through which the
ganglion cyst can be reached. Good early results in a limited
series have been reported using this technique, although the cyst
may recur.

Prognosis

Recovery from suprascapular neuropathy occurs with both
conservative treatment and surgical intervention.56–58,61–63
Symptomatic improvement in both pain and strength is typical
in the athlete after a suprascapular nerve release. Continued
atrophy despite normalization of the EMG is frequently noted
despite successful decompression. Return to sport can be
allowed on a symptomatic basis as the athlete’s strength
improves and pain decreases. Good strength of external rota-
tion is most important in a throwing athlete, who depends on
these muscles for arm deceleration in the follow-through phase
of throwing. Athletes who are allowed to return to throwing
before good external rotation strength has returned are at risk
for secondary rotator cuff pathology. No significant problems
have been reported, however, in volleyball players who have
returned to play despite significant infraspinatus atrophy.56

MUSCULOCUTANEOUS NERVE

Anatomy

The musculocutaneous nerve originates from the lateral cord
of the brachial plexus near the inferior border of the pectoralis
minor and contains fibers from the C5 and C6 spinal nerve
roots, with occasional contributions from C7. It continues
between the axillary artery and the median nerve, entering the
upper arm by passing obliquely through the coracobrachialis
muscle and between the biceps and brachialis muscles that it
innervates (Figure 5). The musculocutaneous nerve terminates
in the lateral antebrachial nerve of the forearm and innervates
the skin on the radial aspect of the forearm. The musculou-
cutaneous nerve is vulnerable to traction injury proximally.75 Its
variable position of penetration through the coracobrachialis
muscle can make it susceptible to injury during surgical
procedures about the shoulder.10,76

Mechanism of Injury

Although rare, isolated musculocutaneous nerve injuries
have been reported in a variety of clinical situations, including
direct trauma to the anterior shoulder,18 fractures of the
humerus and clavicle,10 and anterior shoulder disloca-
tions.38,41,75 The musculocutaneous nerve can be stretched
across the humeral head or coracoid with the arm in the
throwing position,18,28 and traction injuries have been reported
in competitive airplane flying43 as well as throwing a football.
Musculocutaneous nerve injuries in weight lifters and rowers
have been attributed to engorgement of the coracobrachialis
muscle.77 Forceful extension of the elbow against resistance
during sports has also been implicated in musculocutaneous
nerve palsy.18 Anterior shoulder surgery, especially for insta-
bility in athletes, has been associated with musculocutaneous
nerve palsy.38,39 The nerve is at risk both with open and
arthroscopic procedures and can be stretched by retractor
placement on the coracobrachialis muscle for exposure.78

Clinical Presentation

Musculocutaneous nerve palsy presents with wasting of the
biceps and brachialis muscles and weakness of elbow flexion.
The athlete reports a variable loss of sensation along the lateral
aspect of the forearm but generally does not complain of any
significant pain. Clinical examination reveals atrophy of the
biceps and brachialis muscles or decreased muscle tone in
patients with partial nerve injury. Elbow flexion is weak but
may be possible using the brachioradialis muscle, which is
innervated by the radial nerve.

Differential Diagnosis

The differential diagnosis for musculocutaneous nerve in-
jury includes rupture of the distal biceps tendon at the elbow,
as well as more diffuse brachial plexus injuries. Distal biceps
tendon rupture is associated with a loss of contour of the
muscle belly and superior retraction. The athlete can still
contract the muscle, although a loss of contour is obvious, and
the distal tendon cannot be palpated in the antecubital fossa. In the acute phase after injury, swelling, ecchymosis, and tenderness are present, differentiating this injury from musculocutaneous nerve palsy. More diffuse brachial plexus injuries, which can include the lateral cord, result in a concomitant loss of wrist and finger extension, and more proximal cervical root injuries typically involve the deltoid and rotator cuff muscles, as well as the elbow flexors. EMG evaluation is the best way to differentiate musculocutaneous nerve injuries from those associated with more diffuse nerve involvement.

**Treatment**

Musculocutaneous nerve injury in athletes generally recovers spontaneously and does not require surgical intervention. Observation, rest, and electrical stimulation usually yield good results. Incomplete lesions of the musculocutaneous nerve can simply be monitored, while complete lesions not demonstrating any recovery within 3 months may be considered for surgical exploration. Complete lesions are rare in the athletic population but can occur after surgical repair for anterior shoulder instability; in the absence of early improvement, these lesions can be explored earlier than 3 months for appropriate nerve repair.

**Prognosis**

The prognosis for musculocutaneous nerve injury in athletes is generally good, with most players improving once the offending activity has been stopped. Spontaneous recovery has been reported after both blunt trauma and shoulder dislocations, although higher-energy trauma carries a worse prognosis. The athlete may be allowed to return to sports once he or she is asymptomatic, with appropriate alterations of technique if the nerve injury is secondary to repetitive use or positioning.

**LONG THORACIC NERVE**

**Anatomy**

The long thoracic nerve is a pure motor nerve to 1 muscle, originating directly from the spinal roots of C5, C6, and C7. The long thoracic nerve passes along the anterior lateral aspect of the chest wall, supplying branches to all of the digitations of the serratus anterior muscle (Figure 6). The long thoracic nerve is well protected throughout its proximal course along the superior chest down to the level of the inferior portion of the pectoralis major. The nerve is susceptible to traction injury between its 2 points of relative fixation: at the scalenus medius muscle at the base of the neck and at the superior aspect of the serratus anterior muscle. Marked anatomical differences may account for the nerve’s variable susceptibility to injury in the athletic population.

**Mechanism of Injury**

Isolated serratus anterior muscle paralysis in the athlete may result from acute injury or, more insidiously, from repetitive motions, positioning, or strain. A wide variety of sports have been implicated in injury to the long thoracic nerve (Table 2). In general, injuries to the long thoracic nerve occur secondary to asynchronous motion of the arm and scapula, which can occur with a missed shot in golf, handball, or tennis or in contact sports in which the arm is jerked into an abnormal position. A direct blow to the shoulder more often results in a diffuse brachial plexus injury than an isolated injury of the long thoracic nerve because of the protected position of the long thoracic nerve along the chest wall.

Long thoracic nerve traction injuries have been reported secondary to repetitive motion such as swimming and tennis and prolonged positioning of the arm while shooting a rifle. Fatigue of the parascapular muscles, as seen in backpackers, rope skippers, and weight lifters, can allow abnormal scapular motion on the chest wall, resulting in a traction injury to the long thoracic nerve. Weight-lifting exercises most commonly associated with long thoracic

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**Table 2. Sports Implicated in Long Thoracic Nerve Injury**

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nerve palsy include behind-the-neck french curls and the bench press. All of these exercises can result in marked translation of the scapula on the chest wall, producing a traction injury to the long thoracic nerve.

Clinical Presentation

The serratus anterior muscle is most critical in the plane of flexion, stabilizing the scapula on the chest wall to create a platform for glenohumeral motion. It also rotates the scapula forward as the arm is elevated above shoulder level. The loss of these 2 functions of the serratus anterior muscle results in the symptoms of long thoracic nerve palsy: an uncosmetic winging of the scapula and limitations in forward elevation. Weakness with overhead activity in association with a vague posterior aching sensation are commonly reported. Pain may be severe initially, but winging may not be obvious until several weeks after the injury, when the pain is starting to improve. On physical examination, athletes with long thoracic nerve palsy demonstrate winging of the scapula and active forward elevation limited to less than 110°. Scapular winging is best demonstrated by having the patient flex the shoulders to 90°, extend the elbows, internally rotate the shoulders, and push against the wall with both hands. The serratus anterior muscle can occasionally be palpated just anterior to the latissimus dorsi, but this test is not reliable. Scapular winging secondary to long thoracic nerve palsy is characterized by elevation and retraction of the scapula such that the scapula appears closer to the midline and slightly more elevated than the contralateral normal scapula. A loss of normal scapulo-thoracic rhythm with attempted arm elevation is best observed from behind, as the injured athlete attempts to elevate the arms. Both scapular position and the plane of weakness in long thoracic nerve palsy readily distinguish this syndrome from winging secondary to spinal accessory nerve palsy. EMG evaluation confirms the diagnosis of long thoracic nerve palsy.

Differential Diagnosis

The differential diagnosis of long thoracic nerve palsy is extensive, including winging secondary to other etiologies, such as trapezius paralysis, brachial plexus lesions, and traumatic serratus anterior muscle avulsions. Posterior shoulder instability, scoliosis, scapular nonunions, and chronic glenohumeral conditions can also result in winging of the scapula. Acute brachial neuropathy involving the long thoracic nerve, diabetic amyotrophy, polio, multiple sclerosis, toxic agents, cold exposure, and infection have been associated with long thoracic nerve palsy; these conditions should be ruled out before attributing long thoracic nerve palsy solely to trauma and sports.

Treatment

Recovery of function in the serratus anterior muscle can occur for as long as 2 years, and, therefore, a prolonged period of observation is recommended before surgical intervention is considered. If a lesion is thought to be secondary to a repetitive-use injury, the offending activity should be stopped. Physical therapy may be beneficial, including passive range-of-motion exercises to stretch the rhomboid and pectoralis minor muscles and avoid a fixed, retracted position of the scapula on the chest wall. Electrical stimulation of the nerve is used to maintain muscle tone. Strengthening of the remaining scapular muscles is encouraged, although no other muscle can adequately substitute for the function of the serratus anterior muscle. A brace to maintain the scapular position has been suggested by many authors, but this may be cumbersome and is generally poorly accepted by the athlete. A brace, however, limits further winging of the scapula, thereby decreasing the continuing stretch on the long thoracic nerve during nerve recovery. Athletes are discouraged from lying with the hand behind the head in the abducted, externally rotated position for prolonged periods of time, as this results in prolonged protraction of the scapula on the chest wall and further traction on the recovering long thoracic nerve. If the athlete’s symptoms persist beyond the 1- to 2-year mark and are severe, operative intervention should be considered. Muscle-transfer procedures to substitute for the serratus anterior muscle have provided variable results. Transfer of the sternal head of the pectoralis major muscle using fascia lata or semitendinosus graft into a hole made through the inferior angle of the scapula has been described and shown good results. Transfers of the rhomboids, teres major, and pectoralis minor muscles have been described in the literature as well, although these muscles tend to be smaller and their vectors of pull are not as ideal as that of the sternal head of the pectoralis major.

Prognosis

In general, the prognosis for recovery after long thoracic nerve palsy is excellent: an average of 8 months, with a range of 1 to 24 months. In 1 large series, all athletes with long thoracic nerve palsy demonstrated a full symptomatic recovery, even though residual weakness was noted. Slight to moderate residual weakness and limitation of forward elevation, along with early fatiguing, are common despite recovery of long thoracic nerve function. A return to sporting activity can occur once the athlete’s symptoms have resolved, even if early fatiguing is noted on physical examination.

SPINAL ACCESSORY NERVE

Anatomy

The spinal accessory nerve (cranial nerve XI) is a motor nerve that innervates the trapezius muscle. It passes distally from the skull through the jugular foramen and pierces the sternocleidomastoid, which it supplies. It then courses posteriorly in an oblique fashion superficially across the floor of the posterior triangle of the neck to the ventral border to the trapezius muscle (Figure 8). The nerve often communicates with the upper cervical roots to form a plexus and travels on the deep surface of the trapezius muscle on the medial border of the scapula. The trapezius muscle has 3 heads that function together to rotate the scapula on the chest wall and allow full abduction. The superior portion of the trapezius elevates the scapula by rotating the lateral border superiorly, whereas the middle portion draws the scapula toward the midline, and the inferior portion draws the angle of the scapula downward (Figure 9).
Figure 7. Pectoralis major transfer for serratus anterior palsy. A, The sternocostal head of the pectoralis major is transferred, along with a fascial graft, to B, the inferior pole of the scapula to substitute for serratus function and stabilize the scapula in the plane of flexion.

Figure 8. Lateral view of the neck showing the spinal accessory nerve (cranial nerve XI). The spinal accessory nerve leaves the skull and pierces the sternocleidomastoid muscle, which it innervates. It then crosses obliquely and posteriorly across the posterior triangle of the neck to the ventral border of the trapezius muscle. Its superficial location in the neck and close proximity to the deep lateral chain of lymph nodes render it susceptible to injury, both by direct blow to the neck and by biopsy of lymph nodes in this area.

Figure 9. Posterior view of the shoulder girdle demonstrating the function of the trapezius muscle. The superior portion of the trapezius elevates the scapula, while the middle portion draws the scapula toward the midline, and the inferior portion draws the angle of the scapula downward. Trapezius paralysis allows drooping of the scapula with migration distally and away from the midline.

posterior cervical node, radical neck dissection, or penetrating injury to the base of the neck. Isolated injuries to the spinal accessory nerve in sports have been reported secondary to crushing injuries, such as a blow to the neck from a hockey stick. Traction injuries to the nerve have been noted with a fall on the point of the shoulder, which increases the acromioma-toid distance. Two separate reports of spinal accessory nerve palsy discuss the dangers of the wrestling “cross-face” maneuver, in which the head is forcefully rotated toward the opposite
shoulder. Stretch palsy of the spinal accessory nerve has also been reported with heavy weight lifting.

Clinical Presentation

The athlete with trapezius muscle paralysis typically complains of drooping of the affected shoulder and weakness with overhead use that began several weeks after the shoulder injury. Weakness of other shoulder muscles as a result of loss of scapular stabilization may also be present. A persistent ache in the posterior shoulder and medial scapula often radiates down the arm. This persistent ache in the shoulder and arm is gradual in onset after injury and may represent stretching of the remaining scapular muscles. Impingement syndrome secondary to forward rotation of the scapula or stretching of the brachial plexus.

On physical examination, the athlete with trapezial paralysis demonstrates drooping of the shoulder laterally and inferiorly and an asymmetric neck line. Female athletes may notice difficulty in keeping the bra strap on the affected shoulder. The scapula lowers and moves further from the midline, its inferior angle drawn upward by the rhomboid muscles. Winging is most pronounced in the plane of abduction, in contrast to long thoracic nerve palsy. The normal contour of the trapezius between the neck and lateral shoulder is lost, and the distal clavicle and acromion appear more prominent secondary to atrophy of the overlying trapezius. Trapezius function is best tested in the plane of abduction by asking the patient to internally rotate the upper arm, pronate the hand, and attempt elevation of the arm in abduction. Full abduction is impossible in this position without an intact trapezius. The shoulder shrug test is not reliable because the levator scapulae muscle, innervated by the dorsal scapular nerve, can perform this function.

Partial palsy of the spinal accessory nerve may allow complete motion, but weakness overhead is noted on physical examination. Frozen shoulder is commonly associated with trapezial paralysis, and restriction in glenohumeral joint motion in the athlete may compound the clinical picture. Stabilization of the scapula on the chest wall by the examiner often markedly improves the athlete’s ability to elevate the arm. As with other nerve injuries, the EMG provides a definitive diagnosis of spinal accessory nerve palsy.

Differential Diagnosis

The differential diagnosis of spinal accessory nerve palsy includes cervical nerve root avulsion and long thoracic nerve palsy with paralysis of the serratus anterior muscle. Cervical root avulsion is characterized by paralysis of multiple surrounding muscle groups. In long thoracic nerve palsy, the scapula moves closer to the midline and higher, as opposed to the characteristic drooping position of spinal accessory nerve palsy. Winging is accentuated primarily in the plane of flexion, as opposed to spinal accessory nerve palsy, in which winging is more readily observed in the plane of abduction.

Treatment

Penetrating injuries to the neck require immediate exploration and nerve grafting (if indicated) and usually provide good results. Most athletic injuries, however, are closed and are best treated initially with observation, a sling, nonsteroidal anti-inflammatory medications, and electrical stimulation to the trapezius muscle at the point of nerve injury. Because this conservative treatment is often unsuccessful in active individuals, surgical exploration is indicated if no clinical or EMG improvement is noted by 6 weeks. Neurolysis delayed beyond 6 weeks has little chance of success in these patients. As with the serratus anterior muscle, no muscles about the shoulder blade can substitute for the function of the trapezius. Resistive exercises to the remaining scapular muscles are of limited benefit. The mainstay of treatment in persistent trapezius paralysis, therefore, is surgical. Static stabilization procedures do not adequately compensate for the complex dynamic function of the trapezius, but dynamic muscle transfer using the levator scapulae and rhomboid muscles has been successful. This technique involves transfer of the levator scapulae from the medial border of the scapula to the lateral scapular spine, just medial to the acromion, and transfer of the rhomboid major and minor muscles onto the body of the scapula to improve their vector pull and more closely simulate the function of the trapezius (Figure 10). Pain is diminished and function is improved, although normal shoulder function is not restored. A muscle-transfer procedure should not be performed as a primary procedure for spinal accessory nerve palsy but only if neurolysis or nerve grafting is unsuccessful.

Prognosis

Spinal accessory nerve injury is rare in athletes, and, thus, generalizations on its prognosis are difficult to make. The prognosis for complete spinal accessory nerve palsy after open or closed injury is typically poor, with progressive worsening of symptoms over time. No other muscle groups around the scapula can adequately compensate for loss of trapezial muscle function, and the likelihood of successful return to sports, with or without surgery, is small. The relatively
asymptomatic athlete, however, may be allowed to return to sport if shoulder function allows.

**SUMMARY**

Nerve injuries around the shoulder in the athletic population are fortunately rare but can mimic symptoms associated with more common injuries. The clinician must be able to recognize and differentiate isolated peripheral nerve injuries from more proximal cervical root and brachial plexus injuries as soon as possible. Familiarity with the clinical presentation, evaluation, and treatment of nerve injuries about the shoulder will assist the sports medicine professional in the identification and management of these often-puzzling injuries.

**REFERENCES**

A Kinetic Chain Approach for Shoulder Rehabilitation

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**Objective:** To introduce an approach to shoulder rehabilitation that integrates the kinetic chain throughout the rehabilitation program while providing the theoretical rationale for this program.

**Background:** The focus of a typical rehabilitation program is to identify and treat the involved structures. However, in activities of sport and daily life, the body does not operate in isolated segments but rather works as a dynamic unit. Recently, rehabilitation programs have emphasized closed kinetic chain exercises, core-stabilization exercises, and functional programs. These components are implemented as distinct entities and are used toward the end of the rehabilitation program.

**Description:** Kinetic chain shoulder rehabilitation incorporates the kinetic link biomechanical model and proximal-to-distal motor-activation patterns with proprioceptive neuromuscular facilitation and closed kinetic chain exercise techniques. This approach focuses on movement patterns rather than isolated muscle exercises. Patterns sequentially use the leg, trunk, and scapular musculature to activate weakened shoulder musculature, gain active range of motion, and increase strength. The paradigm of kinetic chain shoulder rehabilitation suggests that functional movement patterns and closed kinetic chain exercises should be incorporated throughout the rehabilitation process.

**Clinical Advantages:** The exercises in this approach are consistent with biomechanical models, apply biomechanical and motor control theory, and work toward sport specificity. The exercises are designed to stimulate weakened tissue by motion and force production in the adjacent kinetic link segments.

**Key Words:** glenohumeral joint, closed kinetic chain, scapula, exercise, function

The goal of most athletic rehabilitation is to return the athlete to the activity that caused the injury. Successful shoulder rehabilitation depends on an understanding of the cause of injury and a complete and accurate diagnosis of the involved tissues. Therefore, a thorough understanding of the physical demands of the activity is a prerequisite to making a complete diagnosis and returning the athlete to safe, pain-free participation.

The kinetic link model, a biomechanical model used to analyze many sport activities, depicts the body as a linked system of interdependent segments, often working in a proximal-to-distal sequence, to impart a desired action at the distal segment. This model illustrates the contribution of the entire body during sport activities rather than focusing on the action of individual segments. Normal, efficient motion and muscle activation are believed to occur in a proximal-to-distal sequence. This proximal-to-distal sequencing should be considered when attempting to restore function via a rehabilitation protocol.

The shoulder pathology is the primary factor that determines the therapeutic treatment. Traditional shoulder rehabilitation after injury includes a phase of rest, control of inflammation, and isolated muscle strengthening. Additional components of shoulder rehabilitation programs are scapular-stabilization, proprioceptive, and closed kinetic chain exercises. However, these exercise regimens tend to isolate the involved tissue initially while neglecting the contributions of the trunk and lower extremity. Clinicians recognize the need to address the legs and trunk as contributors to shoulder function and for general conditioning, but their protocols often integrate the shoulder with the rest of the body late in the rehabilitation process. In kinetic chain shoulder rehabilitation, the legs and trunk are integrated into most of the shoulder exercises from the onset. This reinforces normal movement patterns and reduces the challenge of learning new movements during rehabilitation.

We present an approach to shoulder rehabilitation that integrates the kinetic link model and normal synergistic muscle-activation patterns with proprioceptive neuromuscular facilitation (PNF) principles. Rather than isolating the shoulder and gradually incorporating the rest of the body, this approach focuses on rehabilitating the entire neuromuscular system by integrating multiple body segments throughout the process. The segmental integration follows the proximal-to-distal movement and muscle-activation sequence consistent with biomechanical upper extremity function. Clinically, kinetic chain rehabilitation has been effective in restoring shoulder function when other methods of shoulder rehabilitation have failed.

**THEORETICAL FOUNDATION**

A common biomechanical model for striking and throwing sports is an open-linked system of segments that work in a proximal-to-distal sequence. The goal of these activities is to impart a high velocity or force on the distal segment. The distal segment may be the hand of a pitcher, the foot of a soccer
athlete, or the hand and racquet of a tennis player. The ultimate velocity of the distal segment depends on the velocity of the proximal segment and the interaction of these segments. The proximal segments, the legs and trunk, accelerate the entire system and sequentially transfer the momentum to the next distal segment. Conservation of momentum explains this sequential interaction. The equation for angular momentum is segment inertia times its angular velocity. The initial acceleration of the proximal segment encompasses all the distal segments as part of its inertia. The sequential deceleration of the proximal segments conserves momentum by transferring segmental velocity distally along the kinetic chain. This proximal-to-distal linkage provides an efficient and effective system to transfer force and produce greater velocity in a distal segment. Kinetic chain rehabilitation incorporates this model by initiating shoulder exercises through proximal segment movement.

Normal motor patterns of voluntary upper extremity movements while standing include lower extremity and trunk muscle activation before the arm motion. Voluntary movements of the upper extremity, such as rehabilitation exercises, are primarily task oriented and are controlled via motor programs. Motor programs are thought to exist for categories of movements, such as walking or throwing, rather than each component of a movement having its own program. Motor programs use coordinated groups of muscles and joint movements, or synergies, often in a proximal-to-distal fashion, to simplify and perform movement tasks. Kinetic chain shoulder exercises employ these natural motor programs by focusing on the neuromuscular system rather than on isolated movement and muscle activation. This method uses and restores normal movement patterns that are familiar to the neuromuscular system so the rehabilitation occurs within the framework of normal function.

Upper extremity motion follows this proximal-to-distal motor program sequence. Upper extremity motion occurs with consistent synergistic muscle activation patterns in the legs and trunk. The task of rapidly reaching forward with the right hand to shoulder level produces a consistent pattern of activation and deactivation of leg and trunk musculature before activation of the anterior deltoid. This sequential pattern includes deactivation of the left soleus, activation of the right tensor fascia lata and rectus femoris, activation of the left semitendinosus and gluteus maximus, and, finally, activation of the right erector spinae before initial deltoid activity. Injury at a distal segment can alter this proximal-to-distal control. Proximal hip muscle activation is delayed in patients with severe ankle joint injury compared with noninjured controls during hip active extension. The possibility that injury to a distal segment alters normal motor programs further supports the need to incorporate these motor programs throughout the rehabilitation process.

The anticipatory patterns of leg and trunk activation are associated with segmental joint accelerations that effectively move the center of gravity forward and up toward the side of unilateral shoulder flexion. These proximal-to-distal synergies are postural adjustments to counteract the disturbance in equilibrium caused by the voluntary arm movement. This pattern of proximal muscle activation before distal movement serves as a foundation for using the trunk and legs to drive the scapula and shoulder during the rehabilitation process. Kinetic chain rehabilitation incorporates these synergies to produce motion and activate involved muscles throughout shoulder rehabilitation.

Shoulder rehabilitation programs incorporate PNF techniques to stimulate synergistic patterns of movement. Kinetic chain rehabilitation incorporates 5 important PNF concepts. The first is that motor behavior is a sequence of total patterns incorporating the head, neck, trunk, and extremities. This is true whether the movement is unilateral, bilateral, or reciprocal. Motor behaviors such as baseball pitching or tennis serving illustrate this concept by generating maximum shoulder internal rotation through the transfer of forces from the legs, through the trunk to the shoulder. Second, normal goal-directed movement and posture depend on synergies to balance muscular activity between antagonists. Third, normal motor development occurs in a proximal-to-distal direction. Fourth, in movement patterns, stronger component patterns augment weaker components by the irradiation reflex, which suggests that as the intensity of an applied stimulus increases, the area of response increases. In kinetic chain shoulder rehabilitation, thoracic extension can stimulate scapular retraction. Applying resistance to thoracic extension should increase this stimulus and elicit an increase in the scapular retraction. Fifth, the clinician helps the athlete relearn the normal movement patterns by selecting and applying appropriate stimuli such as positioning, manual contact, or resistance. The clinician becomes part of the exercise environment by giving visual, auditory, and tactile feedback.

RATIONAL FOR KINETIC LINK REHABILITATION

Kinetic chain rehabilitation approaches the shoulder as part of a kinetic link system and attempts to address shoulder function in a proximal-to-distal manner. The proximal trunk segment, rather than the more distal arm, acts as the "initiator" for appropriate shoulder motion. Based on this proximal-to-distal premise, quality arm elevation and shoulder function depend on trunk and scapular control. Trunk and scapular control exercises begin at the onset of therapeutic exercise in kinetic chain shoulder rehabilitation, since neither depends on arm motion. If the goal of an exercise activity is scapular movement, arm elevation is not required. However, scapular motion and control are prerequisites for proper arm elevation.

Kinetic chain rehabilitation applies elements of biomechanical and motor control theories to PNF and closed kinetic chain exercise techniques. By using multiple body segments in the exercises, adjacent segments can facilitate the activation of involved muscles to develop appropriate shoulder motion and function (irradiation). Adjustments of posture and the amplitude of movement by proximal segments can control the location and intensity of the loads of a given exercise. Early in the rehabilitation, the shoulder may require a great deal of facilitation, so the role of the adjacent segments may be exaggerated. Decreasing the role of the facilitating segments later in the progression increases the load and functional demand on the shoulder.

Successful acquisition of movement patterns is feedback sensitive and requires consistent observation to avoid compensatory movements. The training of movement patterns, rather than isolated muscles, often requires verbal and tactile feedback. This immediate feedback may help the athlete to identify and correct movement errors. Gradual removal of the feedback is a form of exercise progression as the athlete gains...
awareness of appropriate and inappropriate movement patterns. The exercise goal is to find movement patterns which the athlete can perform successfully while progressively loading deficient tissue anywhere in the kinetic chain.

Imbalances in the action of scapular force couples may result in scapular dyskinesis (abnormal scapular movement), glenohumeral translation, or rotator cuff overload. The function of the shoulder complex depends upon muscular force couples about the scapula and glenohumeral joint. Synergistic scapular muscle actions allow proper positioning and stability of the scapula while maintaining the glenohumeral center of rotation throughout arm motion. Due to its anatomical location on a rounded thorax, normal scapular motion is multiplanar. Scapular motion provides optimal muscle length-tension ratios and reduces the muscular energy requirements of the rotator cuff during arm motion. Scapular function mediates the demand on the rotator cuff, promotes energy conservation in the upper extremity, and aids in glenohumeral stability.

Appropriate scapular motion requires attention to muscular flexibility. The upper trapezius and the pectoralis minor are common sites of myofascial tightness and hypertonia in athletes with shoulder pain and can limit normal scapular motion. Throwing athletes commonly present with muscular tightness in the external rotators of the shoulder. Tightness of the posterior capsule and decreased infraspinatus and teres minor flexibility can create excessive tilting of the scapula into protraction when the glenohumeral joint internally rotates at 90° of abduction. These areas of inflexibility may be detrimental to scapular control and mobility. The kinetic chain exercises can aid in attaining flexibility, but stretching, massage techniques, therapeutic modalities, or joint mobilizations may be necessary.

Scapular dyskinesis is often present with glenohumeral pathology, such as instability and rotator cuff impingement syndrome. Muscular weakness, inflexibility, and neuromuscular adaptations contribute to this loss of scapular control and scapular dyskinesis. Rotator cuff strengthening is a necessary component of the rehabilitation of these glenohumeral pathologies. The proximal-to-distal model suggests that effective and efficient rotator cuff strengthening depends on scapular control. In kinetic chain shoulder rehabilitation, intervention to normalize scapular movement precedes attempting to load the rotator cuff.

A primary role of the rotator cuff is to compress the humeral head in the glenoid and provide dynamic glenohumeral stability. To do this effectively, the rotator cuff must operate from a stable scapular base and meet minimum strength requirements. Exercising the rotator cuff without scapular stability could increase the risk of glenohumeral translation, create pain in rehabilitation, and increase the risk of further injury. Closed kinetic chain exercises promote cocontraction of rotator cuff musculature at submaximal levels. Applying axial compression through the glenohumeral joint, as in closed-chain exercises, decreases glenohumeral translation at various levels of elevation. Therefore, closed kinetic chain exercises have an important role in shoulder rehabilitation programs. In these exercises, the clinician can determine and control the proximal load and scapular position by varying the athlete’s stance and posture. Early in the rehabilitation process, closed kinetic chain exercises promote safe, functional cocontractions and can functionally strengthen the rotator cuff in preparation for open-chain exercises.

PROXIMAL SEGMENT CONTROL

Based on proximal-to-distal sequencing, the arm ultimately depends on the segments proximal to it for movement. Full arm elevation requires full scapular retraction, which requires spinal extension, hip extension, and so on. The large muscles of the hips and trunk thereby help position the thoracic spine to accommodate appropriate scapular motion. In many athletic activities, these muscles must provide stability for effective function of the shoulder girdle. Normal motor patterns of forward arm elevation demonstrate ipsilateral activation of hip extensors before deltoid activation. Kinetic chain rehabilitation attempts to take advantage of this by exaggerating the role of the hip extensors in an athlete with limited forward elevation. Forcing hip extension by including an ipsilateral step-up with a shoulder-flexion exercise seems to facilitate the shoulder flexion (Figure 1). Adding a PNF technique, the verbal cue to “get tall,” encourages the thoracic extension that is necessary for complete arm elevation. Additional resistance to the hip extension may stimulate an irradiation reflex to synergistic muscles and activate deficient shoulder flexors.

Hip and trunk motion can facilitate shoulder motion in other planes. Proximal-to-distal muscle activation in rotational patterns consistent with PNF can facilitate shoulder rotation. These types of movement patterns promote sequential muscle activation and coordination of proximal segment movement that can be built upon as the shoulder rehabilitation progresses. A basic exercise that illustrates this is the “shoulder dump.” To attain right shoulder external rotation and scapular retraction, the athlete assumes a left-foot-forward stance and begins with the left hip flexed, trunk flexed and rotated to the left, and right
Figure 2. A, Starting position for the shoulder-dump exercise. Body weight is on the contralateral-side leg with trunk flexion and rotation. B, Finishing position. Body weight is on the ipsilateral-side leg with thoracic extension.

Arm at knee level (Figure 2A). The athlete then shifts weight to the rear foot while extending and rotating the trunk to the right. Active retraction of the right scapula and external rotation of the right arm coincides with this weight shift and trunk extension (Figure 2B). The action simulates dumping a container backward. The degree of arm elevation, or the height at which the imaginary container is dumped, depends on the level of recovery and functional ability.

SCAPULAR FUNCTION AND CONTROL

Kinetic chain rehabilitation exercises use functional movement patterns to facilitate scapular motion and then to strengthen scapular musculature. Complementary movements by the legs and trunk, postural adjustments, and plane-of-motion modifications attempt to load scapular musculature and minimize muscular compensations. A common clinical scapular compensation involves the substitution of the upper trapezius, or exaggerated shoulder shrugging, during a scapular-retraction exercise. The kinetic chain approach deemphasizes the upper trapezius by concentrating on scapular depression with the retraction. Clinically, adjustments in the direction and amount of complementary trunk motion seem to minimize or eliminate muscular compensations so the scapula remains congruent with the thorax. One technique is to increase trunk rotation and thoracic extension with scapular retraction. Other feedback methods such as verbal queuing to “pull down,” manually tapping on the lower trapezius, or applying manual resistance along the medial border of the scapula may assist active scapular depression and retraction.24

The first goal in obtaining scapular control and function is scapular retraction. One technique to aid in the reeducation of this movement is a modification of the previously described shoulder-dump exercise. By removing the arm movement, this becomes a trunk-facilitated scapular exercise. Complementary trunk motion, rather than isolated arm movements, helps establish the scapular retraction. The arm can remain in a sling during this exercise. The starting position is one of gravity-assisted scapular protraction (Figure 3A). Scapular retraction accompanies active spinal extension and ipsilateral rotation (Figure 3B). As scapular motion and control improve, reducing trunk motion, increasing arm elevation, or adding extrinsic loads increases scapular muscular demand.52

In addition to the modified shoulder dump, other scapular exercises include sternal lifts (Figure 4), tubing “fencing,” (Figures 5A and 5B), and dumbbell or tubing punch and pull. Sternal lifts involve reciprocal thoracic flexion-extension with the emphasis on thoracic extension and scapular retraction. The athlete should feel as though he or she is pushing the sternum up and out but avoid lumbar hyperextension (Figure 4). If the athlete has difficulty pulling the scapula inferiorly and medially, the trunk and hip flexion in the reciprocal movement should increase.

Tubing fencing is a frontal-plane scapular-retraction exercise. In the starting position, the athlete reaches for the tubing with the involved arm in a lateral lunge stance (Figure 5A). The angle of the tubing should be horizontal or angled downward, to encourage scapular depression. From the reaching and lunging position, the athlete pushes off the leg on the involved side and pulls the arm into adduction. In the finished position, the elbow of the involved arm is against the ipsilateral hip, the shoulder is in approximately 90° of external rotation, and the body weight is on the leg of the uninvolved side (Figure 5B). The movement is similar to a lunge and parry in the sport of fencing. The athlete should focus on thoracic extension in the concentric phase of the exercise and on pulling the scapula medially without shrugging.

Punches with dumbbells are a protraction exercise that loads the serratus anterior concentrically and the posterior...
shoulder musculature eccentrically. A complementary stride accompanies the punches, and repetitions should be rhythmic to incorporate the proximal-to-distal activation and promote reciprocal scapular motion. For example, a contralateral forward stride accompanies a forward punch, and an ipsilateral lateral stride accompanies a lateral punch (Figure 6). The height and direction of the punch vary the rotator cuff load. By punching to knee level, the punch is gravity aided and reduces the load. Horizontal punches place the greatest load on the rotator cuff, extending the resistance the greatest distance from the shoulder joint.

CLOSED KINETIC CHAIN AND AXIALLY LOADED EXERCISES

In kinetic chain shoulder rehabilitation, closed kinetic chain exercises are exercises in which the hand is relatively fixed. An example of this is the scapular-clock exercise, in which
Proper posture and proximal stability are important for these exercises. The posture should be “athletic,” with feet shoulder-width apart, weight evenly distributed, slight hip and knee flexion, back straight, and head up. By assuming an athletic stance, the athlete can load the hips and trunk during these static exercises to promote proximal-to-distal activation patterns (Figure 7). Closed kinetic chain exercises should stimulate appropriate cocontractions of the shoulder girdle musculature at safe, pain-free positions within the arc of motion.

Kinetic chain shoulder rehabilitation includes light, axially loaded, active-motion exercises to promote active range of motion and as a transition to open-chain exercises. Decreasing the weight of the arm, as in upper extremity aquatherapy, diminishes the activation of the rotator cuff musculature.54 Supporting the arm on a surface and lightly compressing through the glenohumeral joint may effectively diminish the weight of the arm as it moves through a range of motion on dry land. This compression and unloading may decrease the demand on weakened rotator cuff musculature during arm motion.

Axially loaded exercises allow the distal segment, usually the hand, to move while the athlete maintains an axial load through the glenohumeral joint. Because the distal segment moves deliberately, these are not strictly closed kinetic chain exercises.44 Axially loaded exercises can incorporate the entire kinetic chain and may unload the weak shoulder girdle muscles by effectively reducing the intrinsic weight of the arm. This leads to increased pain-free shoulder active range of motion and minimized compensation patterns. Exercises such as table slides, ball rolling, and wall slides (Figure 8) are axially loaded shoulder exercises. The proximal legs and trunk can initiate these exercises, and the sliding hand can follow a flexion, abduction, diagonal, or curvilinear path, depending on the exercise goal.
PROGRESSION GUIDELINES FOR KINETIC CHAIN SHOULDER REHABILITATION

Safety and appropriate progression are major concerns in any rehabilitation program. A method exists to address these concerns in closed kinetic chain functional rehabilitation programs for the lower extremity.55 Many of those principles are applicable to this upper extremity approach. The clinician needs to monitor exercise volume to avoid overloading the involved tissue when integrating multiple segments. When scapular exercises include arm elevation, rotator cuff activation will increase. An exercise program may be limited to 5 or 6 integrated exercises to avoid loads that weaken tissue.

It is important to continually monitor scapulothoracic rhythm, since this can be an early indicator of a compensation pattern. Reevaluation of the complete movement is necessary to accurately discern local fatigue from a proximal deficiency as the cause for the compensation. A common proximal deficiency that limits the proper performance of the shoulder dump is ipsilateral hip extensor or abductor weakness. Failure to achieve solid hip extension or allowing the hip to fall into adduction is a sign that hip weakness may be limiting the athlete’s ability to perform the exercise. Including an ipsilateral-posterolateral stride in the exercise often allows the athlete to perform this shoulder movement without compensation. The stride may bring a normally subconscious hip muscle-activation pattern to a conscious level, or the hip may require independent strengthening to adequately contribute to the shoulder function. A goal of kinetic chain rehabilitation exercises is to perform movement patterns without compensations. Altering the dominant plane of motion, posture, resistance, or tactile or verbal feedback can achieve this goal. The exercises must then progress to the normal or appropriate movement pattern without exaggerated feedback or proximal facilitation. Progressively removing this feedback while the athlete maintains appropriate distal movement may allow the athlete to develop an internal feedback system. The athlete learns to maintain the appropriate shoulder motion as the feedback varies and facilitating motion is reduced to normal levels. The exercises, therefore, progress via this reduction in facilitation.

The initial emphasis of this rehabilitation approach is quality of movement in integrated movement patterns. The movements progress from the proximal segments to the distal segments of the kinetic chain. To progressively load the distal segments, the exercises advance from static closed kinetic chain to dynamic axially loaded to open kinetic chain. Progressions include reducing feedback, adding resistance, changing the stabilizing surface, and altering the movement pattern as the athlete gains rotator cuff strength and scapular control. Decreasing an axial load moves the exercises toward open kinetic chain, effectively increasing the intrinsic resistance to the rotator cuff by requiring it to control more of the arm’s weight.54 An example of this progression toward shoulder elevation might be standing upper extremity weight shifts, scapular clock, rhythmic ball stabilization, wall slides, and dumbbell punches. This distally focused progression would occur concurrently with a proximal scapular progression that begins with sternal lifts (Figure 4) and the modified shoulder dump (Figure 3).

The exercises become more sport specific as scapular control, active range of motion, and shoulder strength approach normal. A goal of these exercises is to fully integrate the strengthening of the scapular, rotator cuff, and trunk musculature with sport-specific movement patterns. These exercises are more traditional but continue to involve the kinetic chain, scapular control, and glenohumeral motion. Examples include standing overhead dumbbell presses in all planes and slow and controlled simulated sport activities. Overhead presses with dumbbells allow the shifting of body weight or striding to
incorporate the proximal kinetic chain. Slow, controlled swinging or throwing movements, with correct mechanics, are difficult exercises that place a premium on kinetic chain stabilization during sport-specific movement patterns. Explosive plyometric activities, such as medicine-ball tossing, are the final progression. The movement patterns of the athlete’s sport become the dominant movement patterns of these advanced exercises.

CONCLUSIONS
This is a nontraditional approach to the rehabilitation of the shoulder that concentrates on movement patterns. The kinetic chain approach addresses glenohumeral motion through scapular control and scapular control through trunk movement. It is consistent with the proximal-to-distal kinetic link model of biomechanics and applies current concepts of motor control and closed kinetic chain exercise.

The best illustration of functional kinetic chain rehabilitation is a spectrum, ranging from dysfunction to full function rather than a step-by-step outline. An athlete’s exercise program is a combination of the various types of exercises gradually progressing along the spectrum toward full function.

Several concepts are important to kinetic chain shoulder rehabilitation:

1. For shoulder rehabilitation to be truly functional, the approach to the upper extremity should follow a proximal-to-distal pathway along a kinetic chain.
2. Muscles around the shoulder function synergistically and should be integrated within a kinetic link system throughout rehabilitation.
3. Scapular control and coordinated rotator cuff activation are vital to successful shoulder rehabilitation and safe shoulder function.
4. Graded closed kinetic chain exercises for the upper extremity belong in the initial phase of shoulder rehabilitation.

This article provides the theoretical background to support the concepts of kinetic chain rehabilitation and some basic techniques. Clinically, many patients who have failed with traditional shoulder programs have benefited from this approach. We hope this information benefits other, similar patients and inspires scientific investigation into the currently unsupported concepts and clinical efficacy of this approach.

ACKNOWLEDGMENTS
We thank Robin Cromwell, PT, for her assistance in developing the ideas presented in this article and her input regarding the case report. We also thank Dr. Ben Kibler for challenging us to think everyday.

REFERENCES
The Application of Isokinetics in Testing and Rehabilitation of the Shoulder Complex

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Objective: We review the application of isokinetic testing and training for the shoulder complex, the interpretation of isokinetic testing data, and the application of normative data in the rehabilitation and performance enhancement of the athlete.

Data Sources: We searched MEDLINE for the years 1989–1999 using the key words "isokinetics," "shoulder," and "upper extremity." Data Synthesis: Isokinetic testing and training is an integral part of the comprehensive evaluation and treatment of the shoulder complex. This mode of exercise allows for objective, isolated joint testing and training.

The scientific and clinical rationale for the use of isokinetics in evaluation and rehabilitation of sports injuries plays a significant role in facilitating the examination, treatment, and performance enhancement of the athlete. The objective documentation that isokinetics provide in the examination, evaluation, diagnosis, prognosis, treatment interventions, and outcomes of the shoulder complex is particularly important for returning the athlete safely and rapidly back to competition. Application of isokinetic exercise and testing for the upper extremity is imperative, due to the demanding muscular work required in sport-specific activities. The large, unrestricted range of motion of the glenohumeral joint and limited inherent bony stability necessitate dynamic muscular stabilization to ensure normal joint arthrokinematics.

Objective information regarding the intricate balance of agonist-antagonist muscular strength surrounding the glenohumeral joint is a vital resource in the rehabilitation and preventative evaluation of the shoulder. Therapeutic exercise and isolated joint testing for the entire upper extremity kinetic chain, including the scapulothoracic joint, are indicated for an overuse injury or postoperative rehabilitation of an isolated injury of the shoulder or elbow.

Our primary purposes in this article are to 1) provide evidence of the scientific and clinical rationale for the use of isokinetics in rehabilitation of injuries to the shoulder complex, 2) describe guidelines regarding the application of isokinetic testing and training of the shoulder complex and interpretation of isokinetic testing data, and 3) present a summation of numerous joint movements and muscular forces.

Conclusions/Recommendations: Isokinetic training and testing is an important part of the comprehensive evaluation and rehabilitation of the patient with a shoulder injury. Research has demonstrated its efficacy in training and in providing clinically relevant information regarding muscular performance. When integrated with a complete history, subjective examination, and physical and functional evaluation, isokinetic exercise can be a valuable tool for the clinician in the assessment, rehabilitation, and performance enhancement of the athlete.

Key Words: Glenohumeral joint, isokinetic exercise, muscle function.

Rationale for Use of Isokinetics in Upper Extremity Strength and Power Assessment

Unlike the lower extremity, in which most functional and sport-specific movements occur in a CKC environment, the upper extremity functions almost exclusively in an OKC format. The throwing motion, volleyball spike, tennis serve, and tennis ground stroke are all examples of OKC activities for the upper extremity. The use of OKC muscular strength, power, and endurance assessment methodology allows for isolation of particular muscle groups, as opposed to closed-chain methods, which use multiple joint axes, planes, and joint and muscle segments. Traditional isokinetic upper extremity test patterns are open chain with respect to the shoulder, elbow, and wrist. The velocity spectrum (1°s⁻¹ to approximately 600°s⁻¹) currently available on commercial isokinetic dynamometers provides specificity, with regard to testing the upper extremity, by allowing the clinician to assess muscular strength, power, and endurance at faster, more functional speeds. Admittedly, most functional activities have angular velocities far exceeding the capabilities of isokinetic dynamometers; however, the velocities in the upper extremity are a summation of numerous joint movements and muscular forces.
The dynamic nature of upper extremity movements is a critical factor in directing the clinician to optimal testing methodology for the upper extremity. Manual muscle testing (MMT) provides a static alternative for the assessment of muscular strength, using well-developed patient positions and stabilization.\textsuperscript{5,6} Despite the detailed description of manual assessment techniques, MMT reliability is compromised by clinician size and strength differences and the subjective nature of the grading system.\textsuperscript{7,8}

Ellenbecker\textsuperscript{9} compared isokinetic testing of the shoulder internal and external rotators with MMT in 54 subjects exhibiting manually assessed, symmetric, normal-grade (5/5) strength. On isokinetic testing, 13\% to 15\% bilateral differences in external rotation and 15\% to 28\% bilateral differences in internal rotation were found.\textsuperscript{9} Of particular significance was the large variability in the size of these mean differences between extremities, despite bilaterally symmetric MMT. MMT is an integral part of a musculoskeletal evaluation. MMT provides a time-efficient, gross screening of muscular strength of multiple muscles using a static, isometric muscular contraction, particularly in situations of neuromuscular disease or in patients with large muscular-strength deficits.\textsuperscript{7,8} The limitations of MMT appear to be most evident when only minor impairment of strength is present, as well as in the identification of subtle isolated strength deficits. Differentiation of agonist-antagonist muscular strength balance is also complicated using manual techniques, as opposed to using isokinetic instrumentation.\textsuperscript{9}

Although several disadvantages of OKC isokinetic testing have been described, there are still several reasons why OKC isokinetic testing and exercise should be incorporated in both assessment and rehabilitation:

1. It is usually necessary to perform isolated testing of specific muscle groups commonly affected by certain pathologic changes. If the clinician never measures the component parts of the kinetic chain, then the weak link will never be identified or adequately rehabilitated. The kinetic chain is only as strong as the weakest link.\textsuperscript{10,11}

2. Muscle groups away from the specific site of injury must be assessed to determine other associated (eg, disuse, pre-existing) weakness.\textsuperscript{12-14}

3. CKC or total extremity testing may not demonstrate the true existing weakness due to compensation by proximal and distal muscles for weak areas.\textsuperscript{11,15}

4. Performing OKC testing allows the clinician significant clinical control over many variables. With isokinetic testing, the examiner controls range of motion, speed, translational stresses, rotational forces, etc. When using CKC exercises or training, control of the aforementioned variables decreases, thereby increasing compensatory muscle activation and potentially risking injury to the patient.

5. Although most patients’ functional activities do not include simply flexing and extending their shoulders in the sagittal plane, numerous studies demonstrate a correlation between OKC testing and CKC functional performance.\textsuperscript{16-23}

6. When a patient has an injury or dysfunction related to pain, reflex inhibition, decreased range of motion, or weakness, abnormal movement patterns often result and create abnormal motor learning. Isolated OKC training can work within those limitations to normalize the motor patterns.

7. The efficacy of rehabilitation with OKC exercises has been clinically demonstrated.\textsuperscript{22-33}

The primary purpose in performing OKC isokinetic assessment is the need to perform isolated testing of the specific muscle groups of a pathologic joint. Although the muscles do not work in an isolated fashion, the “weak link” in the kinetic chain is difficult to identify objectively unless specific, isolated OKC isokinetic testing is performed. If a muscle cannot function normally in an isolated OKC pattern, then the muscle cannot function normally in a composite or integrated CKC pattern. The importance of performing isolated testing of the kinetic chain to identify specific dysfunction has been discussed by several authors, including Boltz and Davies,\textsuperscript{12} Gleim et al,\textsuperscript{13} Nicholas et al,\textsuperscript{14} and Strizak et al.\textsuperscript{34}

**ISOKINETIC TESTING CONSIDERATIONS**

In this section, we will briefly describe some general guidelines and principles of isokinetic testing. For more detailed information, the reader is referred to \textit{A Compendium of Isokinetics in Clinical Usage}\textsuperscript{10} and \textit{Isokinetic Exercise and Assessment},\textsuperscript{35} as well as other comprehensive texts featuring isokinetic exercise and testing.\textsuperscript{36-38}

The purposes of isokinetic testing include objective recording of muscular function, athletic screening, testing to establish a database, serial reassessments, and development of normative data. Among the absolute and relative contraindications for testing and using isokinetics are soft tissue healing constraints, pain, limited range of motion, effusion, joint instability, and acute strains and sprains.

A standard test protocol should be established to facilitate the reliability of the testing. Considerations include educating the patient regarding the particular requirements of the testing, testing the uninvolved side first, providing appropriate warm-ups and familiarization at each velocity, being consistent in protocols and verbal instructions, using properly calibrated equipment, and providing appropriate stabilization.

Isokinetic assessment allows the clinician to objectively assess muscular performance in a way that is both safe and reliable.\textsuperscript{25} Isokinetic testing affords the clinician objective criteria and provides reproducible data to assess and monitor a patient’s status. Isokinetic testing has been demonstrated to be reliable and valid.\textsuperscript{39-50} A variety of types of tests can be performed, from power to endurance tests. Our primary recommendation is to perform velocity-spectrum testing to assess the muscle’s capabilities at different velocities.\textsuperscript{10} Additionally, velocity-spectrum testing is important because deficits may be identified at only 1 velocity.\textsuperscript{10}

**ISOKINETIC DATA ANALYSIS**

One advantage of isokinetic testing is in providing numerous objective parameters that can be used to evaluate and analyze a patient’s or athlete’s performance. Isokinetic testing data that are frequently used to analyze muscular performance include peak torque, time rate of torque development, acceleration, deceleration, range of motion, total work, and average power. For more specific details on the various parameters and how to measure and interpret them, consult an isokinetic reference text.\textsuperscript{10,35-38} The following criteria are summarized in general terms for applying isokinetic test data:

- **Bilateral comparison.** The evaluation of the involved to the uninvolved extremity is probably the most common comparison. Bilateral differences of 10\% to 15\% are considered
sensitive for significant asymmetry. However, this single parameter, if used by itself, has limitations.

- Unilateral strength ratios. Comparison of agonist-antagonist muscle groups is typically obtained by dividing the value of the weaker of the 2 muscle groups into the value of the stronger muscle group to obtain a ratio. Comparing the relationship between the agonist and the antagonist muscles may identify particular weaknesses in certain muscle groups and gives valuable information regarding muscular strength and power balance.

- Torque- and work-to-body-weight ratios. Comparing the torque or work with body weight adds another dimension to interpreting test results. Even with bilateral symmetry and normal unilateral strength ratios, the torque- or work-to-body-weight relationship is often altered. Use of a normalized measure such as torque-to-body-weight or work-to-body-weight ratios allows for comparison between individuals of different sizes and morphologic structure within similar test populations.

- Normative data. Although the use of normative data is sometimes considered controversial, their proper use relative to a specific patient population and dynamometer system can provide guidelines for testing and rehabilitation.

- Relative fatigue ratios. This ratio is typically calculated by dividing the work in the second half of a specified number of repetitions by the work in the first half of the specified number of repetitions. This ratio is used to determine the endurance or fatigue resistance of the muscle groups being tested.51-52

APPLICATION OF ISOKINETIC TESTING AND TRAINING FOR THE GLENOHUMERAL JOINT

Dynamic strength, power, and endurance assessment of the rotator cuff musculature is of primary importance in rehabilitation and preventive screening of the glenohumeral joint. The rotator cuff forms an integral component of the force couple in rotator cuff musculature, which is of primary importance in rehabilitation and preventive screening of the glenohumeral joint. The role of the supraspinatus muscle for the glenohumeral joint, as well as the inferior (caudal) glide component action provided by the infraspinatus, teres minor, and subscapularis muscles, must stabilize the humeral head within the glenoid against the superiorly directed forces exerted by the deltoid with humeral elevation.54 Muscle imbalances, primarily in the posterior rotator cuff, have been objectively documented in patients with glenohumeral joint instability and impingement.55-58 Davies et al57 randomly selected 30 charts for 124 patients who had been identified and isolated without the use of isokinetic instrumentation.

Initial testing and training using isokinetics for rehabilitation of the shoulder typically involves the modified base position. The modified base position is obtained by tilting the dynamometer approximately 30° from horizontal base position.10,59 The patient’s glenohumeral joint is placed in 30° of abduction and 30° of forward flexion into the plane of the scapula, or scapulation, with a 30° diagonal tilt of the dynamometer head from the transverse plane (Figure 1). This position has also been termed the (30°/30°/30°) internal-external rotation position by Davies.10,59 The modified base position places the shoulder in the scapular plane 30° anterior to the coronal plane.60 The scapular plane is characterized by enhanced bony congruity and a neutral glenohumeral position, which results in a midrange position for the anterior capsule ligaments and enhances the length-tension relationship of the scapulohumeral musculature.60 This position does not place the suprascapular structures in an impingement situation and is well tolerated by patient populations.59

Isokinetic testing using the modified base position requires consistent application of the patient to the dynamometer. Studies have demonstrated significant differences in internal and external rotation strength, with varying degrees of abduction, flexion, and horizontal abduction and adduction of the glenohumeral joint.51-53 The modified base position uses a standing patient position on many dynamometer systems, which can lead to compromises in both glenohumeral joint isoinertial and test-retest reliability. Despite these limitations, valuable data can be obtained early in the rehabilitative process using this neutral, modified base position, which is safe and comfortable for most patients with most pathologies and postoperatively.10,59,64

Knops et al46 conducted a test-retest reliability study of the modified neutral position for internal and external rotation of the glenohumeral joint. This position places the arm in a 30°/30°/30° position. Velocity-spectrum testing at 60°, 180°, and 300°·s⁻¹ was performed with intraclass correlation coefficients applied to determine the degree of test-retest reliability. This position of testing produced high test-retest reliability, with intraclass correlation coefficients ranging between 0.91
Joint abduction. Specific advantages of this test position are reported in 90° of glenohumeral joint posterior rotator cuff. Changes in length-tension relationships and the line of action of scapulohumeral and axiohumeral musculature are required precursor to use of the 90° abducted position by these authors. Isokinetic testing at 90° of abduction can be performed in either the coronal or scapular plane. Benefits of the scapular plane are similar to those discussed in the modified position and include protection of the anterior capsular glenohumeral ligaments and a theoretical length-tension enhancement of the posterior rotator cuff. Changes in length-tension relationships and the line of action of scapulohumeral and axiohumeral musculature are reported in 90° of glenohumeral joint abduction, compared with a more neutral adducted glenohumeral joint position. Use of the 90° abducted position for isokinetic strength assessment more specifically addresses muscular function required for overhead activities.

Durall et al recently completed a study on the reliability of testing subjects in the plane of the scapula (scaption). Fifteen subjects were tested and retested at 60°, 180°, and 300°-s⁻¹. Intraclass correlation coefficients were 0.87, 0.82, and 0.70 at each speed, respectively. This study again shows the degree of test-retest reliability of isokinetic testing of the shoulder complex.

Primary emphasis is placed on the assessment of internal and external rotation strength of the shoulder during rehabilitation. The rationale for this apparently narrow focus is provided by an isokinetic training study by Quincy et al. Six weeks of isokinetic training of the internal and external rotators produced statistically significant improvements, not only in internal and external rotation strength but also in flexion and extension and abduction and adduction strength as well. Isokinetic training of flexion and extension and abduction and adduction produced improvements only in the position of training, or specificity of training response. The overflow of strength caused by training the internal and external rotators provides rationale for the primary emphasis on strength development and assessment in rehabilitation. Additional research has identified the internal and external rotation movement pattern as the preferable testing pattern in patients with rotator cuff tendinosis.

### Interpretação de Shoulder Internal Rotation-External Rotation Testing

#### Bilateral Comparisons

Similar to isokinetic testing of the lower extremity, assessment of an extremity’s strength, power, and endurance relative to the contralateral side forms the basis for standard data interpretation. This practice is more complicated in the upper extremity due to limb dominance, particularly in the unilaterally dominant sport athlete. In addition to the complexities added by limb dominance, isokinetic descriptive studies demonstrate disparities in the degree of limb dominance, as well as the presence of strength dominance only in specified muscle groups.

In general, a maximum limb dominance of the internal and external rotators of 5% to 10% is assumed in nonathletic and recreational-level upper extremity sport athletes. Ellenbecker and Bleacher found significantly greater internal rotation dominant arm strength (P < .01), with no significant difference in external rotation strength, in 38 active adult females between the ages of 18 and 45 years. Testing was performed using the NORM isokinetic dynamometer (Cybex, Inc, Ronkonkoma, NY); the subjects were seated with stabilization straps and the shoulder in the scapular plane and at 45° of glenohumeral joint abduction.

Several studies have been performed to determine the degree of unilateral strength dominance in unilaterally dominant upper-extremity-sport athletes. Significantly greater internal rotation strength has been identified in the dominant arm in professional, collegiate, and high school baseball players, as well as in elite-level junior and adult tennis players. No difference between extremities has been demonstrated in concentric external rotation in professional or collegiate baseball pitchers or in elite junior and adult tennis players. This selective strength development in the internal rotators produces significant changes in agonist-antagonist muscle balance. In all the aforementioned activities, the internal rotators are the primary muscle group used during the acceleration phase of the throwing or overhead activity. Consequently, muscular adaptation is specific, which has implications for the rehabilitation and prevention of injuries.

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Figure 1. The modified base, or 30°/30°/30° internal-external rotation, position is typically used for initial isokinetic testing and training.
Unilateral Strength Ratios (Agonist-Antagonist)

Assessing the muscular strength balance of the internal and external rotators is of vital importance when interpreting upper extremity strength tests. Alteration of this external/internal rotators ratio (ER/IR) has been reported in patients with glenohumeral joint instability and impingement. The initial descriptions of the ER/IR ratio in normal subjects were published by Ivey et al and Davies for both males and females. An ER/IR ratio of approximately 66% is normal. One unique aspect of the ER/IR ratio is that it appears to remain approximately 66% throughout the velocity spectrum. The ER/IR ratio is one of the few unilateral strength ratios in the body to demonstrate this unique, consistent relationship at all velocities.

Widespread reports of alteration of the ER/IR ratio, due to selective muscular development of the internal rotators without concomitant external rotation strength, are present in the literature. This alteration has provided clinicians an objective rationale for the global recommendation of preventive posterior rotator cuff strengthening programs for athletes in high-level overhead activities. Biasing this ratio in favor of the external rotators has been advocated by clinicians for both prevention of injury in throwing and racquet-sport athletes, as well as after insult or surgery to the glenohumeral joint. The authors refer to the biasing of the unilateral strength ratio to provide dynamic stabilization to the glenohumeral joint as the contrecoup concept of shoulder stability. Using the ER/IR unilateral strength ratio for a patient with unilateral anterior inferior instability is analogous to looking at the hamstrings/quadriceps strength ratio in the patient with an anterior cruciate ligament-deficient knee. To dynamically stabilize the knee to prevent anterior tibial translation, emphasis is placed on the hamstrings because they are synergistic with the anterior cruciate ligament and, therefore, try to dynamically compensate for the ligament deficiency. This same principle should be applied to the shoulder. We recommend creating a posterior-dominant shoulder in the patient with anterior-inferior glenohumeral joint instability to produce a 10% increase in the normal ER/IR ratio, thereby resulting in a unilateral ratio of 76% and changing the strength of the external rotators from approximately two thirds of the internal rotators to about three fourths of the internal rotators. Examples of ER/IR ratios are presented with respect to population and apparatus specificity (Tables 1, 2).

### Table 1. Unilateral External/Internal Rotation Strength Ratios of Professional Baseball Pitchers*

<table>
<thead>
<tr>
<th>Velocity (°-s⁻¹)</th>
<th>Dominant Arm</th>
<th>Nondominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: Wilk et al</td>
<td>180 Peak torque</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>300 Peak torque</td>
<td>61</td>
</tr>
<tr>
<td>Source: Ellenbecker and Mattalino</td>
<td>210 Peak torque</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>210 Work (single repetition)</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>300 Peak torque</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>300 Work (single repetition)</td>
<td>62</td>
</tr>
</tbody>
</table>

*Data expressed as external rotation percentage of internal rotation strength.

### Table 2. Isokinetic Peak Torque- and Single-Repetition Work-to-Body-Weight Ratios and External/Internal Rotation Ratios in Elite Junior Tennis Players, Aged 12-17 Years (60 Males, 38 Females)*

<table>
<thead>
<tr>
<th>Motion (Mean °-s⁻¹)</th>
<th>Dominant Arm</th>
<th>Nondominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males, 210</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>Males, 300</td>
<td>10</td>
<td>18</td>
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<tr>
<td>Females, 210</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Females, 300</td>
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<td>11</td>
</tr>
<tr>
<td>Internal rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males, 210</td>
<td>17</td>
<td>32</td>
</tr>
<tr>
<td>Males, 300</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>Females, 210</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Females, 300</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>External rotation/internal rotation ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males, 210</td>
<td>51</td>
<td>64</td>
</tr>
<tr>
<td>Males, 300</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>Females, 210</td>
<td>70</td>
<td>66</td>
</tr>
<tr>
<td>Females, 300</td>
<td>67</td>
<td>69</td>
</tr>
</tbody>
</table>

*Data compiled using CYBEX 300 Series and 6000 concentric isokinetic dynamometer and data expressed as a percentage of peak torque- or single-repetition work-to-body weight. (Foot-pounds of torque or work/body weight in pounds).

### Use of Normative Data

Use of normative or descriptive data can assist clinicians in further analyzing isokinetic test data. Care must be taken to use normative data that is both population and apparatus specific. Tables 2, 3, and 4 present data from large samples of specific athletic populations on 2 dynamometer systems, using body weight as the normalizing factor.

Another application for normative data is to normalize the isokinetic parameters to the patient’s body weight when bilateral injury is present. Bilateral comparisons and unilateral strength ratios may be within normal limits; however, if the patient has torque- and work-to-body weight ratios that are lower than normative values, the patient may not be fully rehabilitated from a muscular standpoint.

### ADDITIONAL GLENOHUMERAL JOINT TESTING POSITIONS

#### Adduction and Abduction

Isokinetic evaluation of shoulder abduction and adduction strength is an additional pattern frequently evaluated because

### Table 3. Isokinetic Peak Torque- to Body-Weight Ratios in 150 Professional Baseball Pitchers* Using the Biodex Isokinetic Dynamometer (%)*

<table>
<thead>
<tr>
<th>Velocity (°-s⁻¹)</th>
<th>Dominant Arm</th>
<th>Nondominant Arm</th>
<th>Dominant Arm</th>
<th>Nondominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>27</td>
<td>17</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>300</td>
<td>25</td>
<td>24</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

*Data expressed as a percentage of foot-pounds of torque relative to body weight in pounds.
of the abductors’ key role in the Inman force couple\(^53\) and the adductors’ functional relationship to throwing velocity.\(^86\text{-}88\) Specific factors important in this testing pattern are limiting range of motion to approximately 120° to avoid glenohumeral joint impingement and consistently using gravity correction.\(^89\) No formal research specifically addressing the test-retest reliability of the shoulder abduction and adduction isokinetic testing pattern has been published.

The interpretation of abduction and adduction isokinetic tests follows the traditional bilateral comparison, normative data comparison, and unilateral strength ratios. Ivey et al.,\(^83\) using normal adult females, reported abduction/adduction ratios of 50% bilaterally. Similar findings were reported by Alderink and Kluck\(^72\) in high school and collegiate baseball pitchers. Wilk et al.\(^90,91\) reported dominant arm ratios of 85% to 95% using a Biodex dynamometer (Biodex, Inc, Shirley, NY). Their analysis used a windowing technique, which removed impact artifact following free-limb acceleration and end-stop impact from the data. Upper extremity testing, using long input adapters and fast isokinetic testing velocities, can produce torque artifact that significantly changes the isokinetic test result. Wilk et al.\(^91\) recommended windowing the data by removing all data obtained at velocities outside 95% of the present angular testing velocity.

### Flexion-Extension and Horizontal Abduction-Adduction

Additional isokinetic patterns used to obtain more detailed profiles of shoulder function are flexion-extension and horizontal abduction-adduction. Both of these motions are generally tested in a less functional supine position to improve stabilization. Normative data are less available in the literature on these testing positions. Test-retest research is available for shoulder flexion-extension testing and demonstrates intraclass correlation coefficients between 0.75 and 0.91.\(^43\) No formal test-retest data are currently available for shoulder horizontal abduction-adduction.

Flexion-extension ratios reported on normal subjects by Ivey et al.\(^83\) were 80% (4:5). Ratios on athletes with shoulder extension-dominant activities were reported at 50% for baseball pitchers\(^72\) and 75% to 80% for highly skilled adult tennis players.\(^75\) Further development of normative data are needed to more clearly define strength in these upper extremity patterns. Body position and gravity compensation are, again, key factors affecting proper data interpretation.

### Scapulothoracic Testing: Protraction/Retraction

In addition to the supraspinatus-deltoid force couple, the serratus anterior-trapezius force couple is of critical importance in a thorough evaluation of upper extremity strength. Gross MMT and screening to identify scapular winging are common in the clinical evaluation of the shoulder complex. Davies and Hoffman\(^24\) found a nearly 1:1 relationship of projection/retraction strength in 250 shoulders. Testing and training the serratus anterior, trapezius, and rhomboid muscles enhance scapular stabilization and strengthen the primary musculature involved in the scapulohumeral rhythm. The promotion of proximal stability to enhance distal mobility is a concept used and recognized by nearly all disciplines of rehabilitative medicine.\(^92\)

### ADDITIONAL CONCEPTS FOR ISOKINETIC TESTING OF THE SHOULDER COMPLEX

#### Concentric versus Eccentric Considerations

The availability of eccentric dynamic strength assessment has had a significant impact on research investigations. The extrapolation of research-oriented isokinetic principles to patient populations has been a gradual process. Use of eccentric testing in the upper extremity is clearly indicated based on the prevalence of functionally specific eccentric work. Maximal eccentric functional contractions of the posterior rotator cuff during the follow-through phase of the throwing motion and tennis serve provide rationale for eccentric testing and training in rehabilitation and preventive conditioning.\(^93\) Kennedy et al.\(^94\) found mode-specific differences between the concentric and eccentric strength characteristics of the rotator cuff. Ellenbecker et al.\(^17\) Mont et al.\(^18\) and Triebert et al.\(^23\) have demonstrated the applications of eccentric training of the rotator cuff muscles, its effects on muscular strength, and its carryover to functional performance. Additionally, Scoville et al.\(^\text{155}\) reported eccentric antagonist/concentric agonist strength ratios in the shoulder using isokinetic instrumentation. Despite these studies, further research on eccentric muscular training is necessary before widespread use of eccentric isokinetics can be applied to patient populations.

Basic characteristics of eccentric isokinetic testing, such as greater force production as compared with concentric contractions at the same velocity, are reported in the internal and external rotators.\(^17,18,96\) This enhanced force generation is generally explained by the contribution of the series elastic (noncontractile) elements of the muscle-tendon unit to force generation in eccentric conditions. An increase in postexercise muscle soreness, particularly of latent onset, is common after periods of eccentric work. Therefore, eccentric testing would not be the mode of choice during the early inflammatory stages of an overuse injury.\(^96\) Many clinicians recommend the use of dynamic concentric testing before eccentric testing. Both

### Table 4. Isokinetic Peak Torque- and Work-to-Body-Weight Ratios in 147 Professional Baseball Pitchers\(^77\) Using the Cybex Isokinetic Dynamometer (%)*

<table>
<thead>
<tr>
<th>Velocity (°·s(^{-1}))</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Arm</td>
<td>Nondominant Arm</td>
<td>Dominant Arm</td>
</tr>
<tr>
<td>210 Peak torque</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>210 Work (single repetition)</td>
<td>41</td>
<td>38</td>
</tr>
<tr>
<td>300 Peak torque</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>300 Work (single repetition)</td>
<td>37</td>
<td>33</td>
</tr>
</tbody>
</table>

*Data expressed as a percentage of foot-pounds of torque relative to body weight in pounds.*
concentric and eccentric isokinetic training of the rotator cuff have produced objective concentric and eccentric strength improvements in elite tennis players.17,18

Use of Isokinetics in Upper Extremity Fatigue Testing

Isokinetic dynamometers have also been extensively used in the measurement of muscular fatigue.51,52 Isokinetic muscular fatigue tests typically consist of measuring the number or repetitions of maximum effort required to reach a 50% reduction in torque, work, or power from the beginning to the end of a certain time period or number of contractions. Relative fatigue ratios compare the work in the last half of a preset number or muscular contractions with the work performed in the first half.51,52,97 Burdett and Van Swearingen98 studied the reliability of isokinetic fatigue tests. They reported intraclass correlation coefficients of 0.48 to 0.73 for work fatigue ratios. Montgomery et al99 reported similar test-retest reliability values, with intraclass correlation coefficients of 0.67 to 0.78 for relative tests of muscular endurance using an isokinetic dynamometer. These values are lower than reliability coefficients generated during the assessment of muscular strength with isokinetic dynamometers.50

Relative fatigue ratios studied in elite tennis players have produced clinically applicable information. Ellenbecker and Roetert25 measured the relative fatigue response in the internal and external rotators of 72 elite junior tennis players using 20 maximal-effort concentric testing repetitions at 300°s⁻¹ in the supine position in 90° of glenohumeral joint abduction. The external rotators fatigued to a level of 69%, while the internal rotators only fatigued to a level of 83%. This finding is significant, due to the substantial contribution of the external rotators in humeral deceleration during overhead throwing and serving activities,4,93 as well as dynamic stabilization of the humeral head in the glenoid.99 The more rapid and more extensive fatiguing of the external rotators than the internal rotators further supports the current concepts of preventive conditioning and balancing of the shoulder external rotators in unilaterally dominant upper extremity athletes.

Similarly, Beach et al100 tested collegiate swimmers at 240°s⁻¹ using 50 repetitions. Relative fatigue ratios for external rotation were 80%, and for internal rotation, 105%. Beach et al100 also found a significant correlation between isokinetic fatigue ratios and shoulder pain in this swimming population.

These studies demonstrate the important role of fatigue testing, both in guiding and providing rationale for the high-repetition training programs used in rehabilitation and in providing a clinically acceptable method for assessing muscular fatigue.

Relationship of Isokinetic Testing to Functional Performance in the Upper Extremity

Dynamic muscular strength assessment is used to evaluate the underlying strength, power, endurance, and balance of strength in specific muscle groups. With this information, the clinician can determine the specific anatomical structures that require strengthening and demonstrate the efficacy of treatment procedures. Isokinetic testing of the shoulder internal and external rotators has been used to demonstrate the functional outcome after rotator cuff repair on select patient populations.101-105

An additional purpose for isokinetic testing is to determine the relationship of muscular strength to functional performance. Several researchers have correlated upper extremity muscle group strength with sport-specific functional tests. Pedegana et al18 found a statistically significant correlation among elbow extension, wrist flexion, and shoulder extension, flexion and external rotation strength measured isokinetically, and throwing speed in professional pitchers. Bartlett et al,60 in a similar study, found that shoulder adductor peak torque production correlated with throwing speed. These studies are in contrast to Pawlowski and Perrin,106 who did not demonstrate a significant relationship with throwing velocity.

Ellenbecker et al17 noted that 6 weeks of concentric isokinetic training of the rotator cuff resulted in a statistically significant improvement in serving velocity in collegiate tennis players. Mont et al18 in a comparable study, found serving velocity improvements after both concentric and eccentric internal and external rotation training. Trieber et al23 used isokinetic testing to document strength changes before and after a 4-week training program with isotonic dumbbell or rubber tubing internal and external rotation strengthening. In addition to documenting strength improvements with isokinetic testing, an increase in tennis serve velocity was measured in the experimental group. A direct statistical correlation between isokinetically measured upper extremity total arm strength and tennis serve velocity was not found by Davies and Ellenbecker2,4 or Ellenbecker75 despite increases noted in earlier studies in serving velocity after isokinetic training.

The complex biomechanical sequences of segmental velocities and interrelationship between the kinetic chain link with the lower extremities and trunk make delineation and identification of a direct relationship between an isolated structure and a complex functional activity difficult. Isokinetic testing can provide a reliable, dynamic measurement of isolated joint motions and muscular contributions to assist the clinician in the assessment of underlying muscular strength and strength balance.10,24,25,50,107 The integration of isokinetic testing with a thorough, objectively oriented, clinical evaluation allows the clinician to provide optimal rehabilitation for both overuse and postsurgical conditions.

APPLICATION OF ISOKINETICS IN DESIGNING REHABILITATION TRAINING PROGRAMS

Many types of exercise programs are currently in widespread use for the rehabilitation of the injured athlete. In this section, we focus on an example of a resisted rehabilitation program that can be used, as well as the specific progression of resistive exercise recommended during rehabilitation. Resisted rehabilitation programs include isometric, concentric and eccentric isometric, concentric and eccentric isokinetics, and isooacceleration and isodeceleration types of programs. More training would be implemented in the terminal phases of rehabilitation, using exercises such as plyometrics and neuromuscular control exercises. We discuss the scientific and clinical rationale for progression through a resisted exercise rehabilitation program, including the specific progression and inclusion of isokinetic exercise in the clinical rehabilitation of upper extremity injuries.
Patient Progression Criteria

Several important concepts predicate the progression through the resistive exercise program: patient status, signs and symptoms, time since surgery, and soft tissue healing constraints. The patient’s progression through the resistive exercise program is determined by continual reassessment of signs and symptoms. Continual reassessment of the signs and symptoms will help the clinician determine the appropriateness of the progression of the patient to the next level of the resisted exercise program.

Resistive Exercise Progression Continuum

The rehabilitation program is designed along a progressive continuum. The program begins with the safest of these stressful exercises (submaximal, multiple-angle isometrics) and advances to the most stressful exercises (full range-of-motion, maximal isokinetics) (Figure 2).

Short-Arc Exercises

The next progression for the patient is from the static, isometric exercises to more dynamic exercises. The dynamic exercises begin with short-arc exercises and the range of motion indicated to avoid the symptomatic area and protect soft tissue healing constraints. Short-arc exercises are often started using submaximal isokinetics, due to the accommodating resistance inherent in isokinetic exercise, making them safe for the patient’s healing tissue. Velocities in short-arc isokinetics should range from 60° to 180° s⁻¹. Velocities slower than 60° s⁻¹ increase joint compressive forces and often create inhibition responses. Velocities greater than 180° s⁻¹ for short-arc isokinetic exercises create too large a range of free-limb acceleration, resulting in insufficient loading of the muscles. The patient works in what is called a velocity-spectrum rehabilitation protocol (Figure 3). When the patient is performing short-arc isokinetics, slower contractile velocities (60° to 180° s⁻¹) are chosen due to the presence of the acceleration and deceleration responses (Figure 4). Isokinetic exercise contains 3 major components: acceleration, deceleration, and load range. The load range is the actual portion of the range of motion in which the preset angular velocity is met by the patient and a true isokinetic load is imparted to the patient. Acceleration is the portion of the range of motion in which the patient’s limb is accelerating to “catch” the preset angular velocity, and deceleration is the portion of the range of motion in which the patient’s limb is slowing before cessation of that repetition. Load range is inversely related to isokinetic speed selection. A larger load range has been found at slower contractile velocities, with a statistically shorter load range at faster contractile velocities.

Consequently, the patient’s available range of motion must be evaluated to determine the optimal range of motion for exercise. With short-arc isokinetic exercise, there is approximately a 30° physiologic overflow through the range of motion. Therefore, the patient with rotator cuff pathology can be exercised in an abbreviated, pain-free range of motion in internal-external rotation; overflow into the painful range of motion does not actually place the injured structures into that movement range, which could cause an iatrogenic response.

Another upper extremity example with isokinetic exercise is the limitation of external-rotation range of motion to 90° during isokinetic training, even though the demands on the athletic shoulder in overhead activities often exceed 90° of external rotation. Limiting the external rotation to 90° protects the anterior capsular structures of the shoulder, with the physiologic overflow concept improving strength at ranges of external rotation exceeded during actual training. Seehaver et al. did not demonstrate a short-arc overflow past the range of motion through which the subjects trained. This is in contrast to previous isokinetic research on physiologic overflow with isokinetic short-arc training. Therefore, further research is needed to verify the clinical efficacy of this concept.

In addition to range of motion, the speed selected for isokinetic exercise is also of vital importance when designing a velocity-spectrum training protocol. The patient should exercise every 30° s⁻¹ through the velocity spectrum. The reason for using every 30° s⁻¹ in the velocity spectrum is the physiologic overflow with respect to speed identified with isokinetic research.

Rest Intervals

When the patient is performing maximal-effort isokinetics using a velocity-spectrum rehabilitation protocol, the rest interval between each set of 10 training repetitions may be as long as 90 seconds. However, this is not a viable clinical rest...
time, because it takes too much time to complete the exercise session. Consequently, rest intervals are often applied on a symptom-limited basis. If the patient does complete a total protocol, a rest period of 3 minutes has been shown to be an effective rest-interval time (Figure 5).59

Additional research provides guidance for rest-interval selection with isotonic and isokinetic exercise in rehabilitation. According to Fleck,113 after an acute bout of muscular work, 50% of the adenosine triphosphate and creatine phosphate is restored within 20 seconds. In 40 seconds, 75%, and in 60 seconds, 87% of the intramuscular stores are replenished. Knowledge of the phosphagen-restoration schedule allows clinicians to make scientifically based decisions on the amount of rest needed or desired after periods of muscular work. An additional factor in determining the optimum rest intervals during isotonic and isokinetic training comes from the concept of specificity. For example, when rehabilitating the shoulder of a tennis player, a high-repetition format is used to improve local muscular endurance. Rest cycles are limited to 25 to 30 seconds, because that is the time allotted during tennis play for rest between points. Applying activity or sport-specific muscular work-rest cycles is an important consideration during rehabilitation.

Isotonic exercises are often implemented between isokinetic submaximal and maximal exercises. The reason for this is that isotonic muscle loading loads a muscle only at its weakest point in the range of motion. Figure 6 demonstrates the effects of isotonic muscle loading through the range of motion. Consequently, when performing isotonic muscle exercise through the range of motion, combined maximal and submaximal loading will occur. With isokinetics, submaximal intensity or maximal intensity loading of the muscle can be performed throughout the range of motion due to the accommodative resistance phenomenon inherent with isokinetic exercise.

Full Range-of-Motion Exercises

The patient is then progressed to full range-of-motion isokinetic exercise, beginning with submaximal and then progressing to maximal exercise. Straight, planar movements are used to initially protect the injured plane of movement. However, various functional patterns, including diagonal patterns, can be incorporated with isokinetic testing equipment. Faster contractile velocities are also used from 180°s⁻¹ up to the maximum capabilities of the isokinetic dynamometer. Reasons for using faster isokinetic testing and training velocities include physiologic overflow to slower velocities, specificity response, neurophysiologic motor learning response, and decreased joint compressive forces.10 Inherent in faster isokinetic testing and training velocities are decreased joint compressive forces. This is based on Bernoulli’s principle, which stated that surface pressure on the articular surface is decreased due to the synovial fluid interface at faster velocities.114 This is probably the result of the interface of the hydrodynamics of the articular cartilage and the synovial fluid movement pattern. Other considerations are the positioning of the patient to use the length-tension curve of the muscle. Patient position with isokinetic exercise is often modified to bias the respective muscles, to stretch them to facilitate their contraction, or to put them into a shortened or lengthened position to better replicate the functional position. Obviously, it is most important to try to replicate the ultimate functional performance position of the individual.

Isoacceleration, Deceleration, and Eccentric Training

Functional activities use accelerative and decelerative movement patterns; therefore, replicating those patterns is recommended with different types of rehabilitation activities. Lim-
Current studies demonstrate the efficacy of performing eccentric exercise or eccentric isokinetic, or both, rehabilitation programs at this time. Ellenbecker et al. reported concentric strength improvement in internal and external rotation after 6 weeks of eccentric isokinetic training of the internal and external rotators in elite tennis players. Mont et al. found both concentric and eccentric strength improvements with eccentric isokinetic training of the rotator cuff in elite tennis players. Despite the paucity of research using eccentric exercise training in patient populations, specific application of eccentric exercise programs to the posterior rotator cuff, quadriceps, and other important muscle-tendon units that must perform extensive eccentric work may be indicated.

Training Specificity

Dural et al. recently completed a training study in which they evaluated the effects of 5 weeks of training the shoulder internal and external rotators on improving scapular plane humeral elevation. Repeated-measures analysis of variance demonstrated no differences between the training groups and the control group.

Dahl et al. trained subjects in the 30°/30°/30° modified neutral position and then tested them in the 90°/90° position. Isokinetic training of the shoulder rotators in the 30°/30°/30° position did not result in improvement in the 90°/90° functional position. Therefore, if one desires a training response in the 90°/90° position of the shoulder, then specificity of training prevails, and the patient must train in that position. The results of both of these studies conflict with the results of Quincy et al.; however, these studies evaluated unique positions that are not straight planar positions. Furthermore, the sample size and training duration may have limited the statistical power to demonstrate a training response.

The Use of Isokinetics in Rehabilitation Outcome Studies

Isokinetic testing plays an important part in the measurement of muscular performance after injury or surgery. The objective documentation that isokinetic testing provides allows clinicians and researchers to report muscle strength, power, and endurance as important outcome measures of an evidence-based rehabilitation program after injury or surgery.

Ellenbecker and Mattalino used isokinetic testing to quantify internal and external rotation strength in patients 12 weeks after glenohumeral joint anterior stabilization using thermal capsulorrhaphy. Return of internal and external rotation strength was complete, and ER/IR unilateral strength ratios were near normal (60 to 66%) 12 weeks postsurgery. These findings provide important information regarding the return of strength after an arthroscopic stabilization procedure and also demonstrate how isokinetic testing can assist clinicians in determining the readiness of the patient for interval sport return programs and discharge from a formal rehabilitation program.

Manske and Davies recently reported an outcome study with emphasis on isokinetic reassessment, as well as isokinetic training, as part of the rehabilitation program. Sixty-seven patients were evaluated and reassessed at discharge and their rehabilitation outcomes described. A statistically significant improvement in torque acceleration energy of the involved shoulder was reported for all testing velocities. All involved extremity values had also returned to within 10% of the uninvolved extremity.

FUNCTIONAL TESTING ALGORITHM WITH EMPHASIS ON EVALUATION OF ISOKINETIC POWER OF THE SHOULDER COMPLEX

Functional Testing Algorithm

Davies et al have developed a progressive functional testing algorithm (FTA) that can be used as 1 method of evaluation of isokinetic power in the injured athlete. Here, we...
will present an overview of the FTA with emphasis on the isokinetic testing components. The FTA is predicated on a systematic, progressive testing sequence advancing from controlled testing to more functional testing. The FTA for the upper extremity is described in Figure 7. The FTA testing strategies are based on the principles of progression and control. Each test in the sequence must be passed at a minimum performance level before the athlete progresses to the next higher level in the FTA. The criteria for the patient to progress from 1 level of the FTA to the next level is presently predicated on empirically based clinical experience, as well as the patient’s subjective pain rating using an analog scale, basic measurements (such as goniometric assessment of range of motion), and kinesthetic testing, as well as isokinetic and functional testing. The primary components of the FTA are a basic measurements section, strength and power testing, and functional testing (Figure 7).

SUMMARY

Our purpose was to present an overview of the scientific and clinical rationale for the application of isokinetics in testing and rehabilitation of the injured athlete. We have discussed terminology used with isokinetics, general guidelines for isokinetic testing, specific examples of isokinetic assessment in the upper extremity, the scientific and clinical rationale for the use of isokinetics in designing rehabilitation programs, and some examples of recent outcomes research demonstrating the efficacy of the application of isokinetics. The concept of a functional testing algorithm with emphasis on isokinetic testing was also described in order to demonstrate the integration of isokinetics with other testing and training methods for the patient with an upper extremity injury.

As mentioned in the introduction of this article, isokinetic assessment and treatment techniques are only one part of the evaluation and rehabilitation process. The assessment and rehabilitation process is tremendously diverse. Therefore, we strongly encourage clinicians to use an integrated approach to assessment and rehabilitation, to critically review the literature, and to contribute to the advancement of the art and science of sports medicine by performing research and sharing those results through research presented at professional meetings and peer-reviewed publications.

REFERENCES


The Role of the Sensorimotor System in the Athletic Shoulder

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Department of Orthopaedic Surgery, Neuromuscular Research Laboratory, Musculoskeletal Research Center, University of Pittsburgh, Pittsburgh, PA

Objective: To discuss the role of the sensorimotor system as it relates to functional stability, joint injury, and muscle fatigue of the athletic shoulder and to provide clinicians with the necessary tools for restoring functional stability to the athletic shoulder after injury.

Data Sources: We searched MEDLINE, SPORT Discus, and CINAHL from 1965 through 1999 using the key words “proprioception,” “neuromuscular control,” “shoulder rehabilitation,” and “shoulder stability.”

Data Synthesis: Shoulder functional stability results from an interaction between static and dynamic stabilizers at the shoulder. This interaction is mediated by the sensorimotor system. After joint injury or fatigue, proprioceptive deficits have been demonstrated, and neuromuscular control has been altered. To restore stability after injury, deficits in both mechanical stability and proprioception and neuromuscular control must be addressed. A functional rehabilitation program addressing awareness of proprioception, restoration of dynamic stability, facilitation of preparatory and reactive muscle activation, and implementation of functional activities is vital for returning an athlete to competition.

Conclusions/Recommendations: After capsuloligamentous injury to the shoulder joint, decreased proprioceptive input to the central nervous system results in decreased neuromuscular control. The compounding effects of mechanical instability and neuromuscular deficits create an unstable shoulder joint. Clinicians should not only address the mechanical instability that results from joint injury but also implement both traditional and functional rehabilitation to return an athlete to competition.

Key Words: proprioception, neuromuscular control, functional stability

The primary role of the shoulder is to place the upper extremity in a position that allows for function of the hand. In order to accommodate this role, the osseous geometry of the glenohumeral joint allows for a high level of mobility. As a result of this increased mobility, stability at the shoulder joint is compromised. The lack of osseous stability requires the shoulder to rely on an interaction between static and dynamic structures to provide joint stability. Statically, capsuloligamentous structures, including the glenoid labrum, glenohumeral joint capsule, and glenohumeral ligaments, and intra-articular pressure provide static joint stability. Dynamically, the rotator cuff, deltoid, biceps brachii, teres major, latissimus dorsi, and pectoralis major muscles provide vital stabilizing support. Functional stability is defined as possessing adequate stability to perform functional activity and results from the interaction between these static and dynamic components. This interaction between the static and dynamic components of functional stability is mediated by the sensorimotor system. The sensorimotor system encompasses all of the sensory, motor, and central integration and processing components of the central nervous system (CNS) involved in maintaining functional joint stability.

Our purpose is to discuss the role of the sensorimotor system as it relates to functional stability, joint injury, and muscle fatigue of the athletic shoulder. In addition, we will provide clinicians with the necessary tools for restoring functional stability in the athletic shoulder after injury.

ROLE OF THE SENSORIMOTOR SYSTEM IN GLENOHUMERAL STABILITY

As previously stated, the sensorimotor system encompasses the sensory, motor, and central integration and processing components involved in maintaining functional joint stability. Sensory information (proprioception) travels through afferent pathways to the CNS, where it is integrated with input from other levels of the nervous system, eliciting efferent motor responses (neuromuscular control) vital to coordinated movement patterns and functional stability.

Originally, Sherrington defined proprioception as the afferent information arising from the “proprioceptive field” and specifically “proprioceptors.” A contemporary interpretation suggests that proprioception is defined as the afferent information concerning the 3 submodalities of joint position sense, kinesthesia, and sensation of resistance. We define joint position sense as the ability to consciously recognize where one’s joint is oriented in space, while kinesthesia describes one’s ability to consciously appreciate joint motion. We define sensation of resistance as one’s ability to appreciate force generated within a joint. All 3 submodalities can be appreciated both consciously and unconsciously, mediating neuromuscular control.

Proprioceptive information originates at the level of the mechanoreceptor or “proprioceptor,” as termed by Sherrington. Mechanoreceptors are sensory neurons or peripheral

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afferents present within the muscle, tendon, fascia, joint capsule, ligament, and skin about a joint.\textsuperscript{8–10} Mechanoreceptors are mechanically sensitive and transduce mechanical tissue deformation as frequency-modulated neural signals to the CNS through afferent sensory pathways.\textsuperscript{8} Deformation to the tissues in which the mechanoreceptors lie causes a mechanically gated release of stored sodium, eliciting an action potential.\textsuperscript{11} An increase in tissue deformation causes an increase in action potentials, thereby increasing neural input to the CNS.\textsuperscript{8,11}

Specifically, at the shoulder joint, Vangsness et al\textsuperscript{10} reported that neural endings exist in ligamentous structures. Low-threshold, slow-adapting Ruffini afferents were most abundant overall, except in the glenohumeral ligaments, where low-threshold, rapid-adapting, Pacinian-type afferents outnumber Ruffini afferents.\textsuperscript{10} Ruffini afferents are believed to be stimulated only with extremes of motion through tensile force, acting as limit detectors.\textsuperscript{8} Like Ruffini receptors, Pacinian corpuscles respond to extremes of motion but through both compressive and tensile mechanisms rather than stretching alone.\textsuperscript{5} No mechanoreceptors were present in the subacromial bursa or glenoid labrum.\textsuperscript{10} Because the capsuloligamentous structures of the shoulder are reported lax in mid ranges of motion,\textsuperscript{12,13} mechanoreceptors present within the joint capsule and ligaments are believed to contribute proprioceptive information when maximal deformation occurs at end ranges of motion.\textsuperscript{5,14} The spiral tightening of the capsule that occurs with abduction and external rotation sequentially tightens the capsuloligamentous structures, stimulating the mechanoreceptors.\textsuperscript{15}

In addition to the capsuloligamentous mechanoreceptors, the musculotendinous mechanoreceptors play a significant role in providing proprioceptive input. Both Golgi tendon organs and muscle spindles are present in the musculature about the shoulder joint.\textsuperscript{8,9} At the tendinous region of muscle, the tension-sensitive Golgi tendon organs are recruited when muscle contraction pulls on the tendon, relaying afferent feedback concerning joint position and musculotendinous tension.\textsuperscript{16,17} As a protective mechanism, stimulation of the Golgi tendon organ facilitates relaxation of the agonist muscle under tension while eliciting contraction of the antagonist muscle group.\textsuperscript{17}

The intrafusal muscle spindle lies parallel to the extrafusal contractile elements of muscle.\textsuperscript{17} Because the intrafusal muscle spindles are innervated by gamma motoneurons, while the extrafusal contractile elements are innervated by alpha motoneurons, muscle spindle sensitivity is adjusted during the entire range of motion, continuously signaling alterations in both muscle length and rate-of-length changes.\textsuperscript{5,17} Afferent proprioceptive information originating from musculotendinous, capsuloligamentous, and cutaneous receptors is integrated with messages descending from higher levels of the CNS at fusimotor neurons within the muscle spindle.\textsuperscript{18,19} All incoming input is adjusted so that a single composite signal is passed from the muscle spindle to the CNS and directly to the alpha motoneurons of the muscle.\textsuperscript{18,19} This resulting proprioceptive input to the CNS results in joint movement and position sense, reflexive muscle contraction, and regulation of muscle tone and stiffness.\textsuperscript{5,18,20} Because the capsuloligamentous and cutaneous afferents influence the muscle spindle, it appears that musculotendinous, capsuloligamentous, and cutaneous mechanoreceptors play a complementary role in movement and joint position sense.\textsuperscript{18}

The proprioceptive information provided by the mechanoreceptors present within the musculotendinous, capsuloligamentous, and cutaneous structures is appreciated at 3 distinct levels of motor control in the CNS. Those levels of motor control include the spinal level, the brain stem, and higher levels of the central nervous system such as the cerebral cortex and cerebellum.\textsuperscript{5,21–23} Each level elicits unique motor responses vital to coordinated movement and functional joint stability. At the spinal level, direct motor responses in the form of reflexes and elementary patterns of motor control result.\textsuperscript{5} (The role of reflexes in glenohumeral joint stabilization is addressed later within this section.) At the brain stem, information from the periphery is integrated with both visual and vestibular input to control automatic and stereotypical movement patterns, as well as modulate balance and posture.\textsuperscript{5,21,24}

In addition, the brain stem may play an influential role at the muscle spindle by maintaining and modulating muscle tone.\textsuperscript{5} The third level of motor control is the higher regions of the central nervous system such as the cerebral cortex and cerebellum. Tibone et al\textsuperscript{25} demonstrated an afferent pathway from the mechanoreceptors present in the joint capsule to the cerebral cortex using cortical evoked potentials. Evidence of this pathway indicates that conscious awareness of proprioception may occur at the cortical level, where proprioceptive information is appreciated and plays a role in voluntary movements that are stored as central commands.\textsuperscript{5} Tyldesley and Grieves\textsuperscript{26} reported that awareness of body position at this level allows for various skills to be performed without conscious reference. The cortical level initiates and modulates both complex and discrete movements and organizes and prepares motor commands.\textsuperscript{5} In addition, the cerebellum plays a significant role by acting as a “comparator.”\textsuperscript{27} Subconsciously, the cerebellum takes information from the periphery and compares outcome movements with expected movements, playing a vital role in motor control.\textsuperscript{27}

The unconscious activation of dynamic restraints occurring in preparation and in response to joint motion and loading for the purpose of maintaining functional joint stability is termed neuromuscular control.\textsuperscript{5} Several neuromuscular control mechanisms contributing to functional joint stability will be discussed in this section, including coactivation of glenohumeral and scapulohoracic musculature, reflex stabilization, preparatory activation, and muscle stiffness.

Coactivation of the dynamic stabilizers at the shoulder joint is vital to dynamic stabilization. Inman et al\textsuperscript{28} first described force couples resulting from coactivation of the dynamic stabilizers around the shoulder, providing joint stability. Two force couples are commonly described. Contraction of the subscapularis muscle counteracts contraction of the infraspinatus and teres minor muscles in the frontal plane, while contraction of the deltoid muscle counteracts contraction of the lower rotator cuff muscles (infraspinatus, teres minor, and subscapularis) in the transverse plane.\textsuperscript{28} Force couples are believed to produce joint compression, which in turn provides maximum joint congruency of the articulating surfaces.\textsuperscript{22} The rotator cuff musculature is essential for dynamic stability by centralizing the humeral head within the glenoid fossa, preventing excessive humeral translation.\textsuperscript{29} Wilk et al\textsuperscript{30} referred to the resulting vector forces that stabilize the humeral head within the glenoid as a “balance of forces.” This muscle balance describes the coordinated synergistic action of all glenohumeral musculature providing joint stability. When those forces are not properly balanced or equalized, abnormal
glenohumeral mechanics and glenohumeral instability may result.\(^{30}\)

In addition to the synergistic action of glenohumeral musculature, the common insertion of the rotator cuff tendons within the joint capsule provides an element of dynamic capsular tension. As the cuff muscles contract simultaneously, the forces generated in their tendinous insertions apply tension to the joint capsule.\(^{31,32}\) This increased capsular tension aids in drawing the humeral head into the glenoid fossa, supplementing joint stability.

In addition to glenohumeral coactivation, a force couple also exists at the scapulothoracic articulation. The upward scapular rotation necessary for full glenohumeral abduction results from combined action by the trapezius (upper and lower portions) and serratus anterior muscles.\(^{33,34}\) In addition to the trapezius-serratus anterior force couple, synergistic contraction of all scapular-stabilization musculature provides a firm base of support for movement of the humerus at the glenoid by drawing the scapula to the thorax. As the head of the humerus moves on the glenoid fossa, the scapula simultaneously rotates, keeping the glenoid fossa and humeral head in proper alignment. Proper alignment is believed to provide an optimal length-tension relationship for the rotator cuff, which is important for glenohumeral dynamic stability.\(^{35}\)

Reflex stabilization is an efferent neuromuscular response elicited at the spinal cord level. Several investigators demonstrated that a spinal reflex exists between fibrous joint capsule and musculature about the feline glenohumeral joint.\(^{36-38}\) Jerosch et al.\(^{39}\) followed up by arthroscopically demonstrating a similar reflex arc between the shoulder capsule and the deltid, trapezius, pectoralis major, and rotator cuff musculature in a human model. Initially, these reflex arcs were believed to play a primary role in joint stabilization.\(^{40,41}\) The stabilizing structures are deformed on application of a traumatic force to the joint, eliciting a feedback, reflexive muscle contraction.\(^{42}\)

The problem is that the time lapse between tissue deformation (mechanoreceptor excitation) and the resulting reflexive response may not be quick enough or the response strong enough to counter a traumatic event.\(^{39,42,43}\) Jerosch et al.\(^{39}\) demonstrated a latency of 100 to 516 milliseconds in humans. While these latencies appear to be fast, they simply might not be sufficient to protect the joint. Speer and Garrett\(^{44}\) speculated that even though the reflex activity may not be quick enough for joint stabilization, reflex activity may play a role in modifying preprogrammed responses effective in altering joint motion. Reflex activity arising from the muscle spindle assists with programmed motor patterns through a dampening function. The reflexive activity regulates both extrafusal and intrafusal length, preventing jerky, oscillation-type movements.\(^{17}\)

A final mechanism responsible for functional joint stability is the role of preparatory muscle contraction and the resulting muscle stiffness.\(^{44}\) Preparatory activation and muscle stiffness are often addressed at the knee and ankle joint.\(^{55-58}\) with minimal literature applying these concepts to the upper extremity.\(^{49}\) The roles of preparatory activation and muscle stiffness at the shoulder joint are much-needed areas of exploration. As a result of preactivation, muscle stiffness is believed to increase. McNair et al.\(^{43}\) defined muscle stiffness as the ratio of change in force per change in length. This increased muscle stiffness resists stretching episodes, heightens muscle spindle sensitivity, and reduces the electromechanical delay involved in reflexive stabilization.\(^{19,45}\)

Peripheral sensory information (proprioception) from previous experiences is learned, stored, and used for planning and executing motor patterns.\(^{50}\) This planning and execution of muscle activation results in preparatory muscle activity, which in turn braces the joint before some external load is placed on the shoulder. Preparatory muscle contraction offers quick compensatory responses for external loads, providing joint stability.\(^{19,49}\) In essence, a stiffer muscle produces a stiffer, more functionally stable joint.\(^{2}\) Dietz et al.\(^{59}\) demonstrated that both preparatory and reactive muscle activity of the triceps brachii muscle occurs during forward falls. This preparatory activation and reactive contraction are believed to provide joint stability.

**SENSORIMOTOR SYSTEM ASSESSMENT**

**Proprioception Assessment**

Measurement of the sensorimotor system encompasses evaluation of the integrity and function of the sensory and motor components along afferent or efferent, or both, neural pathways, as well as the resulting muscle activation patterns.\(^{51}\) We discuss common assessments of both proprioception and neuromuscular control as they relate to the shoulder.

We previously stated that proprioception is defined as the afferent information concerning the 3 submodalities of kinesthesia, joint position sense, and sensation of resistance.\(^{3}\) As such, measurement techniques attempt to quantify these submodalities through clinical assessment. Kinesthesia assessment is addressed through threshold to detection of passive motion (TTDPM). TTDPM quantifies one's ability to consciously detect shoulder movement and is often performed on some type of proprioception testing device (Figure 1).\(^{52-56}\) Subjects are fitted with a blindfold, headphones, and a pneumatic sleeve to eliminate visual, auditory, and tactile cues, causing them to

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**Figure 1.** An individual performing either joint position sense or threshold to detection of passive motion on a proprioception testing device. The subject lies supine with the upper extremity supported at 90° of abduction and in elbow flexion. The subject is fitted with a blindfold, pneumatic air splint, and headphones to eliminate visual, tactile, and auditory cues. Using a handheld switch, the subject signals when either the joint position is passively reproduced or motion is detected. (Reprinted by permission from Lephart SM, Kocher MS: The role of exercise in the prevention of shoulder disorders, in Matsen FA, Fu FH, Hawkins RJ (eds): The Shoulder: A Balance of Mobility and Stability. Rosemont, IL, American Academy of Orthopaedic Surgeons, 1993.\(^{29}\))
rely strictly on sensation from peripheral afferents to detect motion. The limb is passively rotated at a velocity from 0.5°·s⁻¹ to 2°·s⁻¹, depending on the literature. Extensive reliability work in our laboratory has shown that slower speeds are necessary to reduce variability, creating a more reliable test. The subject signals as soon as the motion is detected; therefore, the amount of rotation occurring before detection is recorded. Testing often incorporates internal and external rotation movements and occurs at both mid and end ranges of rotation. End-range external rotation is more sensitive to motion detection.

Joint position sense is measured in the laboratory setting with a number of assessment tools, including isokinetics, standard goniometry and electrogoniometry, proprioception testing devices (Figure 1), and electromagnetic motion analysis systems (Figure 2). Joint position sense assessment measures the ability to appreciate where one’s extremity is oriented in space. Testing protocols usually begin by placing the upper limb in some standardized position and allowing the subject to appreciate its spatial orientation. The subject reproduces the presented joint position. Variations in testing include both active and passive reproduction of joint positions. As in kinesthesia testing, visual and tactile cues are often negated.

In addition to traditional assessments of proprioception (joint position sense and kinesthesia), our laboratory is currently using a 6 degrees-of-freedom electromagnetic motion analysis system as part of our proprioception testing battery. Because proprioceptive input influences motor performance, replication of a path of motion is being implemented. Figure 2 demonstrates an athlete reproducing a presented motor pattern. Using the motion analysis software, the clinician quantifies the

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Figure 2. A, An individual performing path replication with electromagnetic motion analysis system’s 6 degrees of freedom, B, with the clinician using a computer-generated image to quantify path variability during rehabilitation and assessment.
degree of 3-dimensional variation between the presented and reproduced path of motion. The motion analysis system allows for a more effective assessment of proprioception by testing in more functional positions, with less input from the testing device.

**Neuromuscular Control Assessment**

Resulting efferent responses to proprioceptive input are measured through neuromuscular control assessments. These assessments can include muscle activation patterns through electromyography (EMG), muscle performance characteristics with isokinetics, and functional performance tests.

Muscle activation patterns are assessed with EMG. EMG records muscle activity by measuring the accompanying electrical potential. Uhlandman et al. used EMG to measure motor responses at the shoulder resulting from isokinetic dynamometer joint perturbations. Trying to establish the relationship between proprioception (passive joint position sense) and motor responses to joint perturbation, the authors reported no correlation between joint position sense and motor latencies.

At the shoulder joint specifically, fine-wire EMG and surface-electrode EMG were used to investigate athletic activity, neuromuscular alterations after injury, and shoulder rehabilitation.

Isokinetic dynamometry can be a valuable tool in assessing muscle performance. Through variations of common muscle performance characteristics such as torque, work, and power, adaptations in muscle performance resulting from rehabilitation, injury, and fatigue can be assessed. Whitley and Terrio demonstrated decreased peak torque with shoulder adduction and internal rotation in baseball pitchers during 1 baseball season. These findings may be associated with injuries to the pitching arm. Wooden et al. showed increased external rotation torque and increased throwing velocity in teenage baseball players after 5 weeks of variable isotonic resistance training. These results indicated the efficacy of resistive training for improving shoulder muscle function and throwing performance.

Finally, neuromuscular control can indirectly be assessed through the use of functional performance tests. Davies and Dickoff-Hoffman described a Functional Throwing Performance Index to assess functional performance after injury or surgery. Individuals toss a rubber playground ball at a 0.30-m × 0.30-m (1-ft × 1-ft) square target on a wall as many times as possible during a 30-second trial. The performance index is calculated by dividing the total number of throws by the number of throws that strike the target. Myers et al. and Padua et al. described a single-arm dynamic stability test. Individuals maintain a single-arm tripod position as still as possible with the involved limb on a force plate and the feet on an unstable surface. Both the amount of sway that occurs over one's center of gravity and the number of compensatory touchdowns were calculated. Because the upper extremity was the only fixed segment on the body, subjects relied on shoulder dynamic stabilization to maintain the tripod position.

Assessments of the sensorimotor characteristics, whether proprioception measures such as joint position sense, kinesthesia, and path replication or neuromuscular control measures including EMG, muscle performance characteristics, and functional performance tests, are valuable tools for both the researcher in the laboratory and the therapist in the clinical setting. Such instruments provide means of assessing sensorimotor characteristics, including deficits after injury and fatigue, and provide a measure of efficacy for improving proprioception and neuromuscular control through surgical intervention and rehabilitation.

**PROPRIOCEPTION AND NEUROMUSCULAR CONTROL AFTER INJURY**

Lehman and Henry presented a shoulder functional stability paradigm illustrating the cyclic role of joint injury on functional stability. Disruption of the stabilizing structures (capsuloligamentous and musculotendinous), whether caused by a traumatic or atraumatic mechanism, results in mechanical instability of the shoulder joint.

Accompanying the disruption of the mechanical stabilizing structures is decreased capsuloligamentous mechanoreceptor stimulation resulting from tissue deafferentation or the increased tissue laxity limiting mechanoreceptor stimulation, or both, thus decreasing proprioception. This combination of capsuloligamentous disruption resulting in mechanical instability and the subsequent proprioceptive deficits contributes to functional instability.

The presence of proprioceptive deficits in unstable shoulders has been repeatedly demonstrated in the literature. Smith and Brunoli were the first to demonstrate decreased proprioception after shoulder joint injury. They reported kinesthetic deficits in subjects who sustained unilateral anterior glenohumeral dislocations. A similar study by Lehman et al. compared the subjects' ability to both detect passive motion and passively reproduce joint positions in normal, unstable, and surgically repaired shoulders. A significant decrease in kinesthesia and joint position sense was seen in subjects with instability when compared with normal individuals and those with surgical reconstructions. Zuckerman et al. similarly demonstrated a significant decrease in joint position sense and kinesthesia when moving into shoulder flexion, abduction, and external rotation in subjects with unilateral glenohumeral instability of traumatic origin. Interestingly, using cortical evoked potentials, Tibone et al. reported no significant differences between normal subjects and subjects with instability. Given that joint capsule mechanoreceptors were stimulated with electrical potentials rather than tissue deformation, these results suggest that capsular laxity alone rather than mechanoreceptor trauma resulting in deafferentation is responsible for proprioception.

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**Journal of Sport Rehabilitation, 5(1):78-79**

*Figure 3. Shoulder functional stability paradigm. The paradigm demonstrates the cyclic progression of functional instability at the shoulder and the role of surgical intervention and rehabilitation in preventing functional instability.* (Reprinted by permission from Scott Lehman and Timothy Henry, 1996, "The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity." *Journal of Sport Rehabilitation, 5*(1):78-79)
deficits. Blasier et al\textsuperscript{53} noted decreased kinesthetic sense in subjects with hypermobility but no history of instability or injury. In the absence of mechanoreceptor trauma, these results again indicate that capsular laxity (resulting from hypermobility) decreases proprioception. Allegrucci et al\textsuperscript{52} focused on kinesthetic awareness in overhead athletes and reported decreased kinesthesia in the dominant limb of overhead athletes compared with the nondominant limb. This decrease may result from the general capsular laxity present in overhead athletes and indicates that increased capsular laxity may account for proprioceptive deficits.\textsuperscript{52} Sainburg et al\textsuperscript{83} demonstrated that patients lacking proprioception were unable to perform multijoint movements that mimic a slicing gesture, suggesting that a proprioceptively deficient joint disrupts coordinated movement at other joints along the kinetic chain.

The deficits in proprioception after joint injury appear to contribute to alterations of the neuromuscular response vital to joint stability.\textsuperscript{22} Glousman et al\textsuperscript{70} measured muscle activity during pitching using fine-wire EMG in subjects with anterior glenohumeral instability. They demonstrated increased compensatory supraspinatus and biceps brachii muscle activity in unstable shoulders to compensate for a lack of glenohumeral stability. In addition, Glousman et al\textsuperscript{70} reported decreased subscapularis, pectoralis major, latissimus dorsi, and serratus anterior muscle activity during the late cocking phase of pitching in individuals with instability. This decreased activity is problematic, because the shoulder relies on activation by these muscles for anterior stability, especially in positions of vulnerability such as the late cocking phase of pitching.\textsuperscript{70} Kronberg et al\textsuperscript{71} demonstrated decreased anterior and middle deltoid muscle activity with shoulder flexion and shoulder abduction in subjects with instability. This disrupted deltoid activity may alter the force couple action that exists between the deltoid and rotator cuff muscles and is vital to functional stability.

The mechanical instability from capsuloligamentous injury does not result in episodes of functional instability in all patients.\textsuperscript{22} Functional instability results from mechanical instability compounded by decreased proprioception and alterations in neuromuscular control. The lack of functional stability can make the athlete susceptible to reinjury and may account for the high rate of recurrence in shoulder dislocation injuries.\textsuperscript{54}

**PROPRIOCEPTION AND NEUROMUSCULAR CONTROL AFTER FATIGUE**

Similar to joint injury, muscle fatigue is believed to affect proprioception and neuromuscular control.\textsuperscript{54,57,59,85–88} Several mechanisms of fatigue have been reported as possible causes of decreased proprioceptive input, thereby affecting neuromuscular control. Unfortunately, no definitive conclusions can be drawn as to the exact mechanism resulting in decreased proprioception. As a result, we discuss several commonly described mechanisms.

Muscle fatigue is believed to desensitize muscle spindle threshold, thereby affecting joint position sense and the neuromuscular responses vital to joint stability.\textsuperscript{57,85} This desensitization results from changes in local metabolism at the muscle.\textsuperscript{85} Pedersen et al\textsuperscript{18} reported that increased intramuscular concentrations of lactic acid, potassium chloride, bradylkinin, arachidonic acid, and serotonin after fatiguing contractions may affect the muscle spindle system, thereby influencing proprioceptive acuity. Djupsjobacka et al\textsuperscript{88–90} noted that increased intramuscular concentrations of several contractile substances resulting from muscle fatigue alter the muscle spindle output, as measured through reflex arcs.

The role of central factors cannot be overlooked when discussing the role of muscle fatigue. Central fatigue occurs at higher levels of the central nervous system, such as the cerebral cortex.\textsuperscript{91} The physiologic strain of fatigue can lead to psychological inhibition.\textsuperscript{92} The fatigue protocol may be taxing not only to the shoulder musculature but also to conscious awareness of proprioception.

An indirect mechanism independent of muscle fatigue but resulting from the bout of exercise to elicit fatigue is the increased ligamentous laxity that occurs with exercise.\textsuperscript{93,94} During cyclic loading, viscoelastic changes resulting from exercise decrease the stiffness properties of ligament.\textsuperscript{55} This decrease in stiffness may desensitize the mechanoreceptors present within stabilizing structures, compromising proprioceptive feedback.\textsuperscript{96} The desensitized mechanoreceptors, in combination with the decreased capsuloligamentous stiffness, may compromise stability in extremes of rotation (ie, positions of vulnerability). Researchers have investigated the effect of muscular fatigue on proprioception and neuromuscular control at the shoulder, elbow, knee, and ankle.\textsuperscript{54,57,59,85,97–100} Carpenter et al\textsuperscript{18} demonstrated decreased proprioception after fatigue using TTDPM assessment. Detection latency increased by 171\% for internal rotation and 179\% for external rotation. Because of the decreased kinesthetic sense after fatigue, the researchers concluded that fatigue affects sensation of joint movement, decreases athletic performance, and increases fatigue-related shoulder dysfunction.\textsuperscript{54} Myers et al\textsuperscript{57} focused on the effect of fatigue on shoulder proprioception and neuromuscular control. Sixteen subjects exhibited decreased ability to actively reproduce joint position in both mid and end ranges of motion. Unlike the previous studies, Myers et al\textsuperscript{57} also included a neuromuscular control measurement.

At the shoulder joint, Myers et al\textsuperscript{57} measured neuromuscular control using the single-arm dynamic stability test. As evident by the number of compensatory events (any touch down to maintain stability), the authors reported a decreased ability to maintain the single-arm push-up position after a bout of isokinetic fatigue (1 compensatory event before fatigue, 14 after) and speculated that fatigue of the force couple musculature vital to dynamic stability was altered, decreasing the dynamic stability. Wickiewicz et al\textsuperscript{101} performed a kinematic analysis of glenohumeral motion after a bout of muscle fatigue and noted an increase in superior humeral migration at 45°, 90°, and 125° of abduction after fatigue.\textsuperscript{101} These results emphasize the importance of the dynamic stabilizers present at the shoulder joint and how fatigue may increase the risk of injury due to a loss of stability. Because few studies to date have examined shoulder neuromuscular control after fatigue, additional research is needed.

The implications from decreased proprioception and neuromuscular control after fatigue are 2-fold. First, afferent proprioceptive feedback integrated at the CNS elicits efferent neuromuscular responses as both spinal reflexes and preprogrammed responses vital to functional stability of the shoulder joint. Because fatigue hinders proprioceptive feedback from the shoulder to the CNS, the neuromuscular responses responsible for joint stability may be hindered, leading to joint instability and eventually joint injury. That joint injury can occur to both the musculoskeletal and...
RESTITUTION OF PROPRIOCEPTION AND NEUROMUSCULAR CONTROL

After capsuloligamentous injury, the goal of management and rehabilitation should be restoration of functional stability at the shoulder joint. As previously stated, functional stability encompasses the interplay of both the mechanical restraints (joint capsule, ligamentous structures, and glenoid labrum) and dynamic restraints (neuromuscular responses by the shoulder musculature). To restore functional stability, both constituents must be restored. Figure 3 illustrates the roles that surgery and rehabilitation play in shoulder functional instability.

Surgical Management of Instability

Surgical management disrupts that vicious cycle of injury by restoring capsuloligamentous integrity and restoring proprioceptive capabilities. Surgical techniques such as variations of the capsular shift, Bankart procedures, and thermal capsular shrinkage address the capsuloligamentous trauma that results from injury, alleviating mechanical instability. Interestingly, surgical management also plays a significant role in restoring the proprioceptive capabilities of the shoulder joint after injury. Surgery retensions the capsuloligamentous structures, facilitating proprioceptive feedback by allowing mechanical stimulation of the afferents present within the joint capsule and ligaments.

As previously discussed, Lephart et al. measured both joint position sense and kinesthesia in normal individuals and those with unstable and surgically reconstructed shoulders. The subjects diagnosed with instability who underwent open or arthroscopic surgical intervention showed no significant difference in joint position sense or kinesthesia of the injured limb when compared with the contralateral limb. Therefore, restoration of capsular tension resulted in restoration of proprioceptive feedback. Zuckerman et al. prospectively studied 30 individuals with unilateral glenohumeral instability of traumatic origin with both joint position sense and kinesthetic testing protocols 1 week before surgery and at 6 and 12 months after surgery. The authors demonstrated significant decreases in both joint position sense and kinesthesia before surgery and partial restoration by 6 months and full restoration by 12 months after surgery.

Thermal Capsular Shrinkage

A contemporary surgical procedure gaining popularity in the orthopaedic community is the use of thermal energy via radiofrequency devices and lasers to address mechanical instability (thermal capsular shrinkage). While thermal capsular shrinkage has been received with much enthusiasm, data concerning its efficacy are anecdotal. No substantial clinical studies address the efficacy of thermal capsular shrinkage. Given that thermal energy denatures the collagenous infrastructure of the shoulder capsule, whether the mechanoreceptors present within the shoulder capsule are also altered is a topic of much controversy.

We measured joint position sense, kinesthesia, and shoulder function in subjects who underwent thermal capsular shrinkage for shoulder instability. We found no significant difference in kinesthesia or either active or passive reproduction of joint position sense 6 to 24 months after surgery. In addition, these subjects had returned to near-normal function at the time of testing. We concluded that the combination of normalized proprioception and the subject’s ability to return to near-normal function after surgery suggests that thermal capsular shrinkage may provide an effective management option for treating glenohumeral instability. Thermal capsular shrinkage and its effect on proprioception, neuromuscular control, and function still need to be investigated prospectively.

Functional Rehabilitation

Whether surgical intervention or a conservative approach is chosen, a rehabilitation program is vital for return to function after shoulder joint injury. As with any injury, rehabilitation should address inflammation and pain reduction, a return to normal range of motion and flexibility, and restoration of strength through traditional rehabilitation exercises. We refer readers to several sources of traditional shoulder rehabilitation exercises. Traditional rehabilitation addressing the aforementioned aspects might be sufficient for return to activities of daily living but not for return to athletic activity. As a result, Lephart and Henry proposed adding “functional rehabilitation” to the traditional rehabilitation protocol.

Functional rehabilitation is believed to prepare an athlete for return to athletic competition by restoring the proprioceptive capability and neuromuscular control of the shoulder joint after injury. Functional rehabilitation is believed to increase the sensitivity of peripheral afferents present in both the capsuloligamentous and musculotendinous structures, reestablish afferent pathways, facilitate coactivation of the force couples, elicit preparatory and reactive muscle contractions, and increase muscle stiffness. Functional rehabilitation should mimic the demands placed on the shoulder joint during athletic activity, making the transition to full activity less stressful for the athlete. To meet these goals, 4 facets of functional rehabilitation must be addressed: awareness of proprioception, dynamic-stabilization restoration, preparatory and reactive muscle facilitation, and replication of functional activities. We discuss each facet of functional rehabilitation individually, providing clinicians with valuable tools for reestablishing functional stability.

Unfortunately, many of these exercises we describe are discussed only in clinical journals, and reports of efficacy are limited to anecdotal evidence. As such, controlled scientific studies are needed to add a level of scientific efficacy.

Awareness of Proprioception. The goals of awareness of proprioception are to reestablish afferent pathways from the mechanoreceptors at the injured joint to the CNS and to facilitate supplementary afferent pathways as a compensatory mechanism for proprioceptive deficits that resulted from joint injury. Because the risk of injury aggravation with proprioception training is low, both kinesthesia and joint position sense training can be initiated early in rehabilitation. Early training of conscious awareness of proprioception is believed to lead eventually to unconscious awareness. Proceptive information is appreciated by the injured athlete in the form of both
joint position sense and kinesthesia. Therefore, rehabilitation should address both aspects.

Clinicians can implement joint position sense training with isokinetic exercises, proprioception testing devices, goniometry, and electromagnetic motion analysis. Joint position sense training can be simply performed by placing the athlete's upper extremity into a predetermined position, then instructing the athlete to reproduce the joint position as accurately as possible. Initially, trials can include visual cues (the athlete can see the limb position), progressing to the removal of visual cues through the use of a blindfold. Joint position sense trials should be performed within mid ranges of motion to stimulate musculotendinous mechanoreceptors as well as in end ranges of motion in positions of vulnerability to stimulate capsuloligamentous afferents. Trials can include both passive reproduction of joint position, in which the clinician, isokinetics, or a proprioception testing device moves the limb while the athlete signals when the joint position is reached, and active reproduction of joint position, in which the athlete actually reproduces the joint position through his or her own muscle contraction. The activity can be varied by having the athlete replicate paths of motion rather than joint position to add an element of functionality.

Kinesthesia training can also be easily performed by the clinician. By simply eliminating external cues via a blindfold and headphones, the clinician uses isokinetics, a proprioception testing device, or simple manual motion to administer the trials. The athlete’s goal is to signal when joint motion is sensed, as quickly as possible once motion is initiated. Recording the degree of motion before joint motion detection is a means of quantifying progress.

Dynamic Stabilization. In this phase of rehabilitation, the primary goal is to reestablish the synergistic coactivation of force couples present at the shoulder. These force couples include the 2 present at the glenohumeral joint, as well as that at the scapulothoracic articulation. By facilitating this coactivation of the force couples at the glenohumeral joint, dynamic stability is restored as the resulting vector forces centralize and compress the humeral head within the glenoid fossa. Also, contraction of the rotator cuff pulls on the glenohumeral joint capsule, applying tension, which results in increased stability.

It is commonly believed that weightbearing exercises in the upper extremity facilitate a level of coactivation of both the glenohumeral and scapulothoracic force couples. Until recently, the use of weightbearing exercises for coactivation of the force couple musculature was strictly anecdotal, with no scientific validity. However, Henry et al performed a fine-wire EMG study to assess the level of coactivation of the 2 force couples present at the shoulder. Subjects in the study performed dynamic rehabilitation exercises, including a push-up, rhythmic stabilization, tracing circles on a slide board, horizontal motion on a slide board, and flexion motion on a slide board. Of the dynamic rehabilitation exercises, 4 exercises produced coactivation of the force couples. Those coactivation exercises included the push-up and the 3 slide board activities. Thus, weightbearing exercises in the upper extremity are suited for re-establishing the glenohumeral coactivation necessary for dynamic stabilization.

As such, we recommend several exercises designed for reestablishing coactivation during rehabilitation. Simple weightbearing shifts on a table can be initiated early in the rehabilitation process due to the low risk of injury reaggravation. Next, a simple tripod stance on a firm surface can be beneficial. Once an athlete is able to maintain the tripod position on a firm surface with ease, moving to some type of
unstable surface is the next logical progression (Figure 4). (The role of tripod-type exercises will be discussed further in the next section.) Additional exercises as described by Henry et al.\textsuperscript{112} are weightbearing activities on the slide board. A simple progression can include limited weightbearing on one’s knees, progressing to a full push-up position. Motions can include circles, figures-of-8, and flexion exercises within the frame of the body (Figure 5A). As rehabilitation progresses and dynamic stability is restored, horizontal motion can be performed with the limb placed in positions of vulnerability (Figure 5B).

At the scapulothoracic joint, several exercises are suggested to facilitate synergistic contraction, providing a stable base of support for upper extremity movement. Wilk et al.\textsuperscript{112} described several exercises to reestablish the scapulothoracic contraction necessary to provide a stable base of support: isometric punches, push-ups, press-ups, and scapulothoracic rhythmic-stabilization techniques. A full description of these exercises is presented in the literature.\textsuperscript{32,112} Moseley et al.\textsuperscript{75} performed an EMG study focusing on scapular stabilization and strengthening exercises. They found that scaption exercises, rowing exercises, push-ups with a plus, and press-ups all provide substantial muscle activity for the scapular stabilizers.

**Preparatory and Reactive Muscle Activation.** The goals of this phase of rehabilitation are to reestablish the preparatory activation that provides joint stability through an increase in muscle stiffness, as well as to stimulate the reflexive contraction that results when a force acts upon the shoulder joint. Through the use of different types of joint perturbation, the shoulder joint is stressed with unexpected types of forces, similar to those experienced during athletic competition. However, full strength, range of motion, and dynamic stability must be obtained before initiating these exercises.

We recommend several exercises to address this phase of the functional rehabilitation. First, glenohumeral rhythmic-stabilization exercises should be performed. While rhythmic-stabilization exercises were not found to elicit coactivation, as commonly believed,\textsuperscript{111} their usefulness should not be underestimated. The athlete lies supine with the elbow extended and the limb projecting upward in the scapular plane. The athlete is instructed to maintain this position while the clinician applies repeated joint perturbations in randomized directions. Several progressions can be incorporated, including progressing from a visual to a nonvisual condition, progressing from the scapular plane position to positions of function and vulnerability, and adding a medicine ball to increase the challenge of performing the task (Figure 6). Rhythmic-stabilization exercises are believed to be very beneficial because they include both preparatory muscle activity, as the athlete prepares for the joint perturbation, and reactive muscle activity as the athlete responds to the unexpected direction of force.

In addition to rhythmic-stabilization exercises, weightbearing exercises (as described in the dynamic-stabilization restoration section of this manuscript) may have an important role in restoring both preparatory and reactive muscle activity. In addition to their coactivation capabilities, weightbearing exercises performed on unstable joints may elicit both preparatory activity to allow maintenance of the weightbearing position and reactive muscle contraction as the athlete responds to unexpected changes from the unstable surface. These exercises can be performed on any unstable surface, including wobble boards (Figure 4A), multiaxial devices, therapy balls (Figure 4B), and minitrampolines. Progressions can include visual to nonvisual conditions and increasing the difficulty by manipulating the unstable surface.

Plyometrics play a vital role in rehabilitation of the athletic shoulder. Plyometrics incorporate stretch-shortening contractions. Stretch-shortening contractions are characterized by an eccentric preload in which elastic energy is stored in the series elastic component of muscle.\textsuperscript{111} This stored energy is then used by the muscle to perform a forceful concentric contraction. The eccentric stretching that occurs with stretch-shortening contractions stimulates the muscle spindle, which in turn activates the myotatic (stretch) reflex in the agonist extrafusal muscle fibers.\textsuperscript{17} The faster the muscle is stretched, the greater the concentric contraction.\textsuperscript{113} The ballistic nature of plyometrics means that restored dynamic stability is essential before a plyometric training program is initiated.

The benefits of plyometric training are numerous. First, athletic movement patterns at the shoulder, including the late cocking phase of pitching, use a quick eccentric stretch followed by a sudden forceful contraction (acceleration phase), a stretch-shortening contraction. Plyometrics recreate the type of eccentric-concentric contraction experienced during athletic activity, providing the vital functional component. Second, preparatory muscle activity is elicited during plyometric training as the athlete prepares for the eccentric load, followed by the reactive (reflexive) contraction from increased stimulation of the muscle spindle. Repeated plyometric training may elicit neural adaptation, increasing muscle spindle sensitivity. Finally, plyometric training may play a role in increasing muscle stiffness. In addition to eliciting preparatory muscle contraction that increases muscle stiffness, high-repetition, low-rest interval eccentric training like that found in plyometric training may increase muscle stiffness by increasing muscle tone and
causing connective tissue proliferation, thus desensitizing the Golgi tendon organ and increasing muscle spindle sensitivity.\textsuperscript{114–116} The role of plyometrics for increasing muscle stiffness is an area warranting additional research.

Swanik et al\textsuperscript{58} demonstrated the effectiveness of shoulder plyometric training, reporting enhanced joint position sense, enhanced kinesthesia, and decreased time to peak torque and amortization after a 6-week plyometric program. They suggested that neural adaptation may have enhanced proprioception and muscle performance characteristics, as demonstrated in this study.\textsuperscript{58} Descriptions of plyometric exercises appear in the functional activities section of this manuscript as well as elsewhere in the literature.\textsuperscript{117,118}

**Functional Activities.** The final facet of functional rehabilitation is the inclusion of activities that mimic athletic function. By mimicking the type of activities and forces experienced by the athlete, the return-to-play transition may be less stressful on the athlete.\textsuperscript{119} It is important to incorporate specificity when implementing functional activities. Therefore, the athlete should be trained in sport-specific positions of function. The position of function for a baseball player or tennis player is a position of vulnerability in abduction and external rotation, while the position of function for an interior lineman on a football team is just below shoulder level anterior to the thorax. Functional rehabilitation should reflect such positions.

Several rehabilitation exercises with modification mimic function for any athlete. The benefits of plyometric exercises and their ability to mimic functional activity have been previously discussed. Plyometrics exercises using a minitrampoline and medicine ball or a simple piece of rubber tubing can mimic the throwing and serving motion in overhead athletes, an interior football line using explosive chest-pass repetitions, or athletic activities that incorporate the powerful trunk motions of pitching, batting, and golf (Figure 7). Because of the amount of joint force exhibited on the shoulder, plyometric exercises should be incorporated only after full, pain-free range of motion, strength, and dynamic stability are achieved.

A second rehabilitation exercise that mimics functional activity is proprioceptive neuromuscular facilitation (PNF). PNF exercises are believed to build strength through functional planes of motion by incorporating both spiral and diagonal patterns of motion that demand neuromuscular coordination.\textsuperscript{41} The diagonal 2 (D2) flexion-extension PNF pattern is often used in the rehabilitation of overhead athletes due to the similarity between its plane of motion and the throwing and serving movement pattern. PNF exercises can be performed manually by the therapist or with rubber tubing or isokinetics (Figure 8). Padua et al\textsuperscript{79} demonstrated the effectiveness of a 5-week manual PNF training study on function. After 5 weeks of PNF training, normal subjects showed a significant improvement in shoulder function as measured with the Functional Throwing Performance Index.\textsuperscript{78,79} These results demonstrate the importance of incorporating activities such as PNF exercises, which mimic function when preparing an athlete for return to competition.

**CONCLUSIONS**

Functional stability at the shoulder joint results from an interaction between the static and dynamic components of joint stability. The sensorimotor system plays an integral role by mediating static and dynamic components of afferent proprio-
ceptive information concerning joint position sense, kinesethesia, and sensation of resistance and the efferent neuromuscular responses that result. These neuromuscular responses are vital to both joint stability and coordinated movement patterns. The neuromuscular responses vital to joint stability include coactivation of the force couples, dynamic capsular tensioning, preparatory and reactive muscle contraction in the form of reflexes, and increased muscle stiffness. After capsuloligamentous injury, proprioceptive input appears to be disrupted, which in turn disrupts the efferent neuromuscular responses. This combination of increased capsuloligamentous laxity and decreased neuromuscular control results in a functionally unstable joint.

Restoration of functional stability in the athletic shoulder requires attention to both the stabilizing structures that are compromised, whether with surgical intervention or a conservative approach, and the neuromuscular responses vital to joint stability through a functional rehabilitation program. We have provided clinicians with the tools necessary for returning the athlete to competition by addressing functional rehabilitation through awareness of proprioception, facilitation of dynamic neuromuscular responses, restoration of preparatory and reactive muscle activity, and implementation of functional activities. The shoulder joint must have the ability to sense forces placed on the capsuloligamentous and musculotendinous structures and respond appropriately with efferent neuromuscular responses, providing much-needed functional stability to the inherently unstable joint.

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The Role of the Scapula in the Rehabilitation of Shoulder Injuries

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Objective: To present a clinical understanding of the role the scapula plays in the mechanics of shoulder function and specialized techniques for the rehabilitation of injuries around the shoulder girdle.

Background: The scapular musculature is often neglected in the evaluation and treatment of shoulder injuries. This lack of attention often degenerates into the incomplete evaluation and rehabilitation of scapular dysfunction. Dysfunction or weakness of the scapular stabilizers often results in altered biomechanics of the shoulder girdle. The altered biomechanics can result in (1) abnormal stresses to the anterior capsular structures, (2) the inability to properly position the humerus in the glenoid fossa, and (3) an increased possibility of rotator cuff compression, and (3) decreased performance.

Description: We review the anatomy and role of the scapula, the pathomechanics of injury and dysfunction, and the evaluation and rehabilitation of the scapula.

Clinical Advantage: Knowledge of how the scapular musculature influence function at the shoulder builds a strong foundation for the clinician to develop rehabilitation programs for the shoulder.

Key Words: scapular rehabilitation, shoulder rehabilitation, impingement syndrome, rotator cuff

The role of the scapula in upper extremity function has received considerable interest in recent years as our knowledge of the shoulder and surrounding structures has increased. The scapula plays several roles in facilitating optimal shoulder function when scapular anatomy and biomechanics interact to produce efficient movement. In normal upper-quarter function, the scapula provides a stable base from which glenohumeral mobility occurs. Stability at the scapulothoracic joint depends on the surrounding musculature. The scapular muscles must dynamically position the glenoid so that efficient glenohumeral movement can occur. When weakness or dysfunction is present in the scapular musculature, normal scapular positioning and mechanics may become altered.1 When the scapula fails to perform its stabilization role, shoulder function is inefficient, which can result not only in decreased neuromuscular performance but also may predispose the individual to shoulder injury.1 We explore and review the role of the scapula in function and describe how to evaluate and rehabilitate scapular dysfunction.

ANATOMY

The scapulothoracic joint is one of the least congruent joints in the body. No actual bony articulation exists between the scapula and the thorax, which allows tremendous mobility in many directions, including protraction, retraction, elevation, depression, and rotation. The lack of bony attachment predisposes this joint to pathologic movement, and, consequently, makes the glenohumeral joint highly dependent on the surrounding musculature for stability and normal motion.2-5 The scapula is attached to the thoracic cage by ligamentous attachments at the acromioclavicular joint and through a suction mechanism provided by the muscular attachments of the serratus anterior and subscapularis.2 This suction mechanism holds the scapula in close proximity to the thorax and allows it to glide during movements of the joint.2

While many muscles serve to stabilize the scapula, the main stabilizers are the levator scapulae, rhomboids major and minor, serratus anterior, and trapezius. The glenohumeral protectors include the muscles of the rotator cuff: the supraspinatus, infraspinatus, teres minor, and subscapularis.4-8 These muscle groups function through synergistic cocontraction to anchor the scapula and guide movement. The scapula moves through a gliding mechanism in which the concave anterior surface of the scapula moves on the convex posterolateral surface of the thoracic cage.2 These muscles work together to coordinate the balance of movement between the shoulder joints, thereby maintaining scapulohumeral rhythm.4-6 When the muscles are weak or fatigued, scapulohumeral rhythm is compromised, and shoulder dysfunction results.4,8,10 This dysfunction can cause microtrauma in the shoulder muscles, capsule, and ligamentous tissue and lead to impingement.4-6

During all movements of the glenohumeral joint (especially movements involving more than 90° of flexion or abduction), it is of paramount importance that the scapular-stabilizing musculature be strong enough to properly position the scapula. For example, the biomechanical research of both Jobe and Pink8 and Bak and Faunl10 demonstrated that if weakness or fatigue of any of the aforementioned structures occurs, scapulohumeral rhythm is disrupted, and secondary impingement (defined as a relative decrease in the subacromial space due to instability of the glenohumeral joint or functional scapulothoracic instability) ensues.4,10 Thus, the role of the scapula in upper extremity function must be considered in any shoulder rehabilitation program.
THE ROLE OF THE SCAPULA

The scapula performs 3 major roles in the production of smooth, coordinated movement about the shoulder girdle. These roles are interrelated to maintain the glenohumeral relationship and provide a stable base for muscular function.

The first role of the scapula is the maintenance of dynamic stability with controlled mobility at the glenohumeral joint. In order to maintain itself as the stable platform for glenohumeral function, the scapula must move in a coordinated fashion with the moving humerus, so that the humeral head is constrained within the glenoid throughout the full range of shoulder motion. The maintenance of proper alignment of the glenoid fossa not only allows for optimal bony constraint but also facilitates muscular constraint by maintaining proper length-tension relationships for efficient contraction of the rotator cuff muscles, thereby compressing the humeral head into the fossa.

While maintaining dynamic stability, the scapular musculature must at the same time provide controlled mobility. During throwing motions, as the arm begins to accelerate, the scapula must be protracted in a smooth fashion laterally and then anteriorly around the thoracic wall to allow the scapula to maintain a normal positional relationship with the humerus. This motion is controlled through eccentric contraction of the medial-stabilizing musculature (mainly the rhomboids and the middle trapezius), thus facilitating the dissipation of some of the deceleration forces that occur in the follow-through phase.

The scapula must also rotate upward with overhead activities to clear the acromion from the rotator cuff. In normal abduction, the scapula moves laterally in the first 30° to 50° of abduction. As abduction continues, the scapula then rotates about a fixed axis through an arc of approximately 65° as the shoulder reaches full elevation. This motion accounts for the 2:1 ratio between glenohumeral abduction and scapulothoracic rotation observed with overhead activity. Upward rotation and elevation are required in order to tilt the acromion upward, hence decreasing the likelihood of impingement and coraco-humeral arch compression.

The second role the scapula plays is as a base for muscle attachment. The muscles that stabilize the scapula attach to the medial border of the scapula, thereby controlling its position. This musculature controls scapular motion mainly through synergistic cocontractions and force couples, which are paired muscles that control the movement or position of a joint or a body part. The main functions of these force couples are to obtain maximal congruency between the glenoid fossa and the humeral head, to provide dynamic glenohumeral stability, and to maintain optimal length-tension relationships. The appropriate force couples for scapular stabilization include the upper and lower portions of the trapezius muscle working together with the rhomboid muscles, paired with the serratus anterior muscle. The appropriate force couples for acromial elevation are the lower trapezius and the serratus anterior working together, paired with the upper trapezius and rhomboid muscles.

In addition to acting as scapular stabilizers, muscles that attach along the lateral border of the scapula perform gross motor activities of the glenohumeral joint. The muscles of the rotator cuff attach along the entire surface of the scapula and are aligned so that their most efficient stabilizing activity occurs with the arm between 70° and 100° of abduction.

Kibler described these muscles working in this manner as a "compressor cuff," compressing the humeral head into the socket.

The third role of the scapula is best represented as the link in the proximal-to-distal transfer of energy that allows for the most appropriate shoulder positioning for optimal function. The scapula is pivotal in transferring the large forces and high energy from the major sources for force and energy—the legs and trunk—to the actual delivery mechanism of the energy and force—the arms and hands. Forces generated in the proximal segments must be transferred efficiently and regulated as they funnel through the shoulder to the hand. These actions can be accomplished most effectively through the stable and controlled platform of the scapula, so that the entire arm rotates as a unit around the stable base provided by the scapulothoracic and the glenohumeral joints.

PATHOMECHANICS

Most of the abnormal biomechanics and overuse injuries that occur about the shoulder girdle can be traced to alterations in the function of the scapular-stabilizing muscles. Injury occurs to muscles through either direct macrotrauma or microtrauma. In addition, the musculature can be inhibited by painful conditions about the underlying joint. Muscle weakness is a common finding about the shoulder girdle, and decreased support of the shoulder due to weakness in any shoulder muscle could lead to pathology. Weakness of the scapulohumeral muscles potentially leads to abnormal positioning of the scapula, disturbances in scapulohumeral rhythm, and generalized shoulder dysfunction.

The most common weak or inhibited muscles are the lower stabilizers of the scapula (serratus anterior, rhomboids, middle and lower trapezi),. The serratus anterior and lower trapezius form an important force couple that produces acromial elevation. If part of that force couple is negated through either fatique or nerve palsy, movement is abnormal. For example, paralysis of the serratus anterior results in reductions in both glenohumeral flexion and abduction. The medial border of the scapula is elevated off the rib cage, resulting in decreased acromial elevation. This problem manifests itself through decreased shoulder abduction and secondary impingement. This lack of acromial elevation and secondary impingement has been seen concomitant with many shoulder problems. Most shoulder injuries incurred as a result of sports activities can be traced to abnormal biomechanics, which, in turn, can be related to improper functioning of the scapular muscles. In fact, scapular instability is found in as many as 68% of rotator cuff problems and 100% of glenohumeral instability problems. The abnormal scapular biomechanics that occur as a result of dysfunction create abnormal scapular positions that decrease normal shoulder function and predispose the shoulder to injury.

The effects of muscle fatigue with regard to scapular stability have also been investigated. Thomson and Mitchell investigated the effect of repetitive exercise on the scapular stabilizers by studying the ability of the scapular musculature to stabilize the scapula after fatiguing exercise in the proprioceptive neuromuscular facilitation (PNF) D2 pattern as measured by the lateral scapular slide (LSS) test. Their results suggest that a fatigue-induced strength deficit of the shoulder musculature can have an adverse effect on scapular positioning by allowing the scapula to glide more laterally during func-
tional activities. The effect of fatiguing exercise on shoulder muscles has also been studied by Carpenter et al and Voight et al, who investigated the effects of exercise and muscle fatigue on shoulder proprioception. Both groups found a significant decrease in joint kinesthesia, measured using the time threshold to detection of passive movement after fatiguing exercise. They hypothesized that a decrease in position sense as a result of fatigue of the shoulder girdle musculature could interfere with normal coordination and joint stability, thus impairing function around the shoulder girdle.

EVALUATION

The evaluation of scapular function is critical to overall success in managing injuries of the shoulder girdle and upper extremity. Several different methods evaluate scapular function. The first step in the evaluation process is to observe the scapula, both statically and dynamically, in relation to its role in the entire kinetic chain.

Static scapular position in the resting position can be observed from behind the patient for abnormalities such as winging or decreased elevation (Figures 1 and 2). The examiner should look for asymmetry, deformity, atrophy or hypertrophy, edema, tenderness, crepitation, and color and temperature changes to help confirm shoulder injury. Static positional abnormalities can be further accentuated by having the individual isometrically contract the stabilizing musculature around the scapula.

Dynamic scapular movement can be evaluated by having the athlete slowly raise and lower the arm in both flexion and abduction. Look for smooth, controlled movement during both the ascending and descending phases of the motion, because scapular dyskinesis is often seen only during the lower, or eccentric, phase of the motion. In addition, during dynamic testing, a frequent finding is excessive lateral sliding of the scapula of an injured shoulder, as evidenced by an increased distance between the medial border of the scapula and the spinous processes of the vertebral column, as compared with the contralateral side.

Kibler described a good provocative maneuver to evaluate scapular muscle strength. The patient is asked to perform an isometric pinch of the scapulae in retraction and hold this position for 15 to 20 seconds. Scapular muscle weakness results in a burning pain in less than 15 seconds. However, in order to validate or properly objectify scapular muscle weakness (with numeric measurements), either manual muscle testing or the LSS test may be used.

Manual muscle testing of each of the individual muscles acting on the scapula has been commonly used in clinics to evaluate shoulder dysfunction. Yet, when done properly, manual muscle testing of each muscle can become very time consuming. Because of this, Kibler has developed the less time-consuming LSS test to evaluate scapular stability. This test compares the distance between a fixed point on the vertebral column and the scapula on the affected side (in specific positions) with that of the unaffected side as varying amounts of loads are placed on the supporting musculature.

The LSS test begins with the establishment of a measurement reference point on the nearest spinous process to the inferior angles of the scapula (Figure 3A). With the athlete’s arms at the sides in the anatomical resting position, the distance from the inferior angle of the involved and the uninvolved scapula is measured from the reference point and compared. Kibler’s second position of measurement is with the patient’s hands on the hips, with the fingers anterior and the thumb posterior (Figure 3B). This position places the humerus in approximately 45° of abduction. Because the second position of measurement is a transitional, graded progression of difficulty to the scapular-stabilizing musculature, many examiners jump directly to the third measurement position of 90° of arm elevation with maximal internal rotation (thumb to floor) at the glenohumeral joint (Figure 3C). Measurements are again taken from the reference spinous process to the inferior angles of the involved and uninvolved scapulae. This final position presents a challenge to the scapular-stabilizing muscles in a much more functional position. For purposes of clinical evaluation, Kibler initially recognized a 1-cm difference as clin-
ically significant.\(^9\) Recently, he has increased this threshold of abnormality to 1.5 cm.\(^7\) When pathology is present, it is not unusual to have asymmetry of as much as 3 cm.

Several studies have been performed to determine the reliability and validity of the LSS test, in which investigators have looked at the accuracy of marking the inferior angle of the scapula in different positions of abduction in comparison with radiographic examination (S.R. Tippett, unpublished data, 1991).\(^7\)\(^,\)\(^33\)\(^,\)\(^34\) The radiographic comparison for the validity of the lateral scapular glide measure was found to have a correlation coefficient of more than 0.90.\(^7\) Reliability has been established at between 0.80 and 0.88 and between 0.77 and 0.85 for intertester and intratester measurement (depending on the position), respectively (S.R. Tippett, unpublished data, 1991).\(^7\)\(^,\)\(^33\)\(^,\)\(^34\) Test-retest reliability is greatest with the arm at the side and progressively decreases with increasing shoulder abduction. The third position (90° of abduction) is the most difficult to measure accurately because of muscle activity, and yet, this position achieved test-retest and intertester reliability of more than 0.78.\(^6\) Therefore, it appears that the LSS test (1) reproduces the desired scapular points and the desired measurements, (2) is a reliable test in terms of reproducibility, and (3) tests muscles that are actually working to stabilize the scapula.\(^7\)

**REHABILITATION**

Once the complete and accurate diagnosis of all factors causing or contributing to scapular and shoulder problems is established, scapular rehabilitation should address all the functional roles of the scapula.\(^1\)\(^,\)\(^7\)\(^,\)\(^11\)\(^,\)\(^17\)\(^,\)\(^32\) To accomplish this, the clinician must first evaluate the patient and determine the exact cause of the patient’s dyskinesis, keeping in mind that an injury is often the result of shoulder dyskinesis rather than direct trauma. Once the pathology is diagnosed, motion must be restored. Proper form and scapular control should also be emphasized. At this stage, care is taken to exercise the patient in ranges of motion that are not impinging muscles and to avoid fatiguing muscles to the point that proper scapular positioning and control cannot be maintained.\(^28\) As motion is restored to larger pain-free ranges, strengthening is incorporated into the program. Finally, as full, pain-free motion is restored and strength progresses, return to sport or work activities can begin. In many cases, shoulder dysfunction can...
be corrected by proper scapular muscular re-education and conditioning. By restoring normal scapular mechanics and force couples, rehabilitation can improve scapular position and motion to decrease impingement and increase rotator cuff efficiency.

Keeping in mind the ultimate goal of full, pain-free motion with proper scapular stabilization and positioning, the clinician can design many exercise variations from a few core exercises (Lexington Clinic Sports Medicine Center, unpublished data, 1999). Being aware of the role of the scapula in upper extremity function is important when designing upper extremity exercises. First and foremost, all the exercises must integrate scapular-stabilization techniques in order to keep the scapula in the proper position to prevent impingement and maintain length-tension relationships of the musculature (Lexington Clinic Sports Medicine Center, unpublished data, 1999).

Every exercise progression must begin with stretching exercises. Weak muscles cannot be strengthened if their antagonistic counterparts are not stretched22 (Lexington Clinic Sports Medicine Center, unpublished data, 1999). Thus, it is important to stretch anterior chest muscles, such as the pectoralis major and minor and others that contribute to the rounded-shoulder
posture, which inhibits scapulohumeral rhythm\textsuperscript{22} (Lexington Clinic Sports Medicine Center, unpublished data, 1999). With a correct posture, facilitated by stretching, restoration of motion and scapular-strengthening exercises can begin. Some core techniques that can be used to restore motion and scapular stability are the scapular clock, towel slide, standing weight shift with the Pro Fitter (Fitter International Inc, Calgary, Alberta, Canada) scapular PNF patterns, and lawnmower exercises.

1. In the scapular-clock exercise, the patient envisions a clock tattooed on the injured shoulder. The patient places the hand of the injured arm on a ball on a plinth. The patient then moves the shoulder in the direction of the 12 o’clock, 3 o’clock, 6 o’clock, and 9 o’clock positions, which facilitates elevation, retraction, depression, and protraction of the scapula, respectively (Figure 4).

2. In the towel slide, the patient stands near a plinth with the hand of the injured arm on a towel on the plinth at the side. Instruct the patient to forward flex at the hips (while keeping the thoracic spine in relative extension) such that shoulder flexion is induced, producing a light stretch. Then instruct the patient to straighten up and extend the shoulder. When the shoulder is fully extended, instruct him or her to concentrate on “pinching” the scapulae together to facilitate the rhomboids and lower trapezius muscle (Figure 5) (Lexington Clinic Sports Medicine Center, unpublished data, 1999).

3. For the Pro Fitter standing weight shift, the patient stands with the hands placed on the Pro Fitter. Instruct the patient to lean forward and shift weight from the right upper extremity to the left upper extremity. This facilitates motion, proprioception, and scapular stabilization (Figure 6).

4. For scapular PNF patterns, the patient lies on the noninjured side or stands. Instruct the patient to resist motion as the scapula is elevated and protracted and depressed and retracted (Figure 7).

5. The lawnmower exercise, which simulates pulling the starter cord of a lawnmower, has wide-ranging variability. It can be used from very early in rehabilitation to facilitate motion by having the patient “pull,” using large amounts of trunk rotation and lower extremity extension to guide shoulder motion. It can be progressed in the intermediate stage by adding dumbbells and decreasing the amount of trunk rotation produced and then to the advanced stage by adding Thera-Band (Quality Health Products, Inc, Indiana, PA) or tubing, minimizing trunk motion, and adding lower extremity movement such as stepping or lateral lunging (Figure 8) (Lexington Clinic Sports Medicine Center, unpublished data, 1999).
Although few researchers have studied multiplanar exercises, Davies and Dickoff-Hoffman36 determined that the PNF D2 pattern (shoulder flexion, abduction, and external rotation) can be used to mimic functional directionality and facilitate triplanar conditioning, with either manual resistance or surgical tubing. They recommended performing this exercise to the point of fatigue or until the athlete loses the ability to maintain the shoulder in a 90° abducted position.36

Other studies have focused on exercise applications for rehabilitation. Moseley et al17 conducted electromyographic testing of scapular muscles during shoulder rehabilitation to determine how scapular muscles could best be exercised in a rehabilitation program. The upper, middle, and lower trapezius; levator scapulae; rhomboid major; middle and lower serratus anterior; and pectoralis minor were tested. Subjects performed each of 16 exercises concentrically, isometrically, and then eccentrically.17 Moseley et al17 determined that rowing, horizontal abduction in neutral, and horizontal abduction with the humerus in external rotation were the primary exercises that focused on scapular retraction. Rowing and horizontal abduction in neutral both optimally exercised all 3 parts of the trapezius, the levator scapulae, and the rhomboids. Horizontal abduction with humeral external rotation exercised the same muscles, except for the rhomboids. The authors concluded that rowing was the ideal exercise for scapular retractors, because it allowed for the greatest range of scapular retraction and had a greater intensity of muscle activity.8,17

The exercise program should be progressed creatively. As the patient's pain-free range of motion improves, more emphasis should be placed on strengthening the scapular musculature to improve stabilization and retraction. The following exercises improve the position of the scapula on the thorax, facilitate scapulohumeral rhythm, and decrease the likelihood of impingement.
5. Latissimus pull-downs are another versatile exercise for an
important scapular-stabilizing muscle. The seated patient pulls the resistance down to the chest (Figure 13). Instruct the athlete to observe proper posture and exaggerate “pinching” the scapulae together. Progress to alternating arm pull-downs to the chest, then to other weight equipment. The exercise can also be made more challenging by altering the direction of the pull. Finally, the patient can begin the exercise with trunk forward flexion and shoulder flexion and extend the trunk while pulling down. Trunk extension facilitates scapular retraction (Lexington Clinic Sports Medicine Center, unpublished data, 1999).

These exercises will not be beneficial for every patient treated. Clinicians are cautioned to avoid using this article as a protocol or “cookbook.” Instead, experiment with the exercise suggestions and develop different techniques for facilitating scapular retraction and stabilization. All the exercises can and should be varied in many ways. Clinicians should challenge themselves to be creative and experiment with different forms of every exercise in order to achieve each individual patient’s rehabilitative goals. Individualize the treatment for each patient’s pathologies and make rehabilitation fun and exciting.

CONCLUSIONS

The shoulder must be considered a kinetic chain made up of several joints. The normal function of the scapula and surrounding musculature is vital to the overall normal function of the shoulder. Rotator cuff strengthening has been an obvious treatment for various pathologies. Since the origins of the rotator cuff muscles arise from the scapula, an effective exercise regime for rehabilitation should include improving the strength and function of the muscles that control the position of the scapula. Weakness of these anchoring muscles may lead to altered biomechanics of the glenohumeral joint, with resultant excessive stress imparted to the rotator cuff and anterior capsule. Advancements in the knowledge of biomechanics and electromyographic patterns of the shoulder have allowed us to develop strengthening exercises that maximally strengthen these “anchor” muscles.

ACKNOWLEDGMENTS

We credit the entire staff of the Lexington Clinic Sports Medicine Physical Therapy Department in Lexington, KY. Special thanks to Keith Duerler, Robin Cromwell, and John McMullen. Their expertise in scapular rehabilitation and the use of their clinic for research are greatly appreciated.

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Rehabilitation after Ligamentous and Labral Surgery of the Shoulder: Guiding Concepts

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**Objective:** To provide treatment guidelines for rehabilitation after ligamentous and labral surgery of the shoulder.

**Data Sources:** We searched Index Medicus for the last 10 years using the key words "shoulder instability," "shoulder exercises," and "shoulder surgery."

**Data Synthesis:** Detailed rehabilitation programs for patients with anterior shoulder instability reconstructions can be found in the literature, but many are based on anecdotal evidence and clinical observation. Randomized, prospective outcome studies on these rehabilitation protocols have not been performed. Therefore, we offer a performance- and criteria-based guideline for rehabilitation that is rooted in basic science, surgeons' recommendations, clinical experience, and common sense.

**Conclusions/Recommendations:** To return an athlete to the preinjury level of function, range of motion, strengthening, proprioception, and functional activities must be used judiciously, keeping healing constraints and arthrokinematics in mind.

**Key Words:** anterior instability, capsulorrhaphy, glenoid labrum

Rehabilitation for the unstable shoulder continues to evolve with the development of new surgical stabilization procedures. Unfortunately, very few prospective outcome studies have compared various surgical techniques and their subsequent comprehensive rehabilitation programs. Several reasons explain why in vivo research on this topic is limited. It is extremely difficult to design outcome studies that control a multitude of variables, such as the surgical procedures and techniques of each surgeon, the types of patients being seen, individual variations in the elasticity of connective tissue, and the ultimate return to activity. We also may not be able to extrapolate the functional outcomes of 1 surgeon and rehabilitation team to other surgeons and teams. Therefore, it is important to base any guidelines for treatment of the shoulder on the healing restraints of the surgical procedure and the biomechanics of movement that may stress the suture line and cause damage. In this case, the suture line refers to the point of attachment of the manipulated tissues that allows for decreased translation of the glenohumeral joint. By knowing the strength of the healing tissue at any given time, exercise can be judiciously progressed for a safe and efficient return to activity.

With these issues in mind, designing a rehabilitation protocol that will encompass all these variables is extremely difficult. Several questions need to be addressed before we can design a comprehensive rehabilitation program to meet the needs of most individuals after surgery for anterior instability of the shoulder. Which motions of the shoulder cause stress on the suture line? When can the suture line take maximum exercise stress? And finally, when can the suture line take the functional stress of return to activity?

HEALING RESTRAINTS

In order to answer these questions and provide appropriate rehabilitation guidelines, we must examine the healing rate of collagen tissue. Injury, or in this case surgery, to vascularized tissue initiates a series of responses collectively known as inflammation and repair. Inflammation and tissue repair processes have been studied extensively. These processes generally last from 1 to 60 days, with final maturation of collagen tissue taking as long as 360 days. The rehabilitation specialist should be able to take advantage of the body's natural healing response to ensure that the glenohumeral joint capsule heals strongly and in the direction of applied stress.

After the initial inflammatory phase of healing (1 to 3 days postsurgery), the tissue repair or proliferative phase begins (days 3 through 20). Fibroblasts begin synthesizing collagenous scar tissue at the suture line. This scar tissue begins to strengthen the plication of the capsule made by the surgeon to reduce the insufficiency in the tissue. Intramolecular and intermolecular bonds develop between the new strands of collagen, but they can be damaged by aggressive tension on the suture line. This scar tissue matures and is remodeled through gentle stresses that allow the shoulder to ultimately regain its full range of motion (ROM). In the first 3 weeks after surgery, the suture line can only handle minimal stress because of the weakness of these bonds. The rehabilitation program in this early stage of healing is designed to relieve pain and minimize inflammation, increase the endurance and strength of the scapulohumeral musculature, and prevent postoperative complications.

From days 21 through 60, the scar tissue in the glenohumeral joint capsule becomes progressively stronger and more responsive to remodeling. Thus, to have the most influence on scar tissue outcome, moderate stresses should be placed on the
suture line in the later phase of tissue repair. Ultimately, peak remodeling will occur from weeks 1 to 8.  

In addition to understanding the healing process, knowledge of the surgical procedures for anterior shoulder instability provides the rehabilitation specialist with important information. Of the multitude of surgical procedures for restoring anterior shoulder stability, most can be placed into 5 categories: open capsulorrhaphy, Bristow surgery, subscapularis transfer surgery (ie, Magnuson-Stack, Putti-Platt), arthroscopic capsulorrhaphy surgery, and thermal capsulorrhaphy (tightening of the capsule). A Bankart procedure is a repair of the glenoid labrum and is rarely performed exclusively, usually being coupled with another capsulorrhaphy procedure.

Before we review the surgical procedures and subsequent rehabilitation guidelines, let us keep a few points in mind. No scientific data suggest that a capsulorrhaphy performed in a certain fashion heals in a certain length of time in any particular patient. The theories of collagen healing can be generalized based on the basic science behind the inflammatory and tissue repair processes. These theories can be matched to various proposed protocols from the experiences of surgeons and rehabilitation specialists, and recommendations for exercise progression can be offered. Unfortunately, these guidelines are not substantiated by critical clinical research.

The progression of the exercise program is the art behind the science of rehabilitation. There are many reasons to progress slowly with stress along the suture lines. Other issues to consider include the generalized ligamentous laxity of the patient, the fixation device used, and whether the surgery was a revision of a previous reconstruction. Repeated injury or longstanding pathology can also compromise the tissues. Initial and periodic consultations with the physician regarding the patient’s program and progress are essential. This communication can provide information regarding safe limits of motion based on the surgeon’s recommendations. For example, a surgeon performing an anterior capsulorrhaphy of the shoulder in a thrower may use a surgical procedure that allows postoperative positioning in the plane of the body with the arm in 90° of external rotation and abduction. This ensures that the athlete will have the motion to throw effectively if he or she recovers successfully. In contrast, stabilization of the shoulder in a football lineman may include postoperative positioning in the plane of the scapula with 45° of external rotation. A good result for this patient does not depend on extremes of ROM. The patient’s program and progress are essential. The surgeon and rehabilitation specialist must communicate about the procedure and how much ROM will be available postoperatively to ensure that early, progressive motion does not compromise the reconstruction.

**Open Capsulorrhaphy**

Open capsulorrhaphy appears to be the gold standard for anterior shoulder stabilization, based on success rates ranging from 91% to 96% and the elimination of further subluxation or dislocation events. Generally speaking, the patient without hyperelasticity who receives a capsulorrhaphy with or without a Bankart procedure has 45° of external rotation and 90° of similar elevation in the plane of the scapula immediately postoperatively. These motions do not stress the suture line, and rehabilitation can be initiated within these ROM limitations. After 3 weeks, the soft tissue has healed enough to begin gentle active or passive stress against the suture line. Minimal stress is required at this stage to allow the tissue to heal at an adequate length and strength. At 6 weeks, the tissue should be healed enough to begin passive stretching against the suture line to obtain the ROM needed for activity. The scar should be mature enough at 12 to 16 weeks to begin most functional activities and return to sport by 24 weeks.

The patient with hyperelasticity of the connective tissue shifts the time for stretching toward 8 or 10 weeks, depending on the signs and symptoms. Some patients scar down to a greater degree and need to start stretching earlier in their rehabilitation program. The rehabilitation approach would be similar for a capsulorrhaphy with or without a Bankart repair. Rarely does a Bankart lesion exist in the absence of capsular looseness.

**Bristow Surgery**

Bristow surgery consists of the transfer of the tip of the coracoid process to the glenoid rim. It is fixed onto the anterior glenoid, and bony healing should occur by 6 weeks. Care should be taken when doing elbow curls, because the short head of the biceps and coracobrachialis are transferred with the bone plug. Because this is not a soft tissue reconstruction, active and active-assisted ROM can begin within a week or so of surgery. Light strengthening can be started as soon as tolerated. At 6 weeks, with the bone healed, these patients should be able to start more aggressive stretching and strengthening symptomatically (in other words, at this point in healing, the patient can begin to stretch as tolerated as long as progress is made without pain and inflammation). Functional return to sport can begin as early as 12 weeks but normally occurs at 16 to 24 weeks.

**Subscapularis Transfer Surgery**

In the operation devised by Magnuson and Stack, the anterior capsulomuscular wall is tightened by advancing the capsule and the tendon of the subscapularis muscle laterally on the humerus. The Putti-Platt procedure is another variation of a subscapularis transfer. The healing restraints are similar to those for capsulorrhaphy. This procedure has the disadvantage of not correcting a labral or capsular defect if present. The return of full ROM may be limited by this surgery, depending on the tightness of the subscapularis.

**Arthroscopic Capsulorrhaphy Surgery**

Arthroscopic capsulorrhaphy has been embraced by surgeons because it does not generate as much scar tissue in the surrounding tissue as its open counterpart. The open procedure uses an arthrotomy, which requires reflection of much more tissue to address the capsule. However, with the arthroscopic procedure, it is possible to stretch the suture line too quickly with early mobilization of the shoulder. The patient should be able to actively lift to 90° in the plane of the scapula early postoperatively but should avoid any concerted efforts to increase ROM until after 6 weeks. Active ROM within the safe ROM (that does not stress the suture line, as recommended by the surgeon) is allowed during the first 6 weeks. In our experience, this consists of limitations similar to those for the open procedure, but again, ROM is not pushed beyond these limits until adequate healing has occurred. If the patient is returning to heavy activities, the soft tissue needs a chance to heal well before vigorous activity is initiated, which may be as
long as 6 months after surgery. Guanche et al. compared arthroscopic versus open reconstruction of the shoulder in patients with isolated Bankart lesions. Postoperatively, they recommended only pendulum exercises and the use of a sling for all patients for the first 4 weeks. This period was followed by progressive rehabilitation, with return to full activity at 4 months. Despite this conservative approach, follow-up at 17 to 42 months revealed that 5 of 15 subjects in the arthroscopic group suffered subluxation or dislocation, compared with only 1 of 12 subjects in the open group. The authors concluded that the inability to mobilize the glenohumeral ligaments arthroscopically may lead to recurrent instability. The arthroscopic procedure is technically demanding, and the lack of a large incision belies the fact that a significant amount of work was performed inside the shoulder. This is further reason to move these patients a bit more conservatively than their open counterparts.

**Thermal Capsulorrhaphy**

Thermal capsulorrhaphy is a relatively new procedure with little research to support rehabilitation guidelines. This procedure requires the capsule to be heated, usually by laser or radiofrequency waves. Depending on the temperature rise in the tissue, the collagen denatures and shortens correspondingly. The strength of the denatured tissue and its healing restraints is still under investigation. Hayashi et al. reported that histologically, collagen and cell morphology in humans returned to normal at 7 to 38 months postsurgery (laser). No human studies have evaluated the strength of the capsule after either treatment or the ultimate fate of the shoulder capsule during the remodeling process. Slecky et al. compared human cadaver shoulder capsule tissue strength under load to failure with and without laser and found the treated tissue less likely to tear at the treated area. However, in the animal model, Schaefer et al. suggested that the biologic response of connective tissue to laser energy causes a further compromise in tissue integrity beyond that attributed to the initial effects of the laser. Although significant capsular shrinkage occurs, this tissue may stretch out over time to a length considerably greater than that noted before the procedure.

We recommend waiting 6 weeks before beginning progressive ROM activities because very few patients appear to have a loss of ROM. The glenohumeral joint should be evaluated often to ensure that no contractions are developing. Strengthening activities can be started early for all these procedures within the safe ROM. There are no suture lines to stress, but there is denatured collagen tissue that should not be stressed too soon. Ellenbecker and Mattalino recently reported on an early follow-up of 20 subjects who underwent thermal capsulorrhaphy. At 12 weeks, 4 of 20 had regained full external rotation (mean, 86.6°) and 12 patients showed a complete return of external rotation strength. These subjects all underwent arthroscopic Bankart repair and capsular shift using the Suretac fixation system (Acufex Microsurgical, Norwood, MA). The thermal procedure was then used to augment the solid fixation. Assessing these results without a comparable control group, which may have received only the thermal capsulorrhaphy without the Suretac system, is difficult. These results do appear promising, and it will be interesting to see if these subjects regain full functional external rotation, maintain stability, and return to overhead athletic activities.

**Glenoid Labrum Surgery**

Glenoid labrum injuries are associated with instability of the shoulder. The Bankart lesion of the anterior inferior labrum must be repaired for stability to be restored. Lesions of the superior labrum (SLAP), as described by Snyder et al., consist of varying degrees of injury to the labrum and the long head of the biceps attachment at the supraglenoidal tubercle. These lesions can range from fraying of the superior labrum to large bucket-handle tears and long head of the biceps avulsions.

SLAP lesions consisting of fraying or small tears can be debrided. These injuries need only symptomatic healing time. The patient can progress with ROM, strengthening, and proprioceptive activities as soon as he or she is comfortable.

Lesions requiring fixation of the labrum and biceps tendon typically need 3 weeks of protection with activity in the safe ROM. This is generally 90° of elevation in the scapular plane and 45° of external rotation. Between 3 and 6 weeks, gentle motion can begin, and at 6 weeks, more progressive activities can be added. Ultimately, these patients should be treated similarly to patients with shoulder instability, with a focus on restoring biceps strength in those patients undergoing tenodesis of the long head of the biceps. Care should be taken not to stress the long head of the biceps, just as in the Bristow surgery, because the long head of the biceps attaches to the superior labrum.

**BIOMECHANICAL RESTRAINTS**

The shoulder in the neutral position puts very little stress on the capsule. The primary restraints to anterior translation with the arm at the side are the superior and the middle glenohumeral ligaments. At 45° of abduction, the middle glenohumeral ligament acts to limit anterior translation. When the arm is elevated to 90° with the humerus in the plane of the scapula, the capsule is under little stress. It is not until the arm progresses from 90° to full elevation that the anterior band of the inferior capsule or glenohumeral ligament complex is gradually stressed.

When the arm is held posterior to the plane of the scapula, stress on the anterior capsule increases the further the arm moves into horizontal abduction. If external rotation of the arm is added to this movement, even more stress is placed on the anterior capsule.

After a surgical procedure to prevent excessive anterior translation, exercises in the plane of the scapula, unless performed far overhead, put little stress on the suture line. As the tissue heals, gradual stress can be applied as the patient exercises into external rotation and posterior to the plane of the scapula. Generally speaking, exercises should be in the plane of the scapula until sufficient healing has occurred, which is close to 6 weeks postoperatively.

**EXERCISES**

Once static stability has been restored with surgery, the rehabilitation program assists in the restoration of motion and dynamic stability of the glenohumeral joint. One only has to see a patient with a flair shoulder caused by a cerebrovascular accident to realize the role that muscles play not only in the movement of the shoulder but also in the stability of the glenohumeral joint. Positioning and stabilization of the scapula provide a stable base for humeral movement. This stable base...
allows the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis), the deltoid, and the long head of the biceps brachii to provide dynamic stability to the glenohumeral joint. 19

ROM exercises that do not stress the suture line can be instituted soon after surgery. Passive or active forward elevation, or both, from 90° and up to 135° in some patients, can be started soon after surgery. Exercises involving external rotation and horizontal abduction place the greatest stresses on the healing tissues and may need to be modified based on healing and the surgical technique. With early, safe movement, shoulder joint adhesions should be kept to a minimum. Grade III and IV joint-mobilization activities can be used after a minimum of 6 weeks, if necessary, to increase joint mobility. ROM activities can be performed 5 to 10 times each, 3 to 5 times per day, and held for 30 seconds.

Resistance exercises for the shoulder girdle musculature can be instituted in the protective phase of rehabilitation, with the emphasis on the scapular muscles. Mosley et al20 demonstrated the best exercises for positioning and stabilizing the scapula (Figures 1-4). Townsend et al21 concluded that the exercises in Figures 3 and 5 should be included in a core-strengthening program for the shoulder in overhead athletes. Blackburn et al22 described the best exercises to stimulate the posterior rotator cuff (Figures 5, 6). In contrast to Blackburn et al, Townsend et al21 reported increased electromyographic output in the shoulder musculature with scaption in internal rotation in the sitting or standing position. We prefer to use prone horizontal abduction with external rotation in lieu of the above recommendation. When attempting to strengthen a weak rotator cuff, elevation of the arm in scaption with internal rotation may allow the humeral head to migrate superiorly and impinge on the very musculature being exercised. Ultimately, the key to using these exercises is to be able to modify the positions to
exercise in the allowable ROM early in the postoperative period. This would mean that the humerus would be kept in the plane of the scapula or more anterior and that the glenohumeral joint would not be externally rotated past the point the surgeon deemed safe for the healing tissue. Strengthening exercises can be performed in 3 to 5 sets of 10 repetitions, once or twice per day. Weights can be progressed to 2.27 kg (5 lb) as tolerated. Exercise tools for resistance can be in the form of dumbbell or wrist weights, rubber tubing, or other convenient materials. Isometric exercises for the shoulder girdle are provided for the home program and are performed 2 to 3 times per day, for 2 to 3 sets of 10 repetitions, with 6-second holds in each direction. These include flexion, abduction, adduction, extension, and internal and external rotation, using submaximal pressure and with the extremity at the side.

Progression to weight machines occurs when the patient’s ROM can be comfortably accommodated and the rotator cuff is strong enough to stabilize the glenohumeral joint. The weight machine’s positioning of the patient should not violate the safe ROM or the healing time frames. For example, many older “pec deck” machines put the patient’s shoulders in extreme horizontal abduction. This position can be detrimental to the unstable shoulder at any time and to the postoperative shoulder in the first 3 to 4 months after surgery. Newer “rehabilitation” weight machines have adjustable lever arms and small increments of weight that suit the postoperative patient. With suitable ROM, 4–5/5 manual muscle tests of the shoulder, and no other symptoms, we allow the patient to progress to weight machine work. If possible, weight increments are 0.91 kg (2 lb), with 10 repetitions, in 3 to 5 sets. Progression should be slow.

Hand placement and depth on the bench and incline press should be more narrow than normal to prevent stress on the anterior capsule when the weight is lowered, and the elbow should not be allowed past the plane of the body. This is true for push-ups and shoulder dips. These guidelines should be followed for up to 4 months postoperatively.

Lephart et al described the loss of proprioception when instability is present in the shoulder. Proprioceptive training
allows for coordinated input from all the muscles about the shoulder girdle. These activities can start as early as the first week postoperatively and include gentle partial weightbearing (leaning into a wall or table), rhythmical stabilization24 (Figures 7, 8), and scapular proprioceptive neuromuscular facilitation.24 In the conservative management of the unstable shoulder, Wilk and Arrigo19 stated that weight shifts can be used early and safely in the rehabilitation program to enhance dynamic stability of the shoulder without placing the surgical procedure at risk. The patient can control the amount of weightbearing through the use of the uninvolved upper extremity and the lower extremities. Rhythmical stabilization is performed at 90° of flexion with submaximal manual resistance placed on the upper arm toward all planes of movement. This technique can also be performed for internal and external rotation at 45° of abduction in the scapular plane. To increase the proprioceptive input and difficulty, the patient is asked to close the eyes during the exercise. Scapular proprioceptive neuromuscular facilitation with manual resistance can be implemented at the first postoperative session, with full diagonal patterns used after 6 weeks. Various oscillating tools, weighted ball tosses with the Plyoback (AliMed Inc, Dedham, MA), neuromuscular training devices, and heavy weightbearing activities (Figures 9-12) can be added in the restrictive,
### Table 1. Phase I, Weeks 0 to 3: Protective

<table>
<thead>
<tr>
<th>Goals</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain and swelling control</td>
<td>Cryotherapy, electrical stimulation</td>
</tr>
<tr>
<td>Mobilization (safe range of motion [ROM]) (10 to 25 repetitions, 2 to 3 times per day)</td>
<td>Grade I, II mobilizations</td>
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<tr>
<td></td>
<td>Sling for comfort for up to 3 weeks</td>
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<td></td>
<td>Passive forward elevation in plane of scapula by 2 days with physician-set limitations</td>
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<tr>
<td></td>
<td>Passive external rotation (ER) in plane of scapula (POS) at abduction (ABD) and ER with physician-set limitations</td>
</tr>
<tr>
<td></td>
<td>Pendulum</td>
</tr>
<tr>
<td></td>
<td>Progress to active ROM in all motions</td>
</tr>
<tr>
<td>Strength (safe ROM) (3 to 5 x 10 repetitions, 2 times per day) (0 to 2.27 kg [5 lb])</td>
<td>Begin with isometrics for flexion, adduction (ADD), ABD, extension (EXT), internal rotation (IR), and ER</td>
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<tr>
<td></td>
<td>Grip strengthening</td>
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<tr>
<td></td>
<td>Wrist curls and extensions</td>
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<tr>
<td></td>
<td>Elbow curls and extensions</td>
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<tr>
<td></td>
<td>Shoulder shrugs with scapular ADD (retraction)</td>
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<td></td>
<td>Bent row (Figure 4)</td>
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<td></td>
<td>Scaption (Figure 1)</td>
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<tr>
<td></td>
<td>Nonweightbearing push-up with plus (Figure 2)</td>
</tr>
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<td></td>
<td>Seated press-up (Figure 3)</td>
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<td></td>
<td>Modified prone horizontal abduction (Figure 5)</td>
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<td></td>
<td>Side-lying ER</td>
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<td></td>
<td>Modified prone 90°–90° ER (Figure 6)</td>
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<td></td>
<td>Arm at side in IR</td>
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<tr>
<td>Proprioception (safe ROM) (10 to 25 repetitions, once per day)</td>
<td>Rhythmical stabilization (Figure 7)</td>
</tr>
<tr>
<td></td>
<td>Weight shifts (progress wall to table) (Figure 8)</td>
</tr>
<tr>
<td></td>
<td>Oscillations (Boing [Boing Ltd, Bristol, UK], Bodyblade [Fitter International Inc, Calgary, Alberta, Canada] or tubing)</td>
</tr>
<tr>
<td>Cardiovascular fitness (30 to 60 minutes, 3 to 5 times per week)</td>
<td>Bicycle</td>
</tr>
<tr>
<td></td>
<td>Stepper</td>
</tr>
<tr>
<td></td>
<td>Walk</td>
</tr>
</tbody>
</table>

As the athlete moves to the active phase of rehabilitation, proprioceptive training may take the form of open and closed chain activities. Various pieces of equipment, such as inflatable balls and discs, are also available for this training. Progression of proprioceptive exercises is symptom and healing related. Proprioception activities can be performed daily in 3 sets of 15 repetitions, or for time, 5 repetitions in 15 to 30 seconds.

### Table 2. Phase 2, Weeks 3 to 6: Restrictive

<table>
<thead>
<tr>
<th>Goals</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>Active ROM against suture line in all directions</td>
</tr>
<tr>
<td>Passive ROM* and active ROM</td>
<td>Progress exercises in Table I through available ROM</td>
</tr>
<tr>
<td>60°–90° ER†</td>
<td>Add weight as tolerated</td>
</tr>
<tr>
<td>45°–60° IR†</td>
<td>Progress intensity of activities in Table I in available ROM</td>
</tr>
<tr>
<td>135°–155° ABD§</td>
<td>No restrictions; progress as tolerated</td>
</tr>
<tr>
<td>135°–165° scaption</td>
<td></td>
</tr>
<tr>
<td>Strength 3+ to 4/5 manually</td>
<td></td>
</tr>
<tr>
<td>Proprioception 30% or less difference between injured and noninjured sides</td>
<td></td>
</tr>
<tr>
<td>Activities of daily living</td>
<td></td>
</tr>
<tr>
<td>All sedentary activities of daily living</td>
<td></td>
</tr>
</tbody>
</table>

*ROM, range of motion.
†ER, external rotation.
‡IR, internal rotation.
§ABD, abduction.

progressed to velocity-spectrum programs, which run from 180° to 300°·s⁻¹. At the end of the active phase, isokinetic testing of the internal and external rotators can be performed at 180° and 300°·s⁻¹. If the athlete demonstrates less than 15% deficits in strength and endurance of the rotator cuff, a functional progression to sport can begin. This marks the beginning of phase IV. Functional drills for football and wrestling athletes after anterior stabilization procedures include modified and traditional push-ups with bilateral and unilateral support.25 Tippett and Voight25 recommended the 1-armed spin as another functional exercise that can also be
Table 3. Phase III, Weeks 6 to 12: Active

<table>
<thead>
<tr>
<th>Goals</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization&lt;br&gt;Passive ROM* and active ROM&lt;br&gt;90°+ ER†&lt;br&gt;Full IR†&lt;br&gt;160°-180° ABD</td>
<td>Gradually increase passive ROM stretching&lt;br&gt;Grade III–IV mobilization techniques&lt;br&gt;Wand&lt;br&gt;Overhead pulley</td>
</tr>
<tr>
<td>Strength&lt;br&gt;4–4+/5 manually&lt;br&gt;15% or less differences isokinetically</td>
<td>Progress above exercise weights to 2.27 kg (5 lb)&lt;br&gt;Progress to weight machines&lt;br&gt;Bench press&lt;br&gt;Military press&lt;br&gt;Seated row&lt;br&gt;Latissimus dorsi pull-down&lt;br&gt;Biceps&lt;br&gt;Triceps</td>
</tr>
<tr>
<td>Proprioception&lt;br&gt;15% or less differences</td>
<td>Progress to full weightbearing on closed chain proprioceptive activities (Figures 11,12)&lt;br&gt;Progress open and closed chain proprioceptive exercises closer to end range (Figure 10)</td>
</tr>
<tr>
<td>Function&lt;br&gt;Light, nonrepetitious overhead activity&lt;br&gt;Light lifting</td>
<td>Activities of daily living as tolerated&lt;br&gt;No sports activities</td>
</tr>
</tbody>
</table>

*ROM, range of motion.<br>†ER, external rotation.<br>†IR, internal rotation.

The overhead athlete, plyometric drills with surgical tubing, medicine balls, or weighted balls and the Plyoback can be performed as part of a functional progression. Some of these activities include exercise tubing plyometrics for external and internal rotation at 90° of abduction, 2-handed chest pass, overhead and diagonal ball tosses, and 1-handed overhead baseball throws.19 In the overhead athlete, the functional progression will lead to an interval throwing program, and ultimately, return to sport at approximately 6 months postoperatively.26

Table 4. Phase IV, Weeks 12 to 24: Functional

<table>
<thead>
<tr>
<th>Goals</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization&lt;br&gt;Passive and active ROM*&lt;br&gt;Obtain full or sufficient ROM to perform sport</td>
<td>Progressive passive and active ROM&lt;br&gt;Continue weight machines&lt;br&gt;Military press&lt;br&gt;Bench press&lt;br&gt;Incline press&lt;br&gt;Rows&lt;br&gt;Flys&lt;br&gt;Plyoback&lt;br&gt;Bodyblade&lt;br&gt;Plyoback&lt;br&gt;Gymnastics&lt;br&gt;Begin return to football activities&lt;br&gt;Begin return to baseball activities&lt;br&gt;Begin return to overhand activities</td>
</tr>
<tr>
<td>Strength&lt;br&gt;5/5 manual muscle testing&lt;br&gt;&lt;10% isokinetic strength difference</td>
<td>Progress to free weights&lt;br&gt;Military press&lt;br&gt;Bench press&lt;br&gt;Incline press&lt;br&gt;Rows&lt;br&gt;Flys&lt;br&gt;Bodyblade&lt;br&gt;Plyoback&lt;br&gt;Gymnastics&lt;br&gt;Begin return to football activities&lt;br&gt;Begin return to baseball activities&lt;br&gt;Begin return to overhand activities</td>
</tr>
<tr>
<td>Proprioception&lt;br&gt;&lt;10% proprioception difference</td>
<td>Weightbearing on unstable surfaces&lt;br&gt;Bodyblade&lt;br&gt;Plyoback&lt;br&gt;Gymnastics&lt;br&gt;Begin return to football activities&lt;br&gt;Begin return to baseball activities&lt;br&gt;Begin return to overhand activities</td>
</tr>
<tr>
<td>Function&lt;br&gt;Gradually progress to functional activities</td>
<td>Light, nonrepetitious overhead activity&lt;br&gt;Light lifting</td>
</tr>
</tbody>
</table>

*ROM, range of motion.

Postoperative Management

Because the healing response of the tissues and the patient’s progress toward particular performance criteria determine the rehabilitation progression, we have created phases of rehabilitation based on 3-week increments. The time frames in these guidelines are loosely applied and should not be construed as a time-based protocol. Obviously, variations are individualized for each patient. The surgeon may have specific items to add to the patient’s program based on information from surgery, and consultation should be ongoing. Tables 1 through 4 outline general rehabilitation guidelines after shoulder reconstruction for anterior instability or glenoid labrum tear. These guidelines may not be appropriate for those with extreme instability or hyperelasticity or those having undergone thermal capsulorhaphy or repeat shoulder reconstruction.

SUMMARY

Although no published formal outcome studies exist for postoperative patients who have undergone shoulder stabilization techniques or glenoid labrum repairs, some science supports a progressive ROM and strengthening rehabilitation program. The rehabilitation specialist must combine the basic science of healing with the biomechanics for each type of surgical procedure to begin a rehabilitation program that will not overstress the suture line. Implementing effective exercises for the shoulder girdle musculature complements proprioceptive and functional activities. No single protocol can satisfy every patient, but a performance- and criteria-based progression, combined with the surgeon’s input, allows each patient to reach his or her top functional level.

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Aquatic-Based Rehabilitation and Training for the Shoulder

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Objective: To describe the application of aquatic rehabilitative exercise to injuries of the upper extremity.

Background: Water has been used for centuries as a medium for rehabilitation, relaxation, and training. Athletes use the pool to rehabilitate specific injuries, as a training medium during injury recovery, and as an alternative training site. The pool can be used to rehabilitate a number of upper extremity impairments, as well as to restore functional movement patterns in a resistive medium.

Description: Exercises can be modified to be performed in pools of varying size and depth. Well-chosen equipment will enhance the rehabilitative opportunities for the clinician and patient.

Clinical Advantages: All aspects of the rehabilitation program, including passive stretching, resistive exercise, functional movement patterns, and cardiovascular training, can take place in the same location. The water’s warmth and buoyancy enhance stretching, while the buoyancy allows initiation of resistive exercise at a low level. The water’s viscosity provides resistance throughout a movement pattern in any plane.

Key Words: upper extremity, athlete, water

The use of water for rehabilitation spans centuries.1 Spas flourished in Europe as knowledge of the healing properties of water grew. However, it was not until the past few decades that clinicians have discovered use of a water-based program to be of great benefit to patients.

Athletes of all ages enjoy engaging in sporting events and activities. Children and adolescents participate on youth sports teams, while adults enjoy events such as running races, triathlons, and adult sport leagues. Master’s-level athletes are continuing to compete well into the sixth and seventh decades of life. Because athletes are training harder, competing more often, and taking less time to taper off, they are prone to overuse injuries. These injuries, such as tendinitis, bursitis, and stress fractures, often require temporary rest from their sport or training. Research has shown that 3 weeks of inactivity can lead to a significant loss of cardiovascular fitness, and 6 weeks of rest can lead to a decrease of as much as 14% to 16% in maximal oxygen consumption.2-4 Because of these losses, athletes may seek an alternative training medium, and many athletes have found a water-based program to be beneficial during their recovery. They can regain mobility and strength and maintain or improve cardiovascular endurance, all while “resting” their injury.

Our purpose is to discuss aquatic-based rehabilitation and training for upper extremity injuries. The physical properties of water will be reviewed, and upper extremity and core body-strengthening exercises will be discussed, along with cardiovascular training programs incorporating upper extremity movement patterns.

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PHYSICAL PROPERTIES OF WATER

The physical properties of water are the basis for its creative uses in rehabilitation. An understanding of these properties will provide the clinician with the theoretical basis for determining position in the water, direction of movement, and type of equipment used. However, this is only a brief overview of these properties; greater detail can be found in other resources.1,5

Buoyancy

Archimedes’ principle of buoyancy states that a body partially or completely immersed in a fluid experiences an upward thrust equal to the weight of the fluid that was displaced. Buoyancy is defined as the upward thrust acting in the opposite direction of gravity and is related to the specific gravity of the immersed object.6 Specific gravity is the ratio of the mass of 1 substance to the mass of the same value of water.6 Therefore, by definition, the specific gravity of water is 1.0, and any body with a specific gravity of less than 1.0 floats. Average specific gravity values for the human body range from 0.97 to 0.95; thus, most humans float.7

Despite their specific gravity, many individuals have difficulty floating due to their body composition and body fat distribution. They may rest just below the water’s surface, or their legs may sink while the trunk remains at the surface. This is of particular importance in treating the athlete, who may be very lean. Athletes rehabilitating shoulder injuries in an overhead position may need to be prone or supine. Buoyant equipment may be necessary on the trunk or at various points along the limb to maintain equilibrium in the pool.

Buoyancy can be used in rehabilitation as assistance, support, or resistance. Assisted exercise occurs when movements are in an upward direction, toward the surface of the water. These exercises are commonly used to increase mobility, such as when allowing the arm to passively abduct toward the
Buoyancy-supported exercises are perpendicular to the upward thrust of buoyancy and parallel to the bottom of the pool. Typically, the limb floats just below the surface of the water, but this depends on the limb’s density and whether a flotation device is used. Examples of buoyancy-supported exercise include horizontal abduction and adduction of the shoulder with the athlete standing.

Buoyancy-resisted exercises are performed toward the bottom of the pool, directly opposing the upward thrust of buoyancy. Some important issues must be considered when using buoyancy as resistance. First, as with weight training on land, the amount of buoyant equipment and the position relative to buoyancy determine the muscle contraction type. Shoulder abduction in a standing position can be buoyancy assisted if little or no buoyancy is used and the speed is slow. Performing the same activity with a large, buoyant bell results in an eccentric contraction of the shoulder adductors. Similarly, buoyancy-resisted shoulder extension is performed standing in 90° of shoulder flexion and extending the shoulder to neutral (Figure 1A). The shoulder extension becomes buoyancy assisted as the shoulder passes neutral (Figure 1B).

A second issue is the speed of movement. Although buoyancy-assisted, -supported, and -resisted activities seem intuitively obvious, the buoyancy component can be overridden by viscosity if the exercise occurs fast enough. For example, shoulder horizontal abduction and adduction is a buoyancy-supported exercise, and shoulder abduction is technically a buoyancy-assisted exercise, but these exercises can still be resistive if they are performed quickly enough to encounter resistance from the water’s viscosity.

Finally, the previous example of buoyancy-supported exercise should provide insight into the change in mechanics from land-based exercise. Consider the above example of buoyancy-supported shoulder horizontal abduction. Frontal-plane abduction is assisted, while horizontal abduction is neither assisted nor resisted by buoyancy. That is, the athlete no longer has to hold the arm abducted against gravity while performing the horizontal component of the exercise. Horizontal abduction exercises in the pool do not require the same shoulder abductor work as the equivocal exercise on land due to the support of buoyancy and the negation of gravity. Fujisawa et al found that exercises performed at 90° of abduction in the water were associated with significantly less electromyographic activity than land-based exercise. Thus, exercises can be started at a lower level in the pool, and progression to land-based activity requires reintegration of land-based rehabilitative exercises.

Hydrostatic Pressure

Pascal’s law states that at any given depth, the pressure from the liquid is exerted equally on all surfaces of the immersed object. As the density and depth of the liquid increase, so does the volume of liquid overhead and, therefore, the hydrostatic pressure. As such, hydrostatic pressure may be used in rehabilitation to reduce effusion or to allow the athlete to exercise an injured extremity without increasing the effusion. Hydrostatic pressure is also responsible for the cardiovascular changes seen with immersion and has a significant impact on exercise training parameters.

Viscosity

Viscosity is defined as the friction occurring between individual molecules in a liquid, which causes resistance to flow. Viscosity is only noticeable when there is motion through the liquid, and it acts as resistance to movement because the liquid molecules adhere to the surface of the body. Because water is more viscous than air, most movement in the water is resisted regardless of buoyancy. Viscosity provides the most common form of resistance training.

Fluid Dynamics

Two different types of water flow exist: laminar flow and turbulent flow. Laminar flow, defined as the smooth flow of water molecules, carries the least amount of resistance because the water molecules are all traveling the same direction and speed. Turbulent flow is interrupted flow, as when laminar flow encounters an object, causing water molecules to rebound in all directions. Turbulent flow can be visualized as the white water and air bubbles next to the skin when a body is moving through water. Equipment choices and body positioning affect turbulent flow. A tapered object causes laminar flow, while an untapered object creates turbulent flow. Turbulent flow produces the resistance used in rehabilitation. Performing internal and external shoulder rotation with the elbows at the side and palms down (forearms pronated) is an example of a tapered object producing laminar flow. This exercise produces little resistance compared with the same exercise when the palms face each other (neutral forearm position), where a great deal
of turbulence is created. The concept of employing surface area to increase turbulence is the basis for using gloves, paddles, and other types of equipment.

Drag is a force caused by fluid viscosity and turbulence. As an object moves through the water, a difference in pressure builds up, with higher pressure in front and lower pressure in back. The eddies formed in the wake tend to cause a force dragging the object back. The faster the movement, the greater the drag and the greater resistance to movement. As movement increases, the drag force increases as the square of the velocity.5

Muscle contraction type is a key consideration when designing an exercise program with increasing resistance based on viscosity. Exercises performed against the water’s resistance almost always elicit concentric muscle contractions. Consider performing the above-shoulder internal and external rotation exercise: the movements elicit reciprocal concentric contractions of the rotator cuff muscles. Eccentric muscle contractions are most easily elicited using large, buoyant objects. Additionally, rapid, alternating movements can generate eccentric contractions as the muscle attempts to slow the limb for the change in direction. High-speed, short range-of-motion exercises are generally required because of the water’s viscosity.

The resistance to an exercise can be increased using viscosity in 2 ways. First, increasing the surface area by use of gloves, paddles, or other equipment increases the resistance significantly. Second, increasing the speed of exercise increases the turbulent flow, thus increasing resistance.

PHYSIOLOGIC RESPONSES TO AQUATIC EXERCISE

Physiologic Responses of Water Immersion

When humans are immersed in water, physiologic changes occur, both at rest and during exercise. The clinician must be aware of these differences in order to modify training programs appropriately. Changes that occur at rest during water immersion are the result of hydrostatic pressure and include, most importantly, a cephalad redistribution of blood flow.10 Right atrial venous pressure increases, which results in a Frank Starling reflex and a subsequent increase in stroke volume (SV).10-15 Both SV and cardiac output (CO) increase, while heart rate (HR) decreases or remains unchanged, via the equation HR X SV = CO. Changes in heart rate are related to the water’s depth, position of the athlete in the water, and exercise efficiency (Table 1). Hormonal changes and diuresis have been observed with sustained periods of water immersion.16-20 Additionally, the hydrostatic pressure on the chest challenges chest expansion and may be problematic for individuals with reduced lung capacity, breathing difficulties, or general fear of the water.

Because of the cardiovascular changes due to immersion and the impact of skill on the cardiovascular response to exercise, the training heart rate should be established in the pool, rather than attempting to apply land-based heart rates to pool exercise.51 In general, heart rates during deep-water exercise are approximately 17 beats per minute lower than during comparable exercise on land.52

Warm water can also place an additional burden on the cardiovascular system as it attempts to prevent overheating. Intense training of athletes should take place in water between 27°C and 28°C (81°F and 83°F) to prevent any heat-related complications. However, for simple rehabilitation exercises that are not cardiovascularly demanding, athletes can safely exercise at 33°C to 34°C (91°F to 93°F).

REHABILITATION

Upper Extremity Training

Impaired Mobility. Mobility may be impaired after an injury such as an elbow or glenohumeral dislocation or after surgery. Impaired mobility can also result from the pain of overuse injuries such as tendinitis or impingement. This impaired mobility may present as altered biomechanics, and a goal of rehabilitation is to restore normal osteokinematics and joint arthrokinematics. The pool is an ideal place to improve shoulder mobility, as the functional upward movement of the glenohumeral joint is assisted by buoyancy. As such, the athlete may discover that normal movement patterns occur earlier in the pool than in a gravity environment. This movement is similar to active-assisted range of motion on dry land, but the buoyancy of the water now supports the injured extremity, instead of having the limb supported by a pulley, wand, or clinician, as would be the case on land. The athlete is able to position himself or herself in a sport-specific position, thereby allowing familiar muscle length-tension relationships to occur throughout the upper extremity and trunk. Buoyant equipment may assist the movement initially and can be discontinued as active and resistive range-of-motion exercises are initiated.

Increasing mobility above shoulder level can be problematic in the pool. Mobility exercises above 90° require exercise to be performed supine for abduction and prone or standing bent forward at the waist for flexion (Figure 2). Performing exercise

Table 1. Cardiovascular Responses to Immersion at Rest1,5,6,8,9,16,19,21

<table>
<thead>
<tr>
<th>Measure</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right atrial venous pressure</td>
<td>Increase (8 to 12 mm Hg)</td>
</tr>
<tr>
<td>Heart blood volume</td>
<td>Increase (180 to 250 mL)</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>Increase (25% of baseline)</td>
</tr>
<tr>
<td>Stroke volume</td>
<td>Increase (25% of baseline)</td>
</tr>
<tr>
<td>Central venous pressure</td>
<td>Increase</td>
</tr>
<tr>
<td>Heart rate</td>
<td>Remain the same or decrease slightly</td>
</tr>
<tr>
<td>Systemic blood pressure</td>
<td>Remain the same or increase slightly</td>
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Figure 2. Overhead shoulder flexion can be obtained by having the athlete flex at the trunk in waist-deep water.
prone or supine requires that the athlete is comfortable floating in the water and able to regain a standing position independently for safety purposes. For the athlete who is comfortable floating on the stomach or back, exercises holding onto the edge, railing, ladder, or buoyant equipment support the arm in an overhead position. For those comfortable in the water in the prone position, a mask and snorkel can be used for breathing while the arm is in a fully overhead position. Buoyant equipment may be necessary on the trunk or thighs, or both, to maintain this position. Pools designed specifically for rehabilitation often have a variety of railings and bars that can be used for stretching in a variety of positions. These exercises can be progressed from active range of motion to prolonged stretching.

The athlete may perform any or all of the stretching routine in the water. A warm-water pool provides an environment that may allow for increased soft tissue extensibility, as muscles may relax in a warm environment. Although a warm-water pool provides only superficial heat, temperature has been found to have a profound effect on the properties of collagen. Additionally, because buoyancy supports the arm and makes the activity passive, water makes stretching easier to perform and optimal positions easier to maintain (Figure 3). A pool designed with railings along 1 wall or appropriate gutters or ladders provides a variety of opportunities to stretch in different positions.

Impaired Muscle Performance. Muscle performance may be impaired due to acute or chronic injuries, surgery, or pain for any reason. For those with an inability to elevate the arm against gravity, the upward assistance of buoyancy provides an opportunity for early intervention. Pool exercises can be progressed from assistive to resistive.

Traditional land-based, open-chain, cardinal-plane, shoulder-strengthening exercises such as flexion and abduction can be adapted to the pool. Also, combination patterns such as proprioceptive neuromuscular facilitation (PNF) diagonals can be used. As mentioned earlier, potential problems with some of these types of upper extremity exercises exist: 1) resistive exercise can be performed only through a partial range of motion in a standing position, and 2) the mechanics are different for some exercises compared with their land-based counterparts. The range-of-motion issue can be addressed with a few modifications, but the change in mechanics is more challenging.

Overhead activity can be performed using several techniques. Resistive tubing can be used in the pool as it is on land. Although performing this type of exercise in the pool provides little additional benefit, it can be incorporated as part of a total training program that is performed in 1 location. For example, an athlete can practice the throwing motion while standing using resistive bands. If lower extremity movements are incorporated, the water provides core body resistance while the band resists arm movement (Figure 4). A second modification is to perform the exercise supine, prone using a snorkel, or standing forward flexed in shallow water with the face out of the water.

Another benefit of water-based, open-chain, upper extremity exercise is the trunk muscle cocontraction that occurs. Arm movement through the water tends to promote balance and stability. Thus, simple, open-chain arm exercises such as bilateral shoulder flexion and extension or bilateral PNF diagonals also serve simultaneously as trunk-stabilization exercises.

When performing open-chain, upper extremity training, equipment such as gloves, paddles, or resistive bells can be used to increase resistance. Resistive boards can be held underwater in front of the athlete to perform a push-pull motion for scapular protraction and retraction to strengthen the rhomboids, trapezius, and serratus anterior. Additionally, sport-specific equipment can be used in the aquatic rehabilitation program. The baseball player can use an old bat to reproduce the swinging motion, while the tennis player can practice the forehand and backhand with an old racket or various pieces of aquatic equipment (Figure 5). The clinician should realize that a small increase in equipment surface area in the upper extremity translates into a significant increase in resistance.

Many shoulder rehabilitation exercises can be performed in the prone position and a few in the supine position. The prone position tends to be more functional, as the position of most arm activities is forward; in this case, toward the bottom of the pool. PNF diagonals or cardinal-plane (flexion, horizontal...
Figure 4. Resistive tubing can be used to train the throwing motion while challenging trunk balance in shallow water.

Figure 5. Sport-specific activities such as the tennis swing can be duplicated using aquatic equipment.

adduction, etc) exercises are buoyancy resisted toward the pool's bottom. Resistance can be added via buoyant or surface area-increasing equipment. Prone resistive exercises, especially those extending from a fully flexed position at the shoulder, are quite challenging because of the resistance of buoyancy and the decreased length-tension relationships of the muscles. To lessen the challenge, the athlete can shorten the levers (ie, bend the elbows), and use a "wrist-neutral" position with movement to decrease surface area with the hand. Moreover, because the athlete is free floating and not stabilized on the pool's bottom, these exercises require a great deal of trunk stabilization.

Stabilization exercises can be performed in both open-chain and closed-chain positions. A variety of resistive and stabilization activities can be performed in provocative positions. Supine, with the arms abducted to 135°, shoulder flexion and extension can be rapidly alternated through a small range of motion in the water. Similarly, shoulder internal and external rotation can be rapidly alternated at 90° of abduction (Figure 6). Both of these exercises are effective in athletes with shoulder instability, as they require neuromuscular input for stabilization of the upper quarter. Elite athletes can perform sets of 30 to 50 repetitions or to fatigue.

Athletes who perform sports requiring closed kinetic chain movements and those who need enhanced proprioception and stability can benefit from closed-chain exercises. Examples are dips at the side of the pool, pull-ups using a ladder or other apparatus, and overhead push-pulls in the supine or prone position. Activities can be performed in the push-up position in very shallow water or using benches, stools, or stepping blocks. Floating in a prone position, the athlete can press flotation equipment toward the bottom with 1 or both hands. This exercise will challenge balance and proprioception as well.

An excellent but often overlooked upper extremity training technique is swimming. Not only does it train the upper extremity, but it also provides cardiovascular benefits, neuromuscular coordination, and stretching and elongation through the legs, trunk, and upper extremities. A snorkel may improve the skill of those individuals with adequate swimming technique who have difficulty coordinating their breathing. Backstroke swimming negates the breathing obstacles, produces elongation through the body, and provides resistance to the neck, back, and leg extensor muscles. Remember that the athlete need not necessarily swim for 25 minutes for the training session; the swimming may be just 1 component of an interval program. For example, an athlete performing intervals may complement deep-water running (working the hip and knee flexor muscles) with backstroke swimming (working the extensor muscles).

**Impaired Proprioception.** Most of the previously described exercises can also serve as proprioceptive exercises if the exercise technique is modified. Because the effects of gravity are minimized with immersion, the proprioceptive input from the force of gravity is negated. Thus, the pool is an ideal medium to retrain this sense. Active-repositioning exercises can be performed in a variety of positions. Many of the shoulder- and core-stabilization exercises constitute exceptional proprioceptive exercises if the visual cues are removed.

Figure 6. Rapid, alternating shoulder internal and external rotation at 90° of abduction while supine is a dynamic-stabilization exercise safely performed in the pool.
The athlete is asked to perform these exercises with the eyes closed and in a variety of postures and positions.

Cardiovascular Training

Using a pool for training, the athlete’s goal of maintaining or improving cardiovascular function can be achieved while resting an injury. Because of the physiologic changes occurring with immersion, the athlete should train at a heart rate 17 to 20 beats per minute lower than on land. The rate of perceived exertion is often unreliable due to the effects of skill and comfort on perceived exertion.

As with any exercise session, an appropriate warm-up and cool down are essential. These should be performed in the pool and may consist of walking, bicycling, or performing calisthenics in the water, followed by stretching. A variety of cardiovascular exercises can be performed and may replicate a movement pattern used in the sport or challenge muscles specific to the sport. Deep-water running and cross-country skiing can be performed with the athlete tethered to the side of the pool or free floating. Both of these activities contain an upper extremity component that can be emphasized through interval work, the use of gloves, or both. When teaching deep-water running, have the athlete “run off the bottom” of the shallow end into the deep end, trying to maintain form. Once the feet leave the bottom, some forward progress will be made because of slight forward lean, but excessive lean, which begins to mimic a swimming stroke, should be avoided. Optimal performed deep-water running requires minimal range of motion at the shoulders and a large range of hip and knee motion. Of course, the technique may be modified as needed for special circumstances.

Cross-country skiing in the pool is an excellent cardiovascular training tool, emphasizing leg, trunk, and shoulder flexion and extension. Both the shoulders and the hips move through a large range of motion, making this activity ideal in sports with such requirements. Significant movement at the glenohumeral joint occurs with cross-country skiing. With the elbows extended, the arms create long levers, which offer a great deal of resistance. The shoulders can be moved slowly through a large range of motion or quickly through a short range of motion, depending upon the specific rehabilitation goals. Unlike deep-water running, in which the knees go through a large range of motion, the knees stay relatively straight throughout the cross-country ski motion, and motion occurs primarily at the hips. Again, the technique can be modified based upon the athlete’s specific needs. The novice cross-country skier should start with smaller arm and leg movements, emphasizing a neutral pelvis and stability of the core musculature. As the athlete’s technique improves, extremity range of motion is increased, and equipment can be added to enhance surface area.

Once the athlete has mastered these cardiovascular training techniques, more advanced techniques, such as vertical kicking, can be incorporated. Vertical kicking can be performed with or without fins and should be initiated with a small flutter kick. Once this technique is mastered, a dolphin kick can be added, although the clinician should keep in mind that it requires a high level of dynamic lumbar control. Kicking can be performed without arm assistance, with the arms held behind the back, or with the hands out of the water. Other arm motions can be added (ie, scaption, internal and external rotation, horizontal abduction and adduction) depending on the athlete’s sport and injury. Any upward motion of the arms (as in flexion, abduction, or scaption) causes a downward movement of the athlete’s body, increasing the challenge of the kicking exercise. This training technique is particularly effective for those athletes needing trunk stabilization or performing rapid movements in a small range of motion.

Flotation vests may be used when teaching the athlete a deep-water technique or if safety is a concern. When possible, the vest should be removed to increase the difficulty of the workout. When choosing a belt or vest, it is prudent to assess the device for the primary location of flotation. Some belts provide the greatest flotation posteriorly, which places the athlete in an excessive forward lean. A more symmetric belt or vest is recommended.

If weightbearing is allowed, the athlete can exercise in shoulder-deep water. Shallow-water running and cross-country skiing are both effective training techniques. The clinician must be aware of the amount of impact and suggest appropriate footwear.

The fundamental guidelines for cardiovascular training should be at the core of program design. The minimum recommendation is 25 minutes, 5 times per week, while the elite athlete may need a longer training period, depending on the season and sport. The pool can also be used for interval training. A number of stations or a variety of exercises performed in a single session can alleviate boredom and assure a well-rounded workout. Ankle floats, arm paddles or gloves, and fins increase the lever arm and resistance. The athlete should be reminded to increase speed to further increase resistance.

The program should be as sport specific as possible. For example, the sprinter can perform interval sprinting, working at peak oxygen consumption, with intermittent jogging for recovery. In contrast, the marathon runner might perform low-intensity, long-duration cardiovascular exercise, maintaining the workload at 70% to 80% maximal oxygen consumption. Similarly, a football lineman may shallow-water sprint with a plow for 6- to 10-second intervals, with light jogging during recovery, to replicate the demands of his sport.

Most importantly, preexisting cardiac conditions must be noted and appropriate precautions taken. Contraindications to cardiovascular training in the pool include all contraindications to similar training on land, as well as cardiac instability, fever, open wounds, and infectious diseases.

Core Body Strengthening

Core body strengthening is critical for every athlete. Baseball players must be able to transfer kinetic energy from the lower extremity to the arm via the trunk musculature. The soccer player must be able to twist and rotate at the trunk while kicking or passing the soccer ball. Core body strengthening is often overlooked, but it can easily be addressed in the pool. Because any upper or lower extremity exercise must be stabilized by the trunk in the pool, most of these exercises also train the core. For example, bilateral shoulder flexion and extension cause posterior and anterior (respectively) displacement of the body, which must be countered by the abdominal and trunk extensor muscles. Similarly, standing leg kicks in the sagittal plane require both single-leg balance and core strength to avoid displacement by the movement of the leg against the water. Cross-country skiing is an excellent total body workout, stressing the body from the shoulders through the trunk and down both legs.
Specific core body strengthening with assistance from the clinician can also be performed. Different types of abdominal contractions can be executed while the athlete is supine, with flotation devices appropriately placed on the trunk or upper limbs as necessary. The athletic trainer can support the lower extremities while slowly turning in a clockwise or counterclockwise direction. The athlete can maintain an isometric contraction of the trunk while the clinician rotates, or the athlete can concentrically contract (side bend) into the resistance of the water. If the athlete starts in a shortened, side-bent position and slowly performs side bending to the opposite side while resisting the water via the rotation of the clinician, an eccentric contraction occurs (Figure 7). Exercises such as leg lifts at the side of the pool should also be included. By lifting the legs straight, the focus is on the rectus abdominus, while lifting side to side in a V fashion (straddle lifts or jumps) works primarily the abdominal oblique muscles. This exercise is also a closed-chain, weightbearing exercise for the upper extremities. Eccentric work of the abdominal muscles can be performed with a soccer ball by doing trunk flexion and extension and slowly allowing the ball to return to the surface of the water (Figure 8). Again, the upper extremities are working isometrically as the trunk flexes and extends. Sport-specific exercises such as trunk rotations with the arms extended can benefit the soccer player, golfer, or quarterback, all of whom require a great deal of rotation for their sports. Modifications can be made to mimic the specific sport. Resisted water walking or jogging with kickboards can be helpful to the football lineman (Figure 9). Figure skaters, as well as long and

Table 2. Sample Rehabilitation Program for a Volleyball Player with Compressive Rotator Cuff Impingement

| Shallow water running forward and backward with exaggerated arm swim |
| Shallow water lateral shuffles with shoulder abduction from 0° to 45° |
| Stretching into overhead position, prone, using a ladder or gutter |
| Stretching into internal rotation and extension (arm behind back) |
| Using buoyant floats |
| Stretching into external rotation using the side of the pool |
| In shoulder-deep water: |
| Shoulder abduction |
| Shoulder flexion |
| Shoulder scaption |
| Shoulder internal and external rotation |
| Shoulder horizontal abduction and adduction |
| Pushing and pulling with resistive board |
| In prone position: |
| Proprioceptive neuromuscular facilitation diagonals through full range of motion |
| Horizontal abduction and adduction |
| Short-arc, high-speed flexion and extension and abduction and adduction in pain-free position |
| In standing position, shallow water: |
| Volleyball drills normally performed on land |
| In deep water: |
| Vertical kicking, with arms out of water and with gloves, performing repeated scaption |
| Cross-country skiing with gloves |
| Pull-ups on ladder |
| Dips in corner |
SUMMARY

We have discussed rehabilitation of the athlete with a shoulder injury in a water-based program. The physiologic changes sustained by the body while immersed, both at rest and during exercise, were reviewed. Impairment-based treatment recommendations were offered, as well as suggestions for cardiovascular conditioning, stretching frequency and duration, and concentric and eccentric strength training. The pool is an effective medium for many aspects of the elite athlete’s training and rehabilitation program. An understanding of the differences between land-based and water-based exercise allows the clinician to establish a comprehensive and effective rehabilitation program for the athlete.

REFERENCES

NATA Research & Education Foundation
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Los Angeles, CA • June 19-23, 2001
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2. Clinical case report abstracts are to be word processed or typed using a letter-quality printer with no smaller than elite (12 cpi) or 10-point typeface. Do not use a dot matrix printer.
3. Top, bottom, right, and left margins should be set at 1.5" using a standard 8.5" x 11" sheet of paper. Type the title of the paper or project starting at the left margin.
4. Provide all information requested on the information form on the next page. Please note that the institution (including the city and state) where the clinical case occurred should be cited, not the current address of the author(s), if different.
5. The title of the clinical case report should not contain information that may reveal the identity of the individual nor the specific nature of the medical problem to the reader. An example of a proper title for a clinical case report is “Chronic Shoulder Pain in a Collegiate Wrestler.”

6. Complete the six different categories of information as required for a clinical case report abstract. These categories are:
   a. Personal Data/Pertinent Medical history (age, sex, sport/occupation of individual, primary complaint, and pertinent aspects of his/her medical history)
   b. Physical Signs and Symptoms (a brief summary of the physical findings)
   c. Differential Diagnosis (array of possible injuries/conditions)
   d. Results of Diagnostic Imaging/Laboratory Tests
   e. Clinical Course (e.g., diagnosis, treatment, surgical technique, rehabilitation program, final outcome)
   f. Deviation From the Expected (a brief description of what makes this case unique)

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Complete the form and mail it, the original abstract, two photocopies of the original abstract, six (6) blind copies (showing no information about the authors or institution) of the abstract and a labeled 3.5” DISKETTE copy (preferably in WordPerfect or ASCII format; if you must send it in Macintosh format, please use a high-density diskette) of your abstract to:

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