Musculoskeletal Injuries in Competitive Swimmers

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Competitive swimming is a rigorous sport being engaged in by an increasing number of young athletes. In swimmers, shoulder pain is the most common musculoskeletal complaint and is usually due to supraspinatus or biceps tendinitis. Glenohumeral instability (often multidirectional) can also be a cause of shoulder pain in swimmers and may be more common than has been reported. Surgical treatment is seldom indicated. Physical therapy modalities and training modifications are the mainstay of treatment. Medial knee pain in breaststroke swimmers and extensor tendon inflammation over the dorsum of the foot are less common injuries and respond to conservative therapy. These overuse syndromes are best prevented by proper training schedules, strength training, flexibility exercises, and avoidance of errors in stroke technique. The rehabilitation program for a competitive swimmer should be chosen with an understanding of the goals of the swimmer and the cooperation of the coach.

Swimming, a popular recreational sport, involves 120 million participants yearly. Of these, more than 165,000 are age-group swimmers registered with United States Swimming, Inc., and almost 19,000 swimmers 25 years of age or older are registered with United States Masters Swimming. In addition, numerous students are in high school and collegiate competitive swimming programs, and an increasing number of people swim regularly for fitness.

As a sport, swimming is unique for several reasons. First, it is an inefficient method of body propulsion in comparison with running. The water in a pool, for example, is a fluid in an open system and is thus not easily compressed by the movements of the swimmer. This lack of resistance contrasts with the greater resistance or "traction" achieved between the runner's shoe and the ground. Therefore, a considerable amount of energy can be expended to swim a short distance.

Second, swimming is an inertial sport that is highly dependent on technique. The force necessary to pull the hand through water is not great; however, body position, drag, limb surface area for propulsion, buoyancy, endurance, and stroke technique are all factors that contribute substantially to swimming ability. Muscle power contributes much less to ability in swimming than in many other sports. In fact, improvements in raw muscle strength do not necessarily correlate with an increase in swimming speed.1

Third, swimming provides both upper-body and lower-body strength training as well as cardiovascular fitness. Paradoxically, despite the intensity of the training, participants have less risk of major injuries in swimming than in most other sports.

Technically, the sport of swimming has improved greatly during the past 20 years. Innovations such as timed-interval training with use of a pace clock, longer yardage workouts, weight training, flexibility exercises, and dietary changes have all accounted for the continued trend of establishment of new swimming records each year. During the past 70 years, the world record times for men have decreased by 47% for
swimmers in comparison with only an 11.2% decrease in world record times for runners over the same 1-mile distance. Equipment changes such as goggles, hand paddles, and kick buoys have also improved the training for swimming.

Most successful competitive swimmers in the United States swim for 10 to 11 months each year in a career that often begins by age 6 years and may last continuously for 10 to 15 years. Many swimmers engage in two swim practices daily, 5 to 7 days per week, and often average 8,000 to 20,000 yards per day, depending on the season. Application of a four-to-one ratio proposed by Counsilman shows that this distance is equivalent to running 32,000 to 80,000 yards per day—or more than 45 miles per day. This increased intensity has placed the competitive swimmer at a greater risk for musculoskeletal injuries.

SHOULDER PAIN
Shoulder pain is the most common musculoskeletal complaint in competitive swimmers. In most studies reported in the literature, the incidence of shoulder pain ranged from 40 to 80%. Richardson and associates studied three groups of swimmers and reported that the incidence of shoulder problems increased with the caliber of the swimmer—the incidence was 57% among the championship group, 52% among the “elite” swimmers, and 27% among the “nonelite” group. The incidence of shoulder pain was approximately equal between the sexes, and the average age at onset was 18 years. Pain was usually located in the anterior or lateral aspect of the shoulder. Almost all the swimmers studied (92%) swam freestyle, backstroke, or butterfly. With these three strokes, the arc of shoulder circumduction is wide. In contrast, those who swim the breaststroke, which involves much less shoulder abduction, are rarely afflicted with shoulder pain.

The most common cause of shoulder pain in swimmers is subacromial impingement and tendinitis of the supraspinatus tendon, long head of the biceps tendon, or both. Recently, however, glenohumeral instability (usually multidirectional) has also been associated with shoulder pain in swimmers and may coexist with tendinitis.

The term “swimmer’s shoulder” has commonly been used to describe pain about the shoulder in swimmers regardless of cause. Classically, however, “swimmer’s shoulder” refers to the painful arc syndrome caused by impingement of the supraspinatus and biceps tendons against the overlying coracoacromial ligament or anterior border of the acromion. This “impingement syndrome,” described by Neer, is also a common cause of shoulder pain in many other overhead-use sports.

ANATOMY OF THE SHOULDER
The shoulder joint, per se, consists of the articulation between the shallow, concave glenoid cavity of the scapula and the convex surface of the humeral head, only a small part of which is in contact with the glenoid cavity at any instant. Most of the internal and external rotation of the upper extremity occurs at this joint.

The shoulder girdle also includes articulations with the thorax and the distal aspect of the clavicle. Together with the glenohumeral joint, these articulations allow a combined shoulder range of motion of 180° of abduction. This coupled motion between the scapulothoracic articulation and the glenohumeral joint occurs in a two-to-one ratio; for every 3° of abduction, the glenohumeral joint is abducted 2° and the scapulothoracic articulation is abducted 1°. The wide range of motion of the shoulder (primarily abduction) necessary for swimming freestyle, backstroke, and butterfly is therefore dependent on the normal coupled motion of the shoulder girdle. What the shoulder joint achieves in range of motion, however, it sacrifices in stability. These characteristics may predispose the shoulder to injury, as it is the most commonly injured joint of the upper extremity in overhead-use sports such as swimming.

The minimally constrained bony architecture of the shoulder joint is stabilized by the surrounding ligaments and muscles (Fig. 1). The glenohumeral fibrous articular capsule and associated ligaments consist of the coracohumeral ligament, which has primarily a suspensory function, and the three glenohumeral ligaments (superior, middle, and inferior).

The coracoid process, the coracoacromial arch, beneath which the supraspinatus and biceps tendons lie. The subacromial bursa, which also is located beneath this arch, allows the
rotator cuff tendons to glide smoothly through the range of motion. This relationship is important in the pathogenesis of swimmer’s shoulder, as it is in other overhead-use sports that may cause an impingement syndrome of the shoulder.

STROKE MECHANICS
Swimming is an activity that relies on maximal propulsive force applied over the extremes in motion of the upper extremity. Depending on the particular stroke, up to 90% of the propulsion is generated from the arm pull. The mechanics of the freestyle stroke illustrate the wide range of motion necessary in the shoulder of swimmers (Fig. 2). The stroke is divided into pull-through and recovery phases (Table 1).8

The combined shoulder girdle motions involved in the butterfly stroke and the backstroke are similar to those in freestyle swimming. For all three strokes, maximal abduction and adduction, internal and external rotation, and flexion and extension are necessary.

If one assumes that a swimmer averages 10,000 yards of swimming per day and completes 10 freestyle cycles with each arm every 25 yards, then the average swimmer makes approximately 4,000 cycles with each arm through this arc of motion daily.

IMPINGEMENT SYNDROME
The space beneath the coracoacromial arch for movement of the supraspinatus and biceps tendons is limited. A painful arc syndrome caused by subacromial impingement of these structures may occur through one of two mechanisms.14

First, if the volume of the structures passing beneath the arch is increased, less space will be available and the possibility of impingement is greater. Rathbun and Macnab,15 with use of a microinjection technique, studied the vascularity of the rotator cuff and biceps tendons. They found that when the shoulder is abducted, such as in the late recovery and hand entry phases of the freestyle stroke, all the vessels of the tendons are almost completely filled. When the arm is at the side, however, in the adducted position (such as in the late pull-through phase of freestyle, butterfly, or backstroke), a constant area of avascularity in both the supraspinatus and biceps tendons extends from their respective points of insertion to 1 cm proximally (Fig. 3). This zone of avascularity has been found in cadavers of all ages.15 Therefore, the supraspinatus and biceps tendons are subjected to constant pressure from the head of the humerus, which tends to “wring out” their blood supply when the arm is held in adduction and neutral rotation.15 Degenerative changes are frequent in these tendons because of the diminished blood supply at the watershed area. Repeated microtrauma in this area results in an inflammatory response in conjunction with edema and an increase in the volume of the tendinous structures.

Second, Neer10 has demonstrated roughness, erosion, and formation of osteophytes on the anterior and inferior aspects of the acromion in response to repetitive impingement by the humeral head. Often, such a response occurs at the point of insertion of the coracoacromial ligament. Consequently, the available space for movement of the supraspinatus and biceps tendons may be decreased. The functional arc of elevation of the shoulder is forward, not lateral; therefore, impingement occurs against the anterior acromion and the coracoacromial ligament during repetitive overhead motions that involve extreme abduction and forward elevation, such as in swimming (Fig. 4). Derangements of the acro-
Table 1.—Mechanics of Freestyle Swimming Stroke

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull-through (right arm) Hand entry</td>
<td>Shoulder is in external rotation and abduction. Body roll begins</td>
</tr>
<tr>
<td>Mid pull-through</td>
<td>Shoulder is at 90° of abduction and neutral rotation. Body roll is at maximum of 40°-60° from horizontal</td>
</tr>
<tr>
<td>End of pull-through</td>
<td>Shoulder is in internal rotation and full adduction. Body roll has returned to horizontal</td>
</tr>
<tr>
<td>Recovery (left arm) Elbow lift</td>
<td>Shoulder begins abduction and external rotation. Body roll begins in opposite direction of pull-through phase</td>
</tr>
<tr>
<td>Mid recovery</td>
<td>Shoulder is at 90° of abduction and external rotation beyond neutral. Body roll is at maximum of 40°-60° from horizontal. Head is turned to side for breathing</td>
</tr>
<tr>
<td>Hand entry</td>
<td>Shoulder is in external rotation and maximal abduction. Hand is in neutral position or slightly pronated</td>
</tr>
</tbody>
</table>

Modified from Richardson and associates.8 By permission of the American Journal of Sports Medicine.

mioclavicular joint may also predispose to subacromial impingement problems. Neer and Welsh16 have classified the progressive pathologic changes associated with impingement into three stages: (1) Stage I consists of edema and hemorrhage of the supraspinatus and biceps tendons from overuse, such as in swimming. Characteristically, this pathologic stage is seen in young athletes (before age 25 years). (2) Stage II consists of fibrosis and tendinitis (usually in those older than 25 years of age). (3) Stage III is characterized by degeneration and rupture of tendons and changes in the bony structure (usually in those older than 40 years of age). Although stage I impingement lesions are most commonly seen during a swimmer's competitive years, progression to stage II or III may occur later in life.

Kennedy and colleagues7 stated that these two seemingly divergent mechanisms for causing supraspinatus and biceps tendinitis are complementary in the explanation of swimmer's shoulder. Rathbun and Macnab15 postulated that tendon degeneration occurs as a result of the avascular area in the supraspinatus and biceps tendons when the shoulder is adducted. Neer and Welsh16 focused on the mechanical impingement of the supraspinatus and biceps tendons under the coracoacromial arch as the arm is repetitively brought into abduction and forward flexion. These inflamed, enlarged tendons are more susceptible to mechanical impingement, which causes further inflammation and establishes a

Fig. 2. Stroke mechanics for freestyle swimming. For the right arm, three phases are identified: hand entry (top), mid pull-through (middle), and end of pull-through (bottom). For the left arm, three stages are likewise depicted: elbow lift (top), mid recovery (middle), and hand entry (bottom).
vicious cycle that becomes clinically apparent as an impingement syndrome.

**Diagnosis.**—Determining the diagnosis of impingement tendinitis is usually not difficult. The differential diagnosis should include primary acromioclavicular pathologic changes, shoulder instability, frozen shoulder, traumatic subacromial bursitis, and calcific tendinitis. Also, as in any patient with shoulder pain, the physician must consider extrinsic conditions that may cause referred shoulder pain. These factors include peripheral nerve entrapments, cervical disk herniation or degenerative disease, thoracic outlet obstruction, and pulmonary or pleural pathologic conditions.

Richardson and associates studied competitive swimmers with shoulder pain and reported that most had been competing for at least 10 years. Of the freestyle swimmers, 60% had pain on the side on which they took a breath during swimming, 75% described pain during both pull-through and recovery phases, and 81% stated that use of hand paddles increased their pain. In 83% of those swimmers, the shoulder pain was worse during the early and middle portions of the season, perhaps because of longer yardage workouts and the common use of hand paddles during that time.

Supraspinatus tendinitis is characterized by point tenderness over the greater tuberosity and anterior acromion, a painful arc of shoulder abduction, and a positive "impingement sign." The impingement test (Fig. 5) reproduces the pain and resultant facial expression when the arm is forcibly flexed forward by the examiner and the greater tuberosity is levered against the anteroinferior surface of the acromion. Relief of pain by injection of 10 ml of 1% lidocaine into the subacromial bursa helps confirm the diagnosis.

Bicipital tendinitis is characterized by localized tenderness over the biceps tendon, a painful catching sensation during resisted forward flexion of the arm with the hand supinated, and pain over the biceps tendon during resisted supination of the forearm.

**Treatment.**—Swimmer's shoulder has been divided into four phases based on the severity of symptoms (not to be confused with the three stages of pathologic changes from shoulder impingement, as described by Neer and Welsh): (1) pain only after heavy workouts, (2) pain (but not disabling) during and after workouts, (3) disabling pain during and after workouts that interferes with the swimmer's performance, and (4) shoulder pain that prevents competitive swimming. Treatment is directed at the phase of pain.
Fig. 4. Impingement of supraspinatus and biceps tendons between humeral head and coracoacromial arch can occur with abduction and internal rotation of humerus, as in recovery phase of freestyle stroke. Note how serratus anterior muscle rotates scapula into abduction as humerus is abducted to allow a greater range of shoulder motion. Scapular rotation also delays impingement of greater tuberosity under coracoacromial arch until humerus is maximally abducted to near 180°. With fatigue or underdevelopment of serratus, humeral impingement may occur at an earlier point in recovery stroke at a lower angle of shoulder abduction.

that the swimmer is experiencing. The treatment for phase 1 and phase 2 swimmer's shoulder is multifaceted (Table 2). Absolute rest of the shoulder is usually not necessary in phases 1 and 2 of the disorder. The training program is altered to decrease total yardage and also to vary strokes throughout the workout so that one motion is not frequently repeated. Thus, the inflamed tendons are rested.

Swimmers with painful shoulders can experience night pain while sleeping. Sleeping on the involved shoulder or with the arm elevated overhead will often increase the pain. The most comfortable position is usually lying supine with the head and shoulders slightly elevated and with pillows positioned on the posterior and lateral aspects of the adducted shoulder and arm.

Physical modalities can usually be beneficial early in the treatment. Ice massage for 5 to 7 minutes until the shoulder becomes numb or the more penetrating use of cold packs for 20 to 30 minutes can reduce inflammation and pain. In all phases of swimmer's shoulder, nonsteroidal anti-inflammatory medications may be effective for short durations.

In addition to varying the strokes and decreasing the total yardage of swimming, stroke mechanics also should be examined and corrected, if applicable. The aim of stroke modification is to limit the extremes of abduction and internal rotation, in which the position of the supraspinatus tendon is most likely to impinge against the coracoacromial arch. The amount of time the arm is in adduction should be limited, to spare the "wringing out" of the hypovascular area of the supraspinatus and biceps tendons. This result can be accomplished by earlier arm recovery, greater body roll, and less internal rotation of the arm at hand entry. 18

Swim fins are used by some coaches to enable swimmers with phase 1 or 2 swimmer's shoulder to continue training while they are receiving treatment. The swim fins increase the power and speed generated by the kick and thereby reduce strain on the shoulder girdle musculature and enable the swimmer to train at a preinjury pace. When using
SWIMMING-RELATED INJURIES

Fig. 5. Shoulder impingement test maneuver forces greater tuberosity of humerus against anteroinferior surface of acromion. Reproduction of patient’s shoulder pain constitutes a positive test result.

a kickboard, swimmers with a shoulder impingement syndrome should hold the board with the affected arm (or arms) flexed slightly at the elbow and shoulder. The standard kickboard position with the arms extended straight out in front of the swimmer with the forearms pronated and resting on the kickboard essentially reproduces the impingement test maneuver and may aggravate the shoulder symptoms. The use of hand paddles should be limited or eliminated because they cause increased stress in the pull-through muscles and their use has been associated with an increased frequency of shoulder pain. Also, easy warm-up and cool-down swims should be part of every workout.

The upper-arm counterforce brace has been found to be an effective aid in treating phase 1 and 2 swimmer’s shoulder (Fig. 6). The principle of the upper-arm strap is similar to that of the forearm strap introduced by Froimson and popularized by Nirschl for the treatment of tennis elbow. The upper-arm brace is an adjustable neoprene band, approximately 8 cm wide and with a thickened area, that is placed high on the arm directly over the biceps tendon (Fig. 7). Although no formal biomechanical studies have been done on the function of the upper-arm brace, it is thought to have a tenodesis effect on the biceps tendon making it a more effective humeral head depressor, especially during contraction of the biceps. Depression of the humeral head creates more space beneath the coracoacromial arch and thereby diminishes subacromial impingement of the supraspinatus and biceps tendons.

Blatz conducted a limited study of 27 age-group swimmers who were 12 to 19 years old and had phase 1 or 2 swimmer’s shoulder. All had reproducible impingement pain. Of the 27 participants, 14 claimed complete relief within 24 to 48 hours while using an upper-arm strap, 10 reported a 75% decrease in their symptoms of pain, and 3 obtained no relief. Thus, 24 of 27 athletes, or approximately 90%, had excellent or good short-term results with use of the strap in this survey.

Manual therapy such as sedative or friction massage may be helpful in the subacute stage of swimmer’s shoulder. Electrical therapy is also a useful modality for treating painful shoulders. The use of interferential currents, high-intensity galvanic stimulation, or Microdyne stimulation can be of benefit for relieving pain and increasing blood circulation. Because of its expense and the difficulty in placement of the electrodes, transcutaneous nerve stimulation is generally used only after other modalities have proved unsuccessful. The proper placement of the electrodes and the correct frequency rate (high or low) are crucial for effective results.

Heat modalities such as hot packs or infrared heat are occasionally useful because of their sedative and analgesic properties. Deeper heat modalities such as shortwave diathermy and ultrasound can be used in the intermediate and late phases of swimmer’s shoulder.

A strengthening program is usually begun with exercises that are below the level of the shoulder, to avoid aggravation of any subacromial impingement tendinitis. Strengthening exercises can begin with isometrics, proceed to variable-resistance exercises (with use of surgical tubing), and then
Table 2.—Rehabilitation for Phase 1 and Phase 2 Swimmer’s Shoulder Caused by Tendinitis and Subacromial Impingement*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Early rehabilitation (acute phase)</th>
<th>Intermediate rehabilitation (subsidence of acute phase)</th>
<th>Late rehabilitation (able to do isometrics free of pain)</th>
<th>Return to swimming†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ice</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NSAID‡</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Swimming training modifications</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Manual therapy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Electrical therapy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Heat</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Range-of-motion exercises</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Isometric exercises</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Elastic-tubing exercises</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Stretching exercises</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Isotonic and isokinetic exercises</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maintenance of flexibility and strength program</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*See text for description of phases. The program for shoulder pain due to glenohumeral instability is similar except that manual therapy and stretching exercises are withheld and exercises to strengthen the rotator cuff muscles are emphasized.
†Strength 90% of unaffected shoulder and range of motion 95% of normal.
‡Nonsteroidal anti-inflammatory drugs.

Therapeutic Exercises.—Therapeutic exercises to correct any muscle strength imbalance or loss of range of motion should be prescribed for swimmers with disorders of the shoulder. Greipp reported on the correlation between lack of shoulder flexibility and pain. Shoulder-stretching exercises are used to maintain or increase the range of motion of the shoulder. Such exercises should involve stretching of all the major muscles that aid in forward swimming propulsion, such as the shoulder internal rotators (pectoralis major, latissimus dorsi, and subscapularis) (Fig. 8). Lack of shoulder external rotation because of tight internal rotators predisposes the swimmer to subacromial impingement of the humerus. Stretching exercises should be done in a gentle, prolonged (up to 3 to 5 minutes), pain-free manner. Ballistic (bounce-type) stretching that stimulates the stretch reflex is not recommended. Contract-relax or neuromuscular facilitation is an alternate stretching technique; for proper performance of these exercises, a partner is often necessary. Muscles that stabilize and elevate the scapula or externally rotate the shoulder are relatively weak in competitive swimmers in comparison with the...
strong shoulder internal rotators that are exercised repeatedly in swimming or hand-pulley drills. This relative muscle strength imbalance makes it more difficult for the swimmer to achieve full elevation of the scapula or to rotate the humerus externally in order to prevent impingement of the greater tuberosity beneath the acromion during overhead motion of the shoulder. This impingement occurs during recovery and early pull-through phases of the freestyle, backstroke, and butterfly stroke. In addition, the rotator cuff muscles and biceps depress the humerus in the glenoid fossa during elevation of the shoulder. Weakness of the rotator cuff muscles allows the humeral head to glide higher in the glenoid fossa and diminishes the available space for movement of the biceps and rotator cuff tendons. This situation predisposes the swimmer to development of tendinitis or a subacromial impingement syndrome. Exercises to strengthen the external rotators with the use of surgical tubing or pulley weights can be performed (Fig. 9).

Most muscle-strengthening programs are aimed at the primary pull-through muscles, which include the latissimus dorsi, subscapularis, and pectoralis major. Recently, Nuber and colleagues reported on an electromyographic study of seven collegiate swimmers. They showed the importance of strengthening the recovery-phase muscles, especially the scapular rotators such as the serratus anterior. The serratus anterior moves the scapula upward and allows it to rotate clear of the abducting humerus. If this muscle fatigues during the course of repetitive arm motion, scapular motion may not coincide with humeral motion, and impingement may be precipitated. Thus, a vigorous program to strengthen the serratus anterior and other scapular rotators as well as the rotator cuff muscles may be an important measure to alleviate or prevent subacromial impingement.

Overall, the basic plan for shoulder muscle rehabilitation is to stretch the already strong anterior pull-through muscles and to strengthen the weaker external rotators and scapular rotators used in the recovery phase of the arm stroke.

Other Therapeutic Measures.—If swimmer's shoulder evolves to phase 3 or 4 in which pain during and after workouts affects performance, then total rest of the affected shoulder may be indicated, and land exercises (kicking, jogging, and bicycle riding) can be used to maintain fitness. When symptoms diminish to phase 1 or 2, rehabilitation can begin according to the aforementioned plan (Table 2).

Local subacromial or bicipital tendon sheath injections of corticosteroids have been advocated by some, discouraged by others, and
Surgical tubing attached to a stationary object offers resistance for effective strengthening.

used with caution by all. Such injections may be indicated in phase 3 or 4 swimmer's shoulder when pain persists despite a trial of nonsteroidal anti-inflammatory drugs, rest, local treatments, exercises, and training modifications. They should always be used with caution because of the transient effect of tendon weakening that has been associated with this treatment and the uncertainty of the long-term effects of repeated injections. Penny and Smith maintained that injections of corticosteroids should be reserved for the national or international class swimmer who is about to participate in a major competition when it is known that a period of rest will follow.

Surgical excision of the coracoacromial ligament has a controversial role in the treatment of phase 3 and 4 swimmer's shoulder. This surgical technique is associated with minimal morbidity, and it can be done as an outpatient procedure with use of a small deltid-splitting approach and a local anesthetic. Kennedy and associates' reported that the indication for surgical intervention is failure of conservative treatment after at least 1 year and definite clinical signs of impingement. Several reports have described successful results with this procedure in swimmers who have returned to high-level competition, although the results of surgical treatment in a large group of competitive swimmers are still unknown. Neer (personal communication) stated that, in his experience, surgical excision of the coracoacromial ligament had not enabled high-level competitive swimmers to return to competition on a long-term basis.

Anterior acromioplasty or excision of the distal aspect of the clavicle (or both procedures) may be indicated if impingement on these structures can be demonstrated or if division of the coracoacromial ligament fails to yield relief. Most swimmers are unable to return to competition after anterior acromioplasty.

SHOULDER INSTABILITY
Recently, involuntary inferior and multidirectional instability has been recognized as a cause of shoulder pain in swimmers. In fact, Neer (personal communication) currently believes that this is the most important factor causing shoulder pain in swimmers. Shoulder instability may be difficult to diagnose because the symptoms of pain may be similar to those caused by impingement tendinitis, and the two conditions can coexist. A prior history of a major shoulder injury may not be elicited. The patient may have discomfort while carrying loads that pull downward on the inferior part of the capsule or with overhead arm movements such as in swimming. Also, a frequent complaint is an arm that feels "dead." Emotional disorders should be ruled out; Neer and Foster found no major emotional problems in their series of patients with involuntary shoulder instability.

The basic lesion that contributes to shoulder instability is an enlarged joint capsule due to repetitive forceful stretching from the wide range of shoulder circumduction performed during swimming (and in other overhead-use sports).

Examination of the shoulder should include stress on the glenohumeral joint in three direc-
tions—anteriorly, posteriorly, and inferiorly—on repeated patient visits. Multidirectional instability should be suspected if apprehension is evident with inferior stress or stress in more than one direction. The result of the impingement injection test is usually negative. Thorough radiographic evaluation of the shoulder is important and should include anteroposterior views in internal and external rotation, an axillary view, and a West Point prone axillary view. Examination under anesthesia and stress films may also be helpful. Double-contrast arthrography and arthrotomography may show a Bankart lesion or an enlarged joint capsule but are often difficult to interpret. Computerized axial arthrotomography improves resolution and may become the procedure of choice in evaluation of difficult or occult cases of glenohumeral instability.

Initially, multidirectional or inferior instability of the shoulder should be treated conservatively—the stroke mechanics should be analyzed and altered, if necessary, and shoulder-strengthening exercises (Table 2) should be performed. The objective of the exercises is to enhance dynamic stability of the shoulder by increasing the strength and tone of the rotator cuff and deltoid muscles without causing mechanical irritation of the capsule or ligaments. For isolated inferior shoulder instability, the emphasis should be on strengthening the shoulder abductors.Manual therapy and stretching exercises should be withheld. A balanced strengthening program of all rotator cuff muscles is indicated for multidirectional instability. Cybex testing can be used to determine whether shoulder muscle imbalance is present. Strengthening can involve isometric, isotonic, and isokinetic training exercises similar to those done for the shoulder impingement syndrome.

Many patients with painful shoulders and demonstrable shoulder instability will have improvement with conservative treatment. Conservative measures should include an appropriate period of rest followed by strengthening exercises below the level of the shoulder to prevent irritation of the joint. When the patient returns to swimming, stroke modification is important to prevent recurrence. Some strokes, particularly the backstroke and butterfly stroke, may need to be avoided.

Surgical treatment may be indicated for the motivated swimmer with hyperlaxity of the ligaments and inferior capsule in whom a 1-year trial of conservative therapy has failed. Neer and Foster described an inferior capsular shift procedure that tightens the glenohumeral capsule. The shoulder joint is approached anteriorly or posteriorly, depending on the direction of the instability, and a T-shaped incision is made in the capsule. The two sides are then sutured as flaps over each other to obliterate the capsular redundancy. The short-term results of this procedure have been satisfactory, and some collegiate swimmers have reportedly resumed competition postoperatively (Neer CS II: Personal communication). The prognosis for returning to a high level of competition, however, should be guarded because by the time an operation becomes necessary, the changes in the soft tissues may be so advanced that repair will allow comfortable daily activities and recreational sports but not the training intensity necessary for successful competition.

**APPREHENSION SHOULDER**

Isolated anterior glenohumeral instability is primarily seen in backstroke swimmers and is termed "apprehension shoulder." The backstroke involves maximal abduction and external rotation of the shoulder, particularly during hand push-off as the backstroker initiates a flip turn. This acquired laxity of the anterior capsule is thought to be caused by repetitive stretching of the capsule during the initiation of the backstroke flip turn and by certain excessive passive shoulder-stretching exercises that many swimmers do in order to improve their flexibility. Cineradiographic studies have shown subluxation of the humeral head anteriorly onto the rim of the glenoid during extreme abduction and external rotation of the shoulder, as with initiation of the backstroke flip turn (Fig. 10). This action causes pronounced stress on the anterior shoulder joint ligaments. With the arm in this position, the subscapularis muscle glides superiorly and is unable to help resist the anteriorly directed force of the humeral head. With repeated stress, the anterior shoulder joint capsule may become excessively stretched, and anterior shoulder instability may ensue.

Apprehension shoulder can be diagnosed by reproducing pain or the sensation of impending subluxation with the shoulder in abduction and external rotation (positive result of the shoulder
apprehension test) (Fig. 11). Conservative treatment involves strengthening of the shoulder internal rotator muscles for anterior stability. These exercises are usually begun with the shoulder adducted and with limitation of extreme external rotation. Isotonic or isokinetic exercises with an emphasis on eccentric strengthening should be prescribed. In addition, modification of the backstroke flip turn and avoidance of incorrect anterior shoulder-stretching exercises are important. If swimmers cannot tolerate the subluxation and if they are unable or unwilling to change the mechanics of their flip turn, surgical treatment may be indicated. Many procedures such as the Magnuson-Stack procedure, the Bankart repair, the Putti-Platt operation, and the Bristow operation have been described for anterior gleno-humeral subluxation. All these procedures have the disadvantage of potentially restricting external rotation of the humerus. If this motion is appreciably limited, the swimmer will probably have to discontinue backstroke competition. The inferior capsular shift procedure may provide anterior stability without substantial loss of external rotation. Often, there is no satisfactory approach to this problem.

Shoulder arthroscopy may be a useful adjunct to the physical examination in diagnosing shoulder instability. Ciullo advocated arthroscopic resection of labral interposition and bucket-handle tears and debridement of small rotator cuff tears that may be a source of pain, but such procedures are not widely performed.

Prevention of shoulder pain in swimmers is perhaps the most important goal. Errors in the training program should be corrected through proper communication with the coach. Ample warm-up and cool-down periods, preventive maintenance stretching, strengthening programs, and proper stroke mechanics are all components of a training program that will minimize injuries. Coaches and swimmers must be aware of the difference between adequate muscle flexibility and capsular laxity caused by unusual or repeated stretching maneuvers. Switching strokes frequently and breathing on alternate sides in freestyle swimming throughout a workout and early and midseason strength training may also be helpful preventive measures.

**BREASTSTROKER’S KNEE**

Knee pain in swimmers occurs primarily in those who do the breaststroke and thus has been termed “breaststroker’s knee.” Kennedy and colleagues surveyed 2,496 competitive swimmers throughout Canada and found 70 who were affected by knee...
pain, all of whom were breaststrokers. Breaststroker’s knee is characterized by pain and tenderness in the medial aspect of the knee joint and has been thought to be due to incorrect mechanics of the breaststroke whip kick. Knee effusions and patellofemoral pain and crepitus have also been reported.

In contrast to the freestyle, backstroke, and butterfly stroke, much of the speed achieved with the breaststroke is contributed by the whip kick. Training regimens often emphasize the development of an efficient and powerful kick. The whip kick was developed as a variation of the frog kick to achieve increased speed, propulsive force, and economy of movement. Counselman precisely described the proper mechanics of the whip kick. Breaststroke swimmers with knee pain tend to have a kick that more closely resembles the frog kick than the whip kick (Fig. 12). Stulberg and associates reported that the primary mechanical fault in the swimmer with breaststroker’s knee is usually excessive abduction of the thighs as the hips and knees are flexed during the recovery phase. This position places excessive valgus and external rotation stress on the medial supporting structures of the knees as the thighs are adducted and the legs are rapidly extended during the propulsion phase of the kick.

Kennedy and associates are of the opinion that a tibial collateral ligament strain is the primary disorder in swimmers with breaststroker’s knee. Stulberg and colleagues, however, studied 23 competitive breaststroke swimmers with knee pain and found that most had pain along the medial facet of the patella and the medial femoral intercondylar ridge. Five swimmers described this pain in addition to tibial collateral pain, and only 5 of 23 swimmers had pain isolated to the tibial collateral ligament only. Stulberg and co-workers also reported that breaststrokers who had been using the whip kick for more than 8 years had clinical evidence of patellofemoral chondromalacia, as seen in two patients who underwent arthroscopy. Interestingly, none of the swimmers had radiographic evidence of osteoarthritis, abnormal patellofemoral-condylar groove relationships, or osteochondritis dissecans. Both tibial collateral ligament strain and chondromalacia of the medial patellofemoral joint may be etiologic factors in breaststroker’s knee; however, Stulberg and associates found only one patient with tenderness of the lateral facet of the patella. Also, chondromalacia of the medial patellar facet is a common finding in young patients regardless of their activity level. Clearly, more research in this area is needed.

Knee symptoms usually begin within 3 years after the first participation in competitive swimming. Initially, the swimmers are symptomatic only while kicking; later, however, they may have excessive valgus stress on the knee joint, which would seemingly produce more stress on the lateral patellofemoral joint; however, Stulberg and associates found only one patient with tenderness of the lateral facet of the patella. Also, chondromalacia of the medial patellar facet is a common finding in young patients regardless of their activity level. Clearly, more research in this area is needed.
knee pain during all activities including climbing stairs and arising from low chairs.

The primary treatment of breaststroker's knee is correction of abnormal kick mechanics, which will decrease the strain on the medial structures of the knee. In the experience of most investigators, this correction alone has been sufficient to eliminate the swimmer's knee pain. Most young swimmers incorrectly abduct the thighs during the recovery phase of the kick and rapidly extend the knees with the legs apart during the propulsion phase of the kick. Particular attention should be placed on keeping the knees closer together during the recovery phase and the mid-kicking phase and preventing the knees from being fully extended until the legs are together at the end of the kicking phase. In addition, reducing the anterior compression forces on the knee by means of hamstring stretching and quadriceps isometric strengthening exercises with emphasis on the vastus medialis may be helpful.

The use of proper warm-up exercises, local applications of ice, and ultrasound can be helpful. The symptomatic breaststroke swimmer should train infrequently with the whip kick and should use other kicks during workouts. The local use of corticosteroids should be avoided.

TENDINITIS ABOUT THE FOOT AND ANKLE
With the exception of those who do the breaststroke, most swimmers strive to develop maximal ankle plantar flexion, which places the foot in a better position to push the water in a backward direction during the propulsive phase of the flutter or dolphin kick. Expert swimmers often will develop 90° of plantar flexion. Conversely, breaststokers need ankle flexibility in the opposite direction (dorsiflexion). This flexibility enables the breaststroke swimmer to place his feet in a good position to push the water backward at a point earlier in the kick than would otherwise be possible and thus achieve a more effective kick. Cureton has shown that expert swimmers with better kicks have greater flexibility in the ankles than average swimmers with poorer kicks. Furthermore, Robertson found a significant relationship between ankle flexibility and propulsive force. Clearly, the extremes of ankle dorsiflexion and plantar flexion are achieved through stretching the muscles of the anterior compartment of the leg and the supporting ligaments about the ankle (Fig. 13). This repetitive motion may lead to inflammation of the extensor tendons. Although not as frequent a problem as shoulder or knee pain, when foot and ankle pain occurs it may considerably alter performance. Tendinitis in this area can be diagnosed when pain and crepitus are present over the extensor tendons during flexion and extension. Treatment includes local applications of ice and ultrasound, non-steroidal anti-inflammatory medication, and, for persistent or severe cases, local corticosteroid injections around the tendon sheaths. Switching the flutter kick to a two-beat instead of a six-beat kick may also relieve symptoms.

CONCLUSION
Competitive swimming is a rigorous sport being engaged in by an increasing number of young athletes, often for prolonged, continued periods that may last for 10 to 12 years. Modern training techniques are producing steady improvements in world record times for competitive swimming but may also be placing the competitive swimmer at greater risk for injury.

Among competitive swimmers, shoulder pain is the most common musculoskeletal complaint. It is usually due to supraspinatus or biceps tendinitis caused by chronic repetitive impingement beneath the coracoacromial arch, and it occurs
in freestyle, backstroke, and butterfly stroke swimmers. The treatment, which is basically conservative, includes alteration of stroke mechanics and workout schedules, flexibility and strengthening exercises, and local measures to reduce inflammation and pain. Surgical excision of the coracoacromial ligament or anterior acromioplasty may be indicated in severe disabling cases when conservative treatment has failed. Postoperatively, the prognosis for the return of a swimmer to a prior level of competition is guarded.

Glenohumeral instability (often multidirectional) can also be a cause of shoulder pain in swimmers and may be more common than has been reported. The diagnosis is often elusive, and evaluation should be thorough. Conservative therapy includes muscle strengthening of the rotator cuff, deltoid, and scapular rotators and altering of stroke mechanics. Surgical treatment to tighten the joint capsule provides short-term satisfactory results for patients in whom conservative treatment has failed. Long-term results of surgical intervention are unknown.

Shoulder pain can be prevented through proper training schedules, strength training, flexibility exercises, and avoidance of errors in stroke technique. Attention should be directed not only to muscles used in the pull-through phase but also to those used in the recovery phase.

"Breaststroker’s knee" is an inflammation of the medial retinacular structures of the knee from repeated stress placed on it by the breaststroke whip kick. Most investigators have found inflammation of the tibial collateral ligament as the source of pain. The treatment is focused on correcting abnormal kick mechanics and limiting the amount of training using the whip kick.

Inflammation of the extensor tendons over the dorsum of the foot occurs less frequently than shoulder or knee pain in swimmers. Treatment includes local application of ice, ultrasound, anti-inflammatory medication, and, occasionally, local injections of corticosteroids.

The approach to treatment of musculoskeletal injuries in the competitive swimmer should be chosen only after the goals of the swimmer and the training program of the coach are understood. Communication and cooperation among the physician, the coach, and the athlete will ensure a treatment program tailored to the needs of the swimmer and will result in a more compliant and satisfied patient.

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