CHAPTER 14

Applied Biomechanics of Swimming

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Introduction

When clinicians think "overhead athlete," swimming is one of the sports that come to mind. Some of the other sports include throwing and pitching, volleyball, and tennis. In the past, the mechanics of the "overhead athlete" were sometimes viewed collectively. Most of the "overhead" sports are mechanically at risk during humeral abduction and elevation with external rotation. That is not the case with the swimmer. It is now clear that the requirements of each sport are distinct, and the precise requirements are able to be defined. Thus, this chapter provides an opportunity to describe the specific biomechanics of swimming as they relate to the clinician.

One unique aspect of swimming mechanics is that the power comes from the muscles of the shoulder girdle. In most sports, there is a ground reaction force and power is transmitted from the legs through the trunk and scapula and out the arms. In swimming, however, the body is being pulled over the arms. Thus the arms are the propulsive mechanism, and the shoulders are quite vulnerable, especially if the scapula cannot act as a stable base for the glenohumeral control muscles. Therefore, one of the primary foci of this chapter is the shoulder.

Because the shoulder is the focus, the most visually apparent pathomechanical clue to impending injury is that of axial rotation and humerus position. The visually apparent pathomechanics are discussed, as are the pathomechanics that are harder to see. These pathomechanics are related to their effect on shoulder injury. In addition, shoulder muscle firing patterns in the normal and the painful shoulder are discussed.

The emphasis of this chapter is identifying injury early and taking steps to minimize anatomic damage. To identify the subtle signs of impending injury, a bridge between the coach and on-deck personnel and the medical team must be built. Hence, this chapter presents such a framework and offers the clinician a problem-solving approach to minimize anatomic damage in the swimmer's shoulder.

Swimmer Characteristics

Unfortunately, approximately half of competitive swimmers develop shoulder pain severe enough to cause them to alter their training schedule at some point during their swimming career.[1] In a survey of 532 collegiate swimmers and 395 master swimmers, not only did approximately half the swimmers have a history of 3 or more weeks of shoulder pain that forced them to alter their training, but more than half of the injured swimmers also had a recurrence. These data point to the need for long-term intervention in the competitive swimmer.

In a separate unpublished survey of 233 competitive swimmers on 17 collegiate teams, the location of pain was queried, as were the positions during the stroke of the most intense pain.[2] The anterior-superior region of the shoulder was identified in 44% of the swimmers as the area of pain. Diffuse pain was identified in 26% of the swimmers, with lesser frequencies reported for the anterior-inferior region of the shoulder (14% of the swimmers), posterior-superior region (10% of the swimmers), and posterior-inferior region (4% of the swimmers). It is likely that swimmers who identified diffuse pain had not acknowledged the pain when it was more localized, and the inciting symptoms were masked by inflammation or more severe damage.

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During the freestyle stroke, 70% of the "most pain" occurred during the first half of pull-through.[2] Another vulnerable point of the stroke appeared during the first half of recovery (18% of the symptoms were elicited during this phase) (Figure 14-1). During the first half of the pull-through, the arm is unilaterally pulling the body over the arm as the arm generates the propulsive force. The humerus has a common tendency to be hyperextended relative to the trunk rotation toward the submerged side (Figure 14-2, *A*). In this position, the humeral head is pushing anteriorly. Any anterior impingement, labral damage, or inflammation would be aggravated in this position.

Toward midrecovery, the humerus is swinging the forearm forward. When the elbow is too high and close to the body, the humerus is in hyperextension, which is most likely causing the pain. It has been suggested that the humerus is moving into maximal external rotation, and this has been equated to the late cocking phase of the baseball pitch. Although it is true that at this point the humerus is as far into external rotation as it goes during the freestyle stroke, it is nowhere near the degree of maximal external rotation required during the baseball pitch. During the midrecovery phase of the freestyle stroke, the humerus is closer to neutral rotation than it is to "maximal" external rotation. This singular fact underscores the issue that the mechanics of injury in the swimmer are unique for that sport; indeed, they are unique for each stroke within swimming. A grouping of all overhead athletes does injustice to the understanding of specific injury mechanics.

Based on the knowledge of where the shoulder hurt during swimming and which phase of the stroke provoked the injury, an anatomical study was designed to determine the proximity of soft tissues with skeletal tissue. Nine cadaver shoulders were placed in the positions during the first half of pull-through, and cross-sections were taken. Five of the specimens exhibited bursal and intraarticular contact with the rotator cuff. This is now called a *double squeeze* (of the rotator cuff). Three of these specimens also revealed the biceps tendon in contact with the coracoacromial arch. Two other specimens demonstrated intra-articular contact only, and two demonstrated bursal contact only.[2] Two of the specimens with intra-articular cuff contact demonstrated greater tuberosity contact with the acromion. The site of intra-articular contact was the most common in the anterior-superior labrum (five specimens). Cadaver specimens greatly simplify the issue of shoulder problems in swimmers because they cannot account for the inflammation that would accompany the microtrauma of injury. The inflammation could cause more, or different, areas of contact. The cadavers cannot account for any pathological instability or muscular fatigue or substitution mechanics that may occur. Although simplified, this cadaver model allows a clinician to understand the multiplicity of anatomical contact areas (bursal and intra-articular areas) during the most painful phase of the freestyle stroke.

The Strokes

The shoulder is the primary area of interest to clinicians working with swimmers because of its vulnerability to injury. The visually apparent mechanics related to potential shoulder injury in the freestyle, backstroke, and butterfly strokes is that of humeral position relative to the axis of the body. Figures 14-2, these three strokes and demonstrates the problem of humeral hyperextension relative to body axis. For the purposes of this chapter, *humeral hyperextension* is defined as a combination of humeral abduction and extension (i.e., the humerus is behind the long-axis of the body while the arm is abducted). This position places stress on the anterior joint structures. Too much or too little body rotation changes the position of the humerus relative to the body axis, and thus is related to humeral hyperextension. Whether these faulty mechanics cause the pathological muscle firing patterns or whether weak or fatigued muscles cause these faulty mechanics is a bit like the issue of the chicken and the egg. The changes in muscle firing patterns are not as visually apparent as is the body rotation; however, knowledge of the faulty muscle firing patterns defines the underlying issues and allows the clinician to effectively and efficiently diagnose and treat the problem.

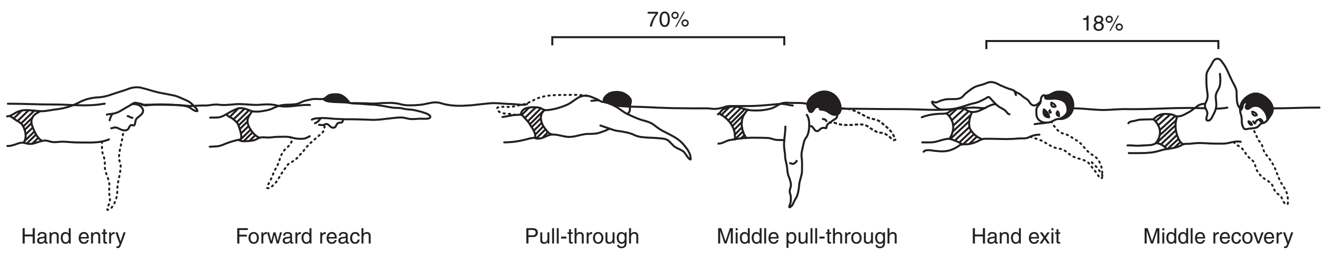


Figure 14-1
Painful phases of the freestyle stroke. Seventy percent of painful symptoms are identified during the first half of pull-through. Eighteen percent of symptoms are identified during the first half of recovery. (From Pink MM, Tibone JE: The painful shoulder in the swimming athlete, *Orthop Clin North Am* 31[2]:248, 2000.)

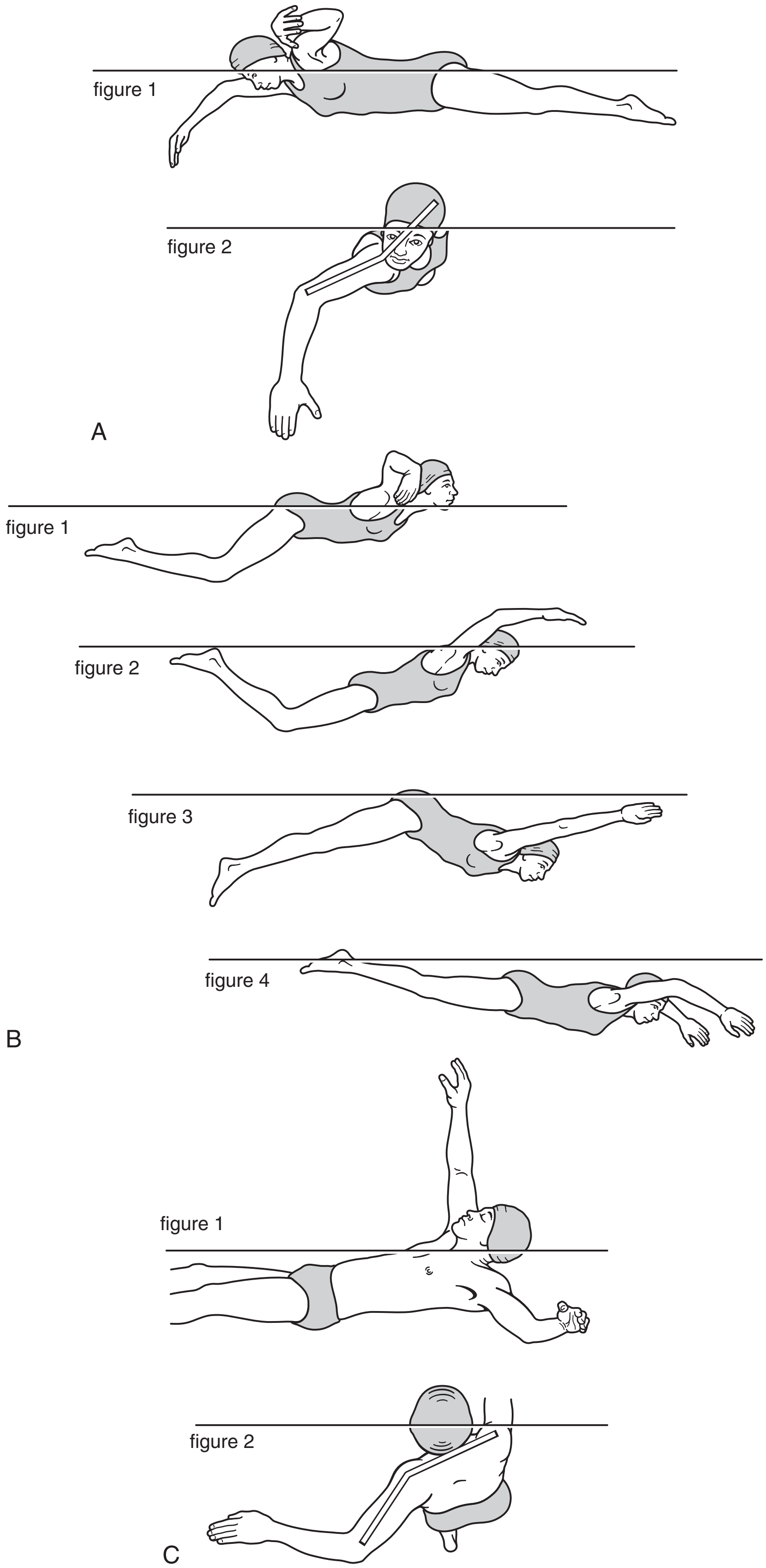


Figure 14-2
Humeral hyperextension. **A,** During the freestyle stroke. Hand exit *(left)* and hand entry *(right)*. **B,** During the butterfly stroke.**C,** During the backstroke.

The following is intended to be a synopsis of the key factors in each of the four competitive strokes. There are multiple excellent books and articles on swimming mechanics for those with an interest in more detail. Some of the articles are referenced herein. Two books on basic swim mechanics are those by Ernest Maglischo[3] and Cecil M. Colwin.[4]

Freestyle Stroke

Mechanics

The basic arm mechanics—with the arm position marking different phases of the freestyle stroke—are as follows (Figure 14-3):

1. The arm enters the water and extends forward in front of the shoulder. The underwater pull-through starts with the *early pull-through* phase, which is marked by the initiation of the backward arm movement. The palm and forearm should face the backward direction with the fingertips pointing down for *as long as possible*.
2. The point at which the humerus is perpendicular to the body is called the *mid pull-through*.
3. Subsequent to mid pull-through is the *late pull-through*. The hand continues back and passes next to the hip until it exits the water, leading with the elbow.
4. After the arm exits the water, the *recovery phase* begins, when the arm is swung above the water to bring the arm into position to pull once again.

The arm motion is accompanied by axial rotation of the body. Many swimmers are taught to rotate, yet some degree of rotation will naturally occur toward the side of arm entry. As the arm is entering and the elbow is extending, the shoulder and side of the body rotate below the surface of the water. During the recovery, that same shoulder and side of the body begin to counter-rotate above the surface of the water (while the opposite shoulder is rotated down).

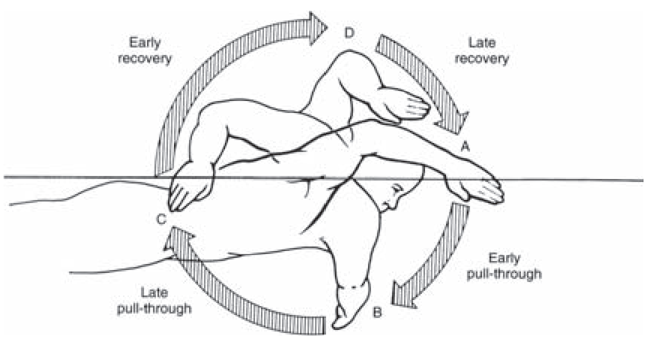


Figure 14-3

Phases of the swimming stroke. (From Pink M, Perry J, Browne A, et al: The normal shoulder during freestyle swimming, *Am J Sports Med* 19:569–576, 1991.)

As previously mentioned, it has been noted that shoulder pain occurs most frequently in two phases of the stroke: (1) the early pull-through to mid pull-through and (2) hand exit to mid-recovery.[2] There is potential in both of these phases for humeral hyperextension that could likely cause pain (see Figure 14-2, *A*). When adjusting to mitigate the pain, the swimmer will most likely seek a path of least resistance and decrease efficiency of the arm stroke while shortening the pull-through phase. One of the easiest ways to see this is during an increase in stroke count.

Swimmers with painful shoulders may begin to use a wider hand-entry and a wider pull-through to diminish the pinching of an inflamed supraspinatus. A wide hand-entry and wide pull-through, combined with the body rotation, can increase the likelihood of humeral hyperextension.

It is important to take notice of the shoulder complex in relation to trunk rotation when a swimmer takes a breath. Observations of elite swimmers from an underwater front view shows a maximum trunk rotation of approximately 30° to 40° down from the surface of the water on each side. The purpose of the rotation should be to aid in the forward progression, not to rotate the body onto its side. It is common for a swimmer to rotate excessively during a breathing cycle, sometimes rotating as much as 90°. In other words, if a swimmer breathes to the right side, there will be a tendency to rotate onto the left side too much. A situation of over-rotating like this is a no-win situation. If the swimmer maintains the optimal pull-through mechanics, the excessive trunk rotation may lead to humeral hyperextension. If the swimmer avoids the humeral hyperextension by keeping the arm in front of the body, it is a major mechanical flaw that will not maximize propulsion.

Another way that the injured swimmer may reduce humeral hyperextension is to adjust the timing of the arm strokes to a "catch-up" timing as opposed to being symmetrically opposite each other. "Catch-up" timing is when the arm phases overlap slightly, so that the recovery arm is on the late recovery while the underwater arm is still in the early pull-through. This reduces body rotation during the early to mid pull-through, thus decreasing the chances for humeral hyperextension.

During the hand exit to mid-recovery, humeral hyperextension can be reduced by swinging the arm wider and decreasing elbow flexion. The elbow does not have to be very high or close to the body (i.e., the emphasis should not be on a high elbow recovery). The recovery should be relaxed and controlled, and it is acceptable to swing the hand around to the side.

The recovery phase should be led by the elbow. Some swimmers try to lead with the hand. They overemphasize the finish motion of the pull-through and actively flick the wrist out of the water upon exit. When they flick the wrist, they are also typically increasing the humeral hyperextension, which increases the vulnerability of the shoulder. Also, it typically changes the initiation of recovery by increasing humeral internal rotation.

Muscle Activity

Clinically, the key to potential pathological conditions in the shoulder during the freestyle stroke may be related to the serratus anterior. In swimmers with normal shoulders, the serratus anterior continually fires above 20% of its maximum.[5] This muscle appears to be stabilizing the scapula in a protracted position as the arm pulls the body over itself. When a muscle continually fires above 20%, it is susceptible to fatigue.[6] With the distances required during swim training, the serratus anterior is certainly vulnerable to fatigue. Indeed, in swimmers with painful shoulders, the serratus anterior demonstrates significantly less muscle action during a large portion of pull-through (Figure 14-4, *A*). Although the serratus anterior diminishes its action during pull-through, the rhomboids increase their activity (Figure 14-4, *B*). It may be that, in an attempt to stabilize the scapula during the absence of the serratus anterior, the primary muscles available are the rhomboids. Yet the action of the rhomboids (retraction and downward rotation of the scapula) is the exact opposite of the serratus anterior (protraction and upward rotation). This may well be positioning the acromion to impinge on the rotator cuff.

Another muscle to consider when studying muscle activity during the freestyle stroke is the subscapularis. In swimmers with normal shoulders, this muscle also continually fires above 20% of its maximum.[5] And, in swimmers with painful shoulders, there is significantly less activity during pull-through (Figure 14-4, *C*).[7]

Of interest, the primary "power" muscles of the shoulder during swimming (the latissimus dorsi and the pectoralis major) demonstrate no significant differences when comparing normal versus painful shoulders. So it appears that these muscles may not be integral in the prevention of injury (Figures 14-4, *D* and 14-4, *E*).[7] Also of note, neither the supraspinatus, teres minor, nor posterior deltoid exhibit any significant differences in muscle activity between painful and nonpainful or normal shoulders (Figures 14-4, *F–H*).[7]

As a clinician, one application of this research information is to ensure there is both a strengthening and endurance component for the serratus anterior and the subscapularis in a swimmer's conditioning program. Another application is to watch for the initial signs of fatigue in these muscles, as that may be the start of a chain of injury.

Butterfly

Mechanics

The butterfly stroke is a bilateral activity, as opposed to a reciprocal, unilateral pattern in the freestyle and backstroke. The pull pattern and body motion are also different, with the butterfly stroke typically consisting more of an S-shaped pulling pattern (Figure 14-5) and the upper body pivoting up and down about the hips, instead of rotating about the central axis as in freestyle and backstroke.

The hands enter the water with the arms extended forward and in front of the shoulder. The upper body presses down at the same time the arms enter the water to generate a more dynamic motion on entry and support the swimmer's forward motion. The hands and arms should remain extended forward during the upper body press, as opposed to aiming downward. This being the case, the magnitude of the upper body press has a great influence on the subsequent motion of the early pull-through and on susceptibility to shoulder pain. Swimmers who press the chest down such that the hands and arms are above the torso are generally in a more risky shoulder position in the early pull-through because this leads to the humeral hyperextension (the humerus is behind the axis of the body). The pulling pattern for a swimmer with a deep upper body press tends to go wide and well outside the shoulder on the early pull-through. If a swimmer is experiencing shoulder pain in the early pull-through, a possible corrective measure for the mechanics is a change in the depth of the upper body press and focusing on keeping the arms in line or in front of the body.

During late pull-through and the beginning of the recovery phase, there is also a chance for the shoulder to be at risk. At the beginning of the late pull-through, the arms are bent and the hands are underneath the hips. The arms then extend, with the hands sweeping outward and the arms lifting upward to exit the water and transition into the recovery phase. There is potential for the humerus to be internally rotated during the arm exit and early recovery phase. A swimmer should not overemphasize the end of late pull-through and lift the hands out of the water too high; instead, he or she should keep his or her hands as close to the surface of the water as possible in the early recovery phase.

With the undulating body motion in the butterfly, the swimmer takes a breath by lifting the upper body upward throughout the underwater pull-through. The swimmer should use the forces generated by the pull-through to lift the upper body just enough for the shoulders and head to clear the surface, but it is common for swimmers to forcefully arch the back and throw the head upward to do this. This action, followed by lunging forward on arm entry, can stress the spine and lower back.

Muscle Activity

As with the freestyle stroke, the pattern of disruptive muscle firing patterns during the butterfly are primarily seen in the muscles attaching to the scapula. The two muscles with clinically relevant muscle firing changes in the painful shoulder during the butterfly are the serratus anterior and the teres minor.[8] In swimmers with painful shoulders,

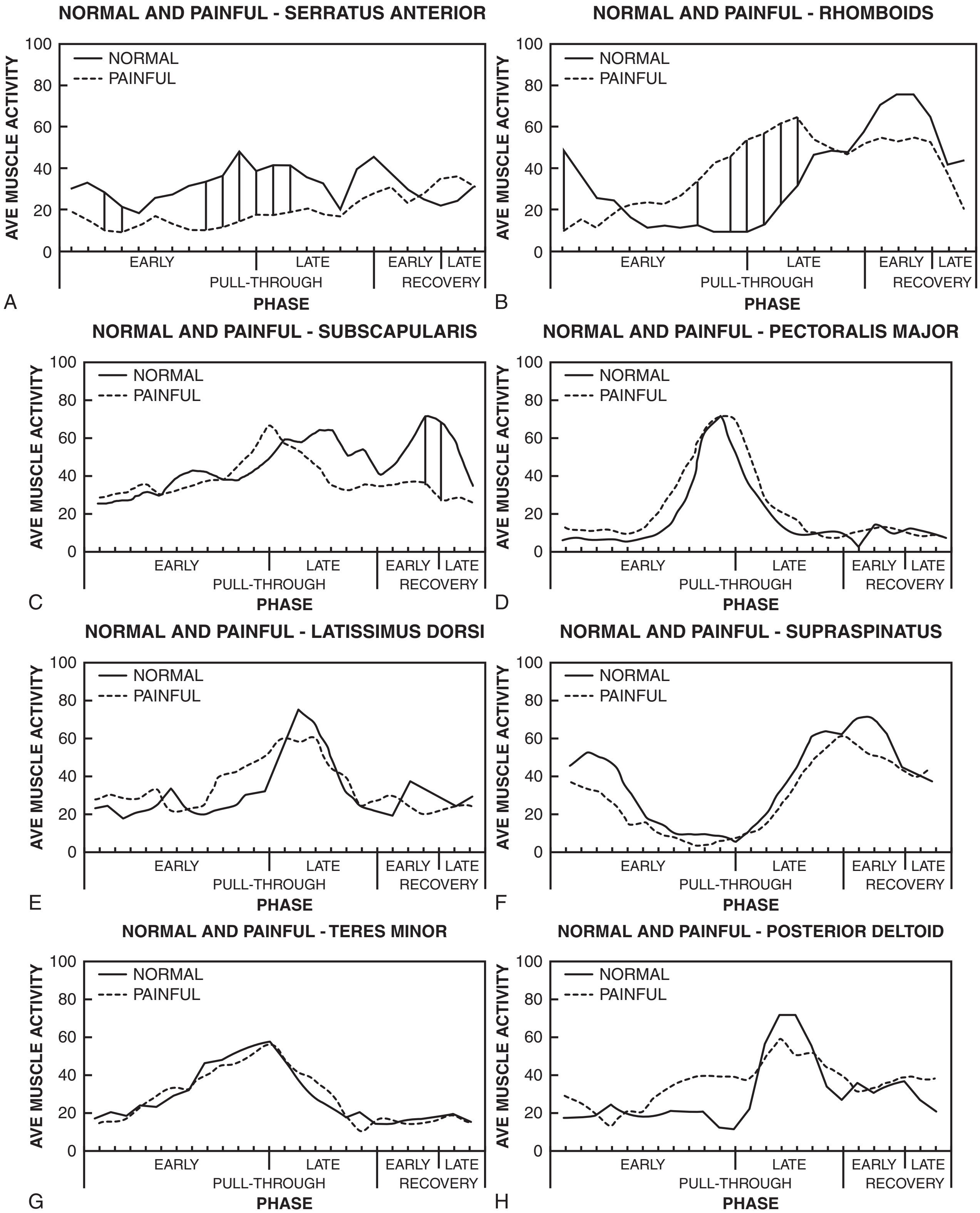


Figure 14-4

Normal and painful shoulders muscle firing during the freestyle. **A,** Serratus anterior. **B,** Rhomboids. **C,** Subscapularis. **D,** Pectoralis major. **E,** Latissimus dorsi. **F,** Supraspinatus. **G,** Teres minor. **H,** Posterior deltoid. (From Scovazzo ML, Browne A, Pink M, et al: The painful shoulder during freestyle swimming: An electromyographic cinematographic analysis of twelve muscles, *Am J Sports Med* 19[6]:579-581, 1991.)

Figure 14-5
S-shaped pull of the freestyle swimming stroke. (From Pink M, Perry J, Browne A, et al: The normal shoulder during freestyle swimming, *Am J Sports Med* 19:569–576, 1991.)

the hand entry is wider than that of the swimmers with normal shoulders. This is also one of the two common points at which swimmers experience shoulder pain during the butterfly stroke.[2] With the wider hand entry, the scapula does not need as much upward rotation or protraction, as evidenced by the decreased activity in the serratus anterior. The teres minor also reveals significantly less action, most likely caused by the altered scapular and humeral position.

During the powerful pulling in the butterfly stroke, the swimmers with painful shoulders continue to demonstrate less action in the serratus anterior. This muscle is not firing enough to stabilize the scapula or to assist with the pulling of the body over the arm. The decreased firing may be attributable to fatigue. In the normal shoulders, the serratus anterior constantly fires above 20% (which, as previously discussed, leaves it susceptible to fatigue). In the painful population, the serratus anterior may have become fatigued, hence the markedly depressed muscle activity and the resultant unstable scapula.

With an unstable or "floating" scapula, the teres minor is unable to control the humeral rotation caused by the powerful pectoralis major. Therefore, these two muscles (the serratus anterior and the teres minor), which are attached to the scapula, lack the synergistic interplay to assist with propulsion and balance the rotatory humeral motion (Figure 14-6).

At the end of the recovery phase, the teres minor also exhibits decreased muscle activity in the swimmer with a painful shoulder. This is most likely because the muscle is preparing for the wider hand entry, and thus does not require as much action.

The butterfly is not a stroke in which the swimmer puts in the same yardage as the freestyle stroke without a rest period between sets. Therefore, the concern is not as great for fatigue in the butterfly as it is for the freestyle. Yet the fact that the swimmers who perform the butterfly actually train largely with the freestyle stroke cannot be overlooked and fatigue must be considered.

Backstroke

Mechanics

The backstroke is similar to the freestyle stroke in that the arms stroke reciprocally and are supported by a trunk rotation and a leg kick. Obviously, the major difference between the backstroke and the freestyle is that the backstroke is performed supine. In the backstroke, the shoulder is vulnerable to injury similarly to the freestyle, and the relationship between the arm and the body orientation is important to note.

The phases are the same for the two strokes. The beginning of the pull-through is marked by the hand entry of the

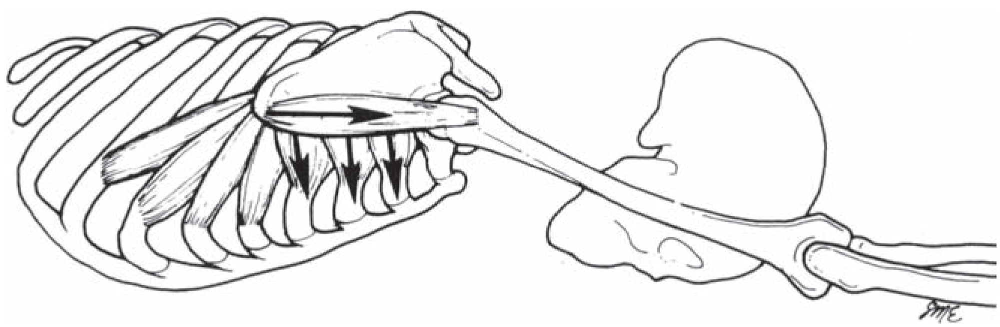


Figure 14-6
With a floating scapula during the butterfly stroke there is no stable base and the teres minor and serratus anterior cannot function adequately.

swimmer with the arm extended above the head. The arm becomes submerged and the hand and arm press toward the feet. The mid pull-through phase begins when the humerus is perpendicular to the body. The arm continues to move toward the feet, and at the end of the late pull-through, the elbow straightens out with a slight downward press before lifting out of the water to start the recovery phase. The elbow is fully extended throughout the recovery phase and travels straight over the top of the water and overhead to the point of hand entry.

The timing of the body rotation as it relates to the arm entry and early pull-through is important. To maximize performance and minimize shoulder vulnerability, the body should be rotating in synchrony with the arm. In other words, if the humerus is oriented 30° below the surface, the torso should be rotated a similar amount below the surface at that time. However, oftentimes this is not the case, because it is typical for the timing of the body rotation to lag behind the arm mechanics. Common symptoms of a late body rotation are a hand entry that crosses inside the shoulder width and a hand entry with the back of the hand. In this situation, in which the arm stroke leads the body rotation, the humerus is hyperextended. For the body rotation and arm motion to be in sync, it is important that the body rotation is initiated at the mid-recovery phase so that at hand entry, the shoulders are horizontal in the water. The body rotation continues as the arm is submerged and the early pull-through is started. The swimmer should rely on the leg kick and the late pull-through to properly execute the body rotation.

Variations across swimmers in the mechanics of the early pull-through phase can also affect the degree of shoulder vulnerability. After the hand enters the water, the early pull-through can vary in depth, palm orientation, and direction of the initial motions. Although observations of today's elite backstrokers show that their palms rotate toward the feet very shortly after hand entry and their arms stay to the side of the body, many swimmers have been taught to press downward immediately after entry to have a deep pull. A deep, early pull-through can lead to a humeral hyperextension because the body is not rotated enough—or soon enough. If a swimmer is experiencing shoulder pain in the early pull-through phase of backstroke and the swimmer is observed to have a straight arm and deep initial pull, then some stress on the shoulder may be relieved with a suggestion to keep the pull more shallow and the arm closer to the body.

At the end of the late pull-through, when the hand exits the water, it is important that the hand exit the water with the thumb first. Lifting the arm out with the pinky first will result in excessive humeral internal rotation. This will increase the pinching of the supraspinatus on the undersurface of the acromion. The hand then rotates during mid-recovery so that the hand can enter the water with the pinky first and the palm rotated out.

Muscle Activity

The muscle action during the backstroke, by mere virtue of the swimmer being on his or her back, is widely different from that of the other strokes. The muscles most active during the powerful pull-through are the teres minor and the subscapularis[9]; and obviously, these two muscles were not designed for power. Even during the peak moments of pulling, the latissimus dorsi reveals 30% less action than does the teres minor and the subscapularis in swimmers with normal shoulders. So, not only is the backstroke swimmer at risk because of the aforementioned humeral hyperextension and levering of the humeral head anteriorly, but these athletes require the small rotator cuff muscles to perform as power muscles.

In addition, during pull-through, the teres minor and subscapularis are constantly active at approximately 30% maximum voluntary contraction. Thus it appears that these two rotator cuff muscles are functioning as power drivers as well as endurance muscles.

At the same time as the depressed activity in the teres minor in the backstrokers with painful shoulders, the rhomboids also exhibit less action.[10] Apparently, the scapula is not retracted properly in early recovery and hence there may be less clearance for the humeral head under the acromion.

A third rotator cuff muscle, the supraspinatus, demonstrates suppressed activity toward mid pull-through in the swimmers with painful shoulders.[10] Given the decreased action in three of the four rotator cuff muscles, one can reasonably conclude that there could be difficulty in depressing the humeral head for adequate clearance of the acromion during pull-through.

Breaststroke

Mechanics

The breaststroke is the oldest of all competitive swim strokes, and it is unique in that the arms do not exit the water. In this stroke, the legs are more of the propeller or power drivers than are the arms. It appears that the least number of complaints of shoulder pain appear to occur with the breaststroke. And, the issue of body rotation along with humeral hyperextension is minimal. This stroke uses a bilateral arm motion in which the arms reach forward and then sweep outward (the beginning of the pull-through), while the elbows begin to flex. When the hands are in line with the mid-chest, the hands move inward in a circular pattern until they meet in front of the chest and are thrust forward (recovery) once again. Because the arms remain in front of the body at all times, the shoulders are not at high risk in the breaststroke.

Just like the butterfly, the body motion in the breaststroke is centered around the hips. The swimmer breathes by lifting the head up as well, but because the breaststroke arm motion leads to a much more natural lifting of the upper body, the spine and lower back are not as susceptible to pain as in the butterfly stroke.

The kicking motion most frequently used in competition is the whip kick, a symmetric, bilateral action (Figure 14-7).

The kick motion starts with the legs fully extended horizontally. The knees bend and move forward as the heels are brought as close to the buttocks as possible. When the heels reach their highest point, the feet rotate outward so that the toes point to the side, and will also move wide of the knees. The knees and feet push backward and inward from that position until reaching full extension with the legs together again. Forward propulsion is generated primarily by the force of the inside of the feet and lower leg pushing directly against the water. The feet and knee orientation during the propulsive portion of the kick can create issues with the knee, and the forceful inward motion can lead to a pulled groin muscle. A swimmer can reduce the risk of injury in these cases with proper warm-up and conditioning.

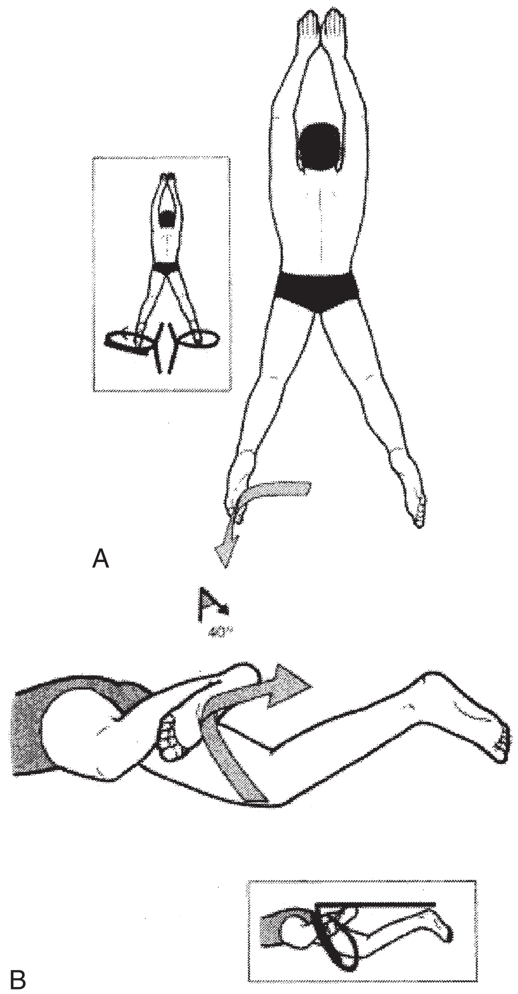


Figure 14-7
Whip kick. **A,** Propulsion generated during the inward portion of the insweep of the breaststroke kick. **B,** Propulsion is produced during the downward portion of the insweep of the breaststroke kick. The illustration shows how water can be displaced backward by the combination of direction and angle of attack during the first downward portion. (From Costill DL, Maglischo EW, Richardson AB, International Olympic Committee: *Swimming,* An IOC Medical Commission Publication, pp 102-103, Oxford, 1992, Wiley-Blackwell.)

Muscle Activity

During pull-through, breaststroke swimmers with painful shoulders demonstrate an increase in activity in the subscapularis and the latissimus dorsi.[11] The increased subscapularis activity, along with a decrease in the action of the teres minor, leads to a relative increase in internal rotation. The increased internal rotation places the arm in a position that is vulnerable to impingement. The increase in latissimus dorsi action may assist with humeral head depression to relieve the impingement.

Subtle Signs of Injury

Pain versus Soreness

Soreness versus pain: One is expected in the competitive athlete and the other is a signal of potential anatomical damage. Thus, it is appropriate to spend a moment discussing the difference between "pain" and "soreness." The perception of pain may be influenced by the society in which the person lives. Some cultures are more reticent to admit to pain than others. For example, baseball players in Japan in the late 1800s were not allowed to admit to pain, but rather would say "Kayui" or "it itches." Groups of athletes can be their own societies. In our training rooms today, we might see the opposite of the Japanese ball players from the 1800s: Upon inquiry and examination, we may find that a good portion of the pain that was initially reported by athletes in the training room may end up being soreness. When societies shift their perception of pain, the relative nature of the pain scale interpretation must shift also. Therefore, it is worth asking an athlete if the feeling is really one of pain or one of soreness. Soreness can be expected. It is natural for intense workouts to cause soreness.

The feeling of "soreness" is loosely herein defined as a generalized feeling in the muscles, whereas the feeling of "pain" is loosely defined as a deeper, and sometimes sharper, more localized feeling. True pain infers the potential for anatomical damage. This damage means it is probably time to see a physician—and perhaps time to cease training until the issue is resolved. The words to communicate pain versus soreness may offer a challenge. Yet every athlete knows what true pain is.

Pain scales are common in medicine. When a nonathlete patient is recovering from surgery, he or she may be encouraged to take his or her pain medications when the pain hits a "3" or "4." The relative shift in the pain scale is very different for competitive athletes. Coaches and strength and conditioning professionals want to break the athletes down with high-level training to ultimately make them stronger. In the case of the swimmer, this is usually mid-season.

Pain exists on a continuum—and yet with our interpretation and discussion of pain, we are trying to fit it into categories. Although the categorization of pain is easiest for discussion purposes, it is not entirely accurate. So, when combining the categorical discussion along with societal influence, interpretation of a pain scale can be difficult in this population. The true accuracy comes from an integration of the pain scale with observations of the athlete, the on-deck personnel, and the medical professionals.

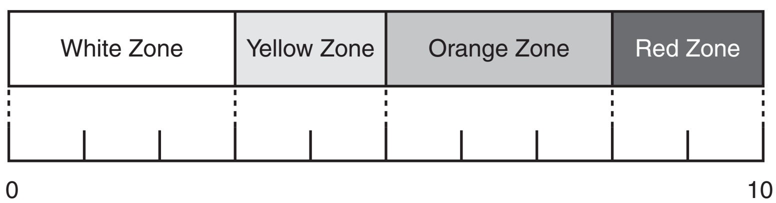
Athlete's Pain Scale

An athlete's pain scale is suggested in Figure 14-8. This scale is currently under investigative study, and hence the reliability and validity are unknown. The authors choose to present it, however, to make the point of differentiating pain from soreness, as well as the point that an athlete's perception of pain may well require a different interpretation from that of a nonathlete.

The standard 10-cm horizontal line is used for this pain scale, which has a mark at every centimeter, with the 0 and the 10 numerically identified (see Figure 14-8). The different zones of white to red are used for the purpose of communicating with the health care professional. The color codes are not necessarily presented to the athlete.

White Zone (0-3). Symptoms in the white zone indicate fatigue and soreness from training rather than true pain. This zone is a normal part of the intensity of training in a competitive athlete. The athlete can continue to train and continue with his or her exercise conditioning program when pain is reported in this zone. As the athlete increases the intensity of pain on the scale, the athlete may progress to "shampoo arm syndrome" (i.e., it is hard for the athlete to lift his or her arm to shampoo his or her hair in the shower after workout) and faulty mechanics by the end of the workout. As the athlete reaches a level 3 pain, ice is recommended, and the athlete needs to make certain he or she is performing his or her conditioning program appropriately. At this point, mechanics are normal at the beginning of the workout, and may have adapted by the end of the workout because of fatigue. Within this zone, the athlete is still able to complete a full workout but may need to minimize certain strokes to avoid pain. Pain may last 2 to 4 hours after practice, but is resolved upon waking the next day.

Yellow Zone (4-5). The yellow zone is the "heads-up" zone, signaling caution, yet basically managed by the athlete and the coach. Almost all competitive athletes reach this zone at some point in the season. The coach is trying to break down the athlete so that he or she can then progress to the next level of performance. If the athlete's pain increases throughout this zone, his or her mechanics may become faulty, stroke disciplines modified, and workout distances decreased. Minor performance inconsistencies develop early in this zone, yet the athlete can still compete well enough to win. As this zone progresses, the performance diminishes. Pain may be experienced with forceful arm movements during swimming. Pain may last 4 to 8 hours following a workout, and could be experienced on waking the next day. Management strategies for this zone include a longer-than-normal warmup with slow swimming. It is recommended that sprint sets and hand paddles be eliminated from practice. Fins can be used during



White Zone (0-3): Normal level
- continue to train
- fatigue and soreness during and post-workout
- handle with coach and athlete

Yellow Zone (4-5): "Heads-up" level
- continue to train
- review conditioning program
- handle primarily with coach and athlete

Orange Zone (6-8): Rehabilitation
- consider removing from training

Red Zone (9-10): Remove from training
- refer to physician
- anatomical damage

Figure 14-8
Athlete's pain scale.

practice to unweigh the shoulders. To maintain a feel of the water, the athlete can kick in a side-lying or vertical position, but with the involved arm down by the side. The conditioning program should be reviewed with the athlete before and after a workout with a level 4 pain. Once again, adaptations in the program performed after the workouts are probably secondary to fatigue (and simple planar motions may exhibit scapular asymmetry), whereas substitution patterns in the program before a workout need attention. The true pain is probably localized (the soreness and fatigue are generalized). Ice is recommended after practice and before bedtime. If the athlete cannot return to pain-free swimming within 7 to 10 days of modifying the stroke, workout, and conditioning program, referral to sports medicine staff may be appropriate.

Orange Zone (6-8). The orange zone is the rehabilitation zone. Once the pain duration consistently spills into the next day (level 6), the swimmer should be referred to sports medicine staff. This could be the start of potential anatomical damage. The power portion of the upper-extremity conditioning program should be considered and probably discontinued by the time the swimmer's pain is in this zone. Early in this zone (level 6), the coach may want to consider a 3-day rest from workouts. If the swimmer does not improve with a 3-day rest, then a referral to a physician is appropriate.

Red Zone (9-10). This zone represents anatomical damage. The athlete is unable to perform at a competitive level, must stop swimming altogether for an undetermined period, and needs to be under the care of a physician, physical therapist, or athletic trainer.

Mechanical Changes

Mechanical changes in the body go hand-in-hand with fatigue, soreness, and pain. Swimmers will modify their stroke because of these factors before they decrease workouts. The mechanical changes caused by fatigue are identified prior to the pain modifications. These alterations obviously show up toward the end of the workout as fatigue increases. When the fatigue-induced mechanical changes show up early in the workout, then the swimmer may need a recovery workout or a day of rest. The butterfly is likely the first stroke to demonstrate mechanical changes, followed by the freestyle and the backstroke. The breaststroke is likely the most mechanically enduring stroke related to fatigue, soreness, and pain.

Mechanical flaws and adaptations are easiest to see from the underwater vantage point. Ideally, all pools would have underwater windows, both laterally and under the pool. A more practical solution is the use of underwater video, which has become an affordable and valuable analysis tool. The most subtle changes in mechanics will be very difficult for a relatively naïve eye to catch, and the use of digital video analysis software can aid a coach and clinician to diagnose mechanics.

Because the medical personnel are not typically on-deck with the swimmers and coaches, it behooves sports clinicians to be a bridge between the clinics and the deck. Thus, it is important that sports clinicians converse with the coaches and on-deck personnel about the subtle mechanical changes that may lead to anatomical damage.

Because the freestyle is the most used stroke, the mechanical changes caused by fatigue, soreness, and pain are noted herein for that stroke. Table 14-1 presents some of the more common potential mechanical changes in the freestyle stroke.

Clinical Implications

Repetitive overuse appears to be a major contributor to shoulder pain in swimmers. In addition to the aforementioned mechanics, which can lend to impingement, other contributing factors for swimmer's shoulder include (1) overuse and subsequent fatigue of the muscles around the shoulder, scapula, and upper back; and (2) glenohumeral laxity. These factors are all related, because impingement may be caused by altered glenohumeral kinematics resulting from muscle fatigue or glenohumeral laxity. Other associated findings include muscle imbalances and inflexibility, such as tightness of the pectoral muscles, and sometimes inflexibility of the posterior capsule and posterior rotator cuff.

Muscle Fatigue and Dysfunction

Because the shoulder is an inherently unstable joint, muscle forces are critical for maintaining stability, proper motion, and painless function. As previously discussed, performance of the swimming stroke requires a highly coordinated pattern of muscles firing at precisely the right time to provide the most efficient and powerful stroke. If one muscle fatigues, it is as if one cog in a machine is malfunctioning. When that one muscle fatigues, it affects the function of other muscles in the kinetic chain.

Muscle dysfunction increases impingement by loss of the humeral head depressor function of the rotator cuff and loss of upward rotation and elevation of the scapula. Loss of the stabilizing effect of muscles may be especially problematic in swimmers with associated shoulder laxity (discussed in the following section). Fatigue of the abdominal and pelvic muscles may also contribute by affecting scapular kinematics and body position in the water.

Laxity

Many competitive swimmers have an element of shoulder laxity.[12,13] A certain degree of laxity may be advantageous by allowing a swimmer to achieve both a body position that

Table 14-1
Common Freestyle Mechanical Changes Caused by Fatigue, Soreness, and Pain

Mechanical Change	Effect on Stroke
Wider hand entry and lateral underwater hand motion	Hand starts wide and "slides" under the belly Less force on the shoulder Flatter hand entry Avoids Neer and Hawkins impingement positions
Shorten underwater reach after hand entry	Hand does not extend as far forward under water after hand entry Avoids positions that mimic Neer and Hawkins impingement positions
Leading with elbow rather than hand during catch and early pull-through	Attempts to decrease amount of force on hand and forearm
Early hand exit	Minimizes humeral internal rotation Looks similar to hand exit with butterfly stroke
Decreased trunk rotation	Related to shorter underwater reach and early hand exit Attempts maintain stroke rate
Premature rotation and lifting of head prior to breathing	Attempts to get arm out of water earlier and with less force in final position of stroke
"Dropped" elbow on recovery	Decreased elbow flexion and height More lateral swing Attempts to avoid painful internal rotation of humerus

reduces drag and a longer sweep during the pull-through phase. It is well-established that there is a narrow distinction between physiological laxity (normal) and pathological instability (abnormal). Normal laxity may increase over time because of repetitive overuse and eventually become a pathological condition. Shoulder stability is controlled by static (i.e., glenohumeral ligaments and capsule) and dynamic (rotator cuff muscles) factors. Loss of the static component (i.e., glenohumeral capsular laxity) requires a greater contribution from the rotator cuff, which can result in muscle overload and eventual muscle fatigue, as described previously. The challenge for the clinician is to distinguish between normal laxity and abnormal instability.

Previous studies have documented the presence of increased joint laxity and glenohumeral instability in swimmers. Bak and Faunø reported that 37 out of 49 competitive swimmers had increased humeral head translation with associated apprehension.[14] Furthermore, McMaster and colleagues found a significant correlation between shoulder laxity and shoulder pain in a group of 40 elite-level swimmers.[15] The presence of underlying generalized joint hypermobility was reported by Zemek and Magee.[13] These authors reported both increased glenohumeral laxity and increased generalized joint hypermobility in elite swimmers. These studies suggest that a combination of acquired and inherent factors contribute to shoulder laxity in swimmers.

The most common pattern of instability is anteroinferior, but there is often a component of multidirectional instability. Subluxation can occur during the backstroke as the hand enters the water with the swimmer on his or her back with the arm in full flexion and external rotation. Posterior instability symptoms, although less common, may be exacerbated because of the position of the arm in flexion, adduction, and internal rotation.

Impingement

Swimmers usually have a nonoutlet type of impingement, in which altered kinematics rather than subacromial pathological changes (i.e., acromial osteophyte or coracoacromial ligament abnormalities) results in abnormal contact. Such impingement may be subacromial (the bursal surface of the rotator cuff against the anteroinferior acromion) or intra-articular (the articular surface of the rotator cuff or biceps tendon impinges on the anterosuperior glenoid and labrum). The position of the shoulder during the recovery phase of the stroke (forward flexion and internal rotation) is a classic position for subacromial impingement. At the end of the pull-through phase of the stroke, the arm goes into hyperextension, which pushes the humeral head anteriorly, which also exacerbates impingement. Use of a video analysis system to document impingement during the freestyle stroke found that impingement occurred when the hand entered the water and in the middle of the recovery phase.[16] The mean duration of impingement was nearly 25% of the total stroke time. This study demonstrated that impingement was most likely in swimmers who have excessive internal rotation during the pulling phase, delayed initiation of external rotation of the arm during the recovery phase, and decreased upward scapular rotation.[17] Hydrodynamic forces exerted by the water may also exacerbate impingement. At the point at which the hand enters the water, the hydrodynamic force exerted on the hand generates a large moment about the shoulder joint caused by the long moment arm in this position. This moment will forcibly elevate the arm, possibly increasing impingement.[16]

Alternatively, intra-articular impingement may occur during the swimming stroke as the articular surface of the rotator cuff can impinge against the anterosuperior labrum adjacent to the biceps attachment as the arm is placed into forward flexion and internal rotation. Such a mechanism could account for the frequent localization of pain around the biceps tendon in swimmers. The position of forward elevation, adduction, and internal rotation may also result in impingement of the coracoid process on the lesser tuberosity and subscapularis tendon.

Muscle fatigue caused by overuse may also contribute to impingement. The normal rotator cuff functions to stabilize the glenohumeral joint and acts as a humeral head depressor, preventing subacromial impingement. It is known that loss of the humeral head depressor function of the rotator cuff results in superior migration of the humeral head and increases the risk of impingement.[18]

Conditioning, Prevention, and Rehabilitation

Stretching

Given the discussion on laxity as well as underwater videography indicating that no extraordinary shoulder joint motion is necessary for a fast, efficient stroke, there is little reason to consider an excessive stretching program for swimmers. As a matter of fact, the stretching performed by many swimmers may actually be harmful to the capsuloligamentous structures. Thus, it is probably more important for swimmers to stop traditional stretching practices than it is to begin proper stretching based on individual physiology. The four stretches demonstrated in Figure 14-9 should no longer be considered in a dry-land program for swimmers.

Stretching is athlete-specific. A simple shoulder screen (Figure 14-10) for coaches and on-deck personnel has been developed to review the flexibility of all members of the team effectively and efficiently. There are three positions for each athlete to review:

Suggested Flexibility Screen for Swimmers

- Tight streamline position (see Figure 14-10)
- 90/90 position (see Figure 14-10)
- 45° position (see Figure 14-10)

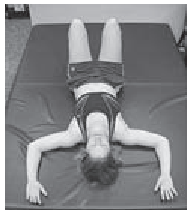
1. **Tight Streamline Position—½ Sit Against the Wall.** This position is a sport-specific, functional position that assesses mobility in the scapulothoracic and glenohumeral joints as well as the length of the latissimus dorsi. The swimmer should be able to complete this desired motion without difficulty with the lumbar

Figure 14-9
Stretches that swimmers should NOT do.

Tight Streamline –$^1/_2$ Sit Against Wall: Assume the following tight streamline position.
(In order to 'pass' this position, all of the 5 questions in this section must be answered with a 'Yes'.)

Are the elbows in full extension?	YES	NO
Are the arms by the ears?	YES	NO
Are the hands clasped?	YES	NO
Are the hands in contact with the wall?	YES	NO
Is the low back in contact with the wall?	YES	NO

90/90 Position: Lie supine with knees bent and feet on surface. Assume 90° of shoulder abduction in the coronal plane and 90° of glenohumeral external rotation.
(In order to 'pass' this position, all 4 of the questions in this section must be answered with a 'Yes'.)



Are the shoulders flat on the floor?	YES	NO
Do the forearms and elbows rest comfortably on the floor?	YES	NO
When the swimmer is asked to press his/her wrists into the surface, are the wrists flat on the surface?	YES	NO
Is the back flat the surface?	YES	NO

45 Position: In standing with the humerus in full adduction (arm by your side), bend your elbows to 90° and externally rotate to 45° or beyond.
(In order to 'pass' this position, both of the questions in this section must be answered with a 'Yes'.)

Do the shoulders rotate to 45° or beyond?	YES	NO
Do the elbows maintain contact with the trunk?	YES	NO

If a swimmer is able to achieve at least two of the positions above, then he/she is well served with the stretching program herein. If the swimmer fails in 2 or all of the positions, then a customized stretching routine from a health care professional is recommended.

Figure 14-10
Shoulder range of motion screen for swimmers.

spine flat against the wall, full elbow extension, and clasped hands against the wall.

2. **90/90 Position.** This position is completed in supine position. It assesses mobility of the inferior and anterior glenohumeral joint capsule as well as the blended anterior band of the inferior glenohumeral and the middle glenohumeral ligaments.[19] Shortening of the pectoralis group is also identified with this position. The swimmer should be able to rest his or her forearm, wrist, and elbow comfortably on the floor in this position while maintaining 90° of elbow flexion and 90° of glenohumeral abduction. The posterior shoulder joint muscles should be in contact with the floor or table.
3. **45° Position.** This position specifically assesses the length of the subscapularis. A competitive swimmer needs to be able to achieve this position with 45° of external rotation while keeping the humerus in an adducted position.

If the swimmer is able to achieve at least two of these positions, then the athlete is well served with the stretching program described in Figure 14-11. If the swimmer is unable to achieve two or more of the positions in the shoulder screen, then consultation with a sports medicine professional is encouraged to help identify the origin of the restriction and develop a customized stretching program for that individual.

Based on the physical demands of swimming, understanding the biomechanics of the stroke and respecting the capsuloligamentous structures, the focus of the recommended stretches is to target the at-risk connective tissue while avoiding insult to the static stabilizers. Observationally, it appears that only three muscle groups of the glenohumeral joint may be at risk of shortening in the swimmer. Those three groups are the (1) pectoralis muscles, (2) latissimus dorsi, and (3) subscapularis. If these muscles have been tight for a prolonged period, there is also a risk of tightness in the capsuloligamentous complex.

However, swimmers tend to have more tightness in the low back than in the shoulder. Although the back is not necessarily at risk during the swim stroke, the "common" posture of the swimmer with forward shoulders, lordotic back, and genu recurvatum indicates that the soft tissue structures in the lumbar spine may shorten. In the long run, this is known to be a potential cause of back problems.

Although there is little, if any, research literature on the musculoskeletal requirements and common limitations of the lower extremity, a swimmer ideally has good range of motion (ROM) at the hip and at the ankle. If there are tight hip flexors, they could contribute to a low back problem. And if there is a limitation in ankle plantar flexion ROM, kicking efficiency could be decreased.

Based on these observations and if the swimmer "passes" the shoulder screen in Figure 14-10, an appropriate dry-land stretching routine can be found in Figure 14-11.

It is recommended that swimmers stretch at a time unrelated to working out or racing (at least several hours prior to getting in the water). Pre-exercise stretching has been found to compromise muscle performance for up to 1 hour.[20-25] Postexercise stretching is not encouraged. Stretching fatigued muscles tends to facilitate muscle spindle and inhibit Golgi tendon organ firing.[26,27] General guidelines for stretching include completing a specific static stretch that targets muscle tissue one to three times for 15 to 30 seconds each, approximately 5 days a week is appropriate.[28-31] Instead of pre-exercise stretching, a longer warmup in the water with increasing intensity is recommended.

Conditioning the Uninjured Swimmer

Given the muscle functions described previously, the following is an offered infrastructure intended to assist the health care professional in designing a conditioning program for the uninjured swimmer that is specific not only to swimming, but also specific for the individual's competitive strokes. Numerous studies identify optimal exercises for the different muscles.[32-41] The suggested optimal exercises are simply that: a suggestion for a starting point in considering the conditioning program.

A program for competitive butterfly, backstroke, and breaststroke swimming will, most likely, include the exercises for the freestyle stroke because most swimmers (regardless of competitive strokes) put in large distances with the freestyle. Coaches are encouraged to implement the strength and endurance program after practice or several hours before practice (Table 14-2). Exercising the muscles of the shoulder complex directly before practice may lead to fatigue and subsequent faulty stroke mechanics.[7]

Rehabilitation

Given the currently known specificity of muscle requirements in the competitive swimmer, the work of the rehabilitation professional can be much more focused than ever before. The intent of these few paragraphs is to give the professional the scaffolding on which to build the nonsurgical rehabilitation program.

A swimmer's inflamed shoulder is treated the same as the inflamed shoulder of any individual. Rest from offending activities, ice, and anti-inflammatory medication may be necessary as well as potential application of modalities such as iontophoresis, ultrasound, or high-voltage galvanic stimulation. Once the inflammatory process is halted, gentle stretches such as those described in the conditioning program are suggested. Consideration needs to be given to safe arcs of motion for the stretches. Identification of the weak

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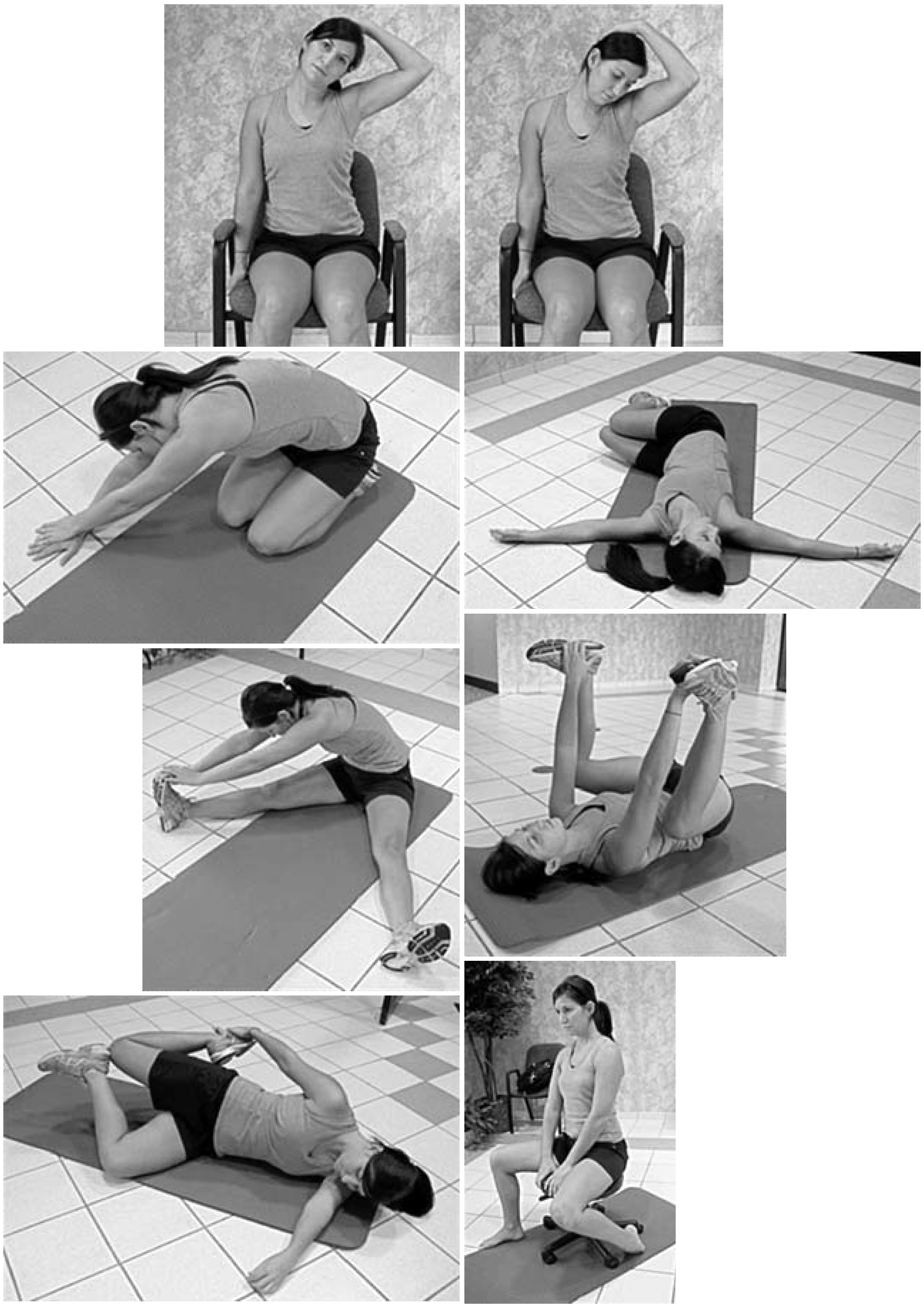

Figure 14-11
Dry-land stretching recommendations for swimmers.

muscles begins at this stage. As reinforcement to the aforementioned material, each swimming stroke carries different muscle injury risk requiring varying levels of strength and endurance.

Once the weak components for the glenohumeral muscles are identified, the specific exercise program can be developed. The optimal exercise program takes into consideration not only those exercises that optimally recruit the specific muscles within a safe and efficient range, but they also use the most effective type of contraction (i.e., isometric or concentric). For example, if the rhomboids were muscles needing strengthening, the optimal exercise is an isometric contraction while the muscles are in the maximally shortened state. Although it is beyond the scope of

Table 14-2
Muscles at Risk During the Swim Stroke and Suggested Exercises

Stroke	Muscles at Risk	Strength or Endurance	Suggested Optimal Exercises
Freestyle	Serratus anterior	Strength	Push-up plus Military press
		Endurance	Scaption moving from medial rotation → lateral rotation with low load—use time as a measure rather than repetitions Upper-body exercises, boxing, or fencing maneuver
	Subscapularis	Strength and endurance	Medial rotation—low load, high number of reps
Butterfly	Serratus anterior	Strength and endurance	Suggestions as with freestyle
	Teres minor	Strength and endurance	Lateral rotation with humeral elevation—low loads—fairly quick motions—high number of repetitions Lateral rotation with humerus ≈30° off the trunk—can be higher load and slower than lateral rotation with humeral elevation
Backstroke	Teres minor	Strength and endurance	Suggestions as with butterfly
	Subscapularis	Strength and endurance	Suggestions as with freestyle
	Rhomboids	Strength	Retraction with an isometric hold
	Supraspinatus	Strength	Flexion—challenging load to complete 15 repetitions
Breaststroke	Supraspinatus	Strength	Suggestions as with backstroke
	Upper trapezius	Strength	Shoulder shrugs

Table 14-3
Return to Swimming Benchmarks

Criteria to Allow Swimming	Swimming Activity Allowed
Benchmark 1	
Reach above shoulder height pain free Pain-free resisted movements 0° to 90°	Swim 1000-2000 yards slowly and comfortably while avoiding antagonizing swim strokes and sprint sets
Benchmark 2	
Pain free with resisted shoulder motions Pain free with most activities of daily living Pain free with swimming 2000 yards	Add 500 yards every three workouts Avoid double workouts at this time
Benchmark 3	
Pain free swimming 4000 to 5000 yards	Short sprint sets Incorporate all swim strokes

this chapter to discuss the specific muscle physiology for each muscle, health care practitioners have such information available to them.

Any individual with shoulder problems benefits from cardiovascular and muscle endurance rehabilitation. Walking, rowing, stationary bicycling, and use of the elliptical are all ways to maintain aerobic conditioning. Muscle endurance training is another integral part of the rehabilitation program for swimmers. Endurance training can be addressed with low-resistance and high-repetition activities.

Plyometric training has also been found to improve endurance. Swanik and colleagues[42] studied the effect of plyometric training on shoulder proprioception, kinesthesia, and selected muscle performance in a group of Division I female swimmers. After a 6-week period of a plyometric training program that focused on the internal rotators of the shoulder complex, both proprioception and kinesthesia significantly improved. The Swanik study confirmed that plyometric exercises for the competitive swimmer helps to promote endurance, glenohumeral joint stability, and neuromuscular efficiency.

Return to Swimming Program

Maintaining a feel for the water is critical during the rehabilitation process and, as a result, coordinating a timely return to the pool is essential. There are specific benchmarks in the swimmer's return to a pool program (Table 14-3) based on their progress. Adherence to a slow, progressive program ensures a healthy return to the sport they love.

Conclusion

The mechanics of swimming are different from that of the "overhead" athlete. Indeed each of the four swim strokes need to be considered independently. With the high rate of injury and reinjury, it is important for clinicians to understand the mechanics and the cause of injury and reinjury for each stroke. Such an understanding will not only allow the clinician and on-deck personnel to catch the subtle signs of injury, but it will also minimize the risk of potential injury and maximize the rehabilitative outcomes.

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