[Sports Physical Therapy]

Biomechanical Considerations in the Competitive Swimmer's Shoulder

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Context: Competitive swimming has become an increasingly popular sport in the United States. In 2007, more than 250 000 competitive swimmers were registered with USA Swimming, the national governing body. The average competitive swimmer swims approximately 60 000 to 80 000 m per week. With a typical count of 8 to 10 strokes per 25-m lap, each shoulder performs 30 000 rotations each week. This places tremendous stress on the shoulder girdle musculature and glenohumeral joint, and it is why shoulder pain is the most frequent musculoskeletal complaint among competitive swimmers.

Evidence Acquisition: Articles were obtained through a variety of medical search sources, including Medline, Google Scholar, and review articles from 1980 through January 2010.

Results: The most common cause of shoulder pain in swimmers is supraspinatus tendinopathy. Glenohumeral instability and labral tears have also been reported, but a paucity of information remains regarding prevalence and treatment in swimmers.

Conclusion: Because of the great number of stroke repetitions and force generated through the upper extremity, the shoulder is uniquely vulnerable to injury in the competitive swimmer. Comprehensive evaluation should include the entire kinetic chain, including trunk strength and core stability.

Keywords: swimmer's shoulder; swim strokes; biomechanics

ompetitive swimming has become an increasingly popular sport in the United States, with swimmers registered with USA Swimming topping 250 000 as of 2007.²⁰ Participation in swimming has steadily grown, with peak increases of membership in the year following Olympic competitions. Nearly 90% of the forward propulsive power in swimming comes from the upper extremities,²⁴ explaining the cause of shoulder pain and injuries. In fact, the most common musculoskeletal complaint among swimmers is shoulder pain.⁵ Richardson et al²⁵ showed that the incidence of shoulder pain was 52% of elite swimmers and 27% of nonelite swimmers. In McMaster and Troup, 19 47% of 10- to 18-year-old swimmers, 66% of senior development swimmers, and 73% of elite swimmers reported a history of pain in the shoulders. The frequency of pain in both studies was highest for the elite swimmers, which may be due to increased training time and number of years of swimming.

The term *swimmer's shoulder* was first coined in 1978, ¹⁶ and it was used to describe anterior shoulder pain during and after workouts. Since that time, swimmer's shoulder has come to represent a group of symptoms, not one specific diagnosis. The underlying cause of pain may be benign (eg, postworkout muscle soreness) or serious (eg, tendonitis,

instability, impingement, labral tears, or symptomatic os acromiale).⁵

Year-round swimmers average 6000 to 10 000 m (6500 to 11 000 yd) per day in practices. Practices are generally held 5 to 7 days per week, often twice a day, up to 3 times per week. This equates to roughly 60 000 to 80 000 m of total swimming distance per week. 4,12,25 With an average stroke count at 8 to 10 per 25 m, swimmers perform 30 000 rotations of each shoulder per week, placing tremendous stress on the shoulder girdle and glenohumeral joint.

There is a paucity of biomechanical information on the swimming shoulder. The movements in swimming are closed-chain mechanics, meaning that the distal segment (ie, the hand) is the relatively fixed segment, whereas the body is moved over the top of the hand. In swimming, 4 competitive strokes are used for training and racing purposes.

THE FREESTYLE STROKE

The front crawl stroke, or freestyle, is practiced for a large proportion of the time in swimming practices (Figure 1). It is also the fastest stroke in swimming races and has generated the most research.

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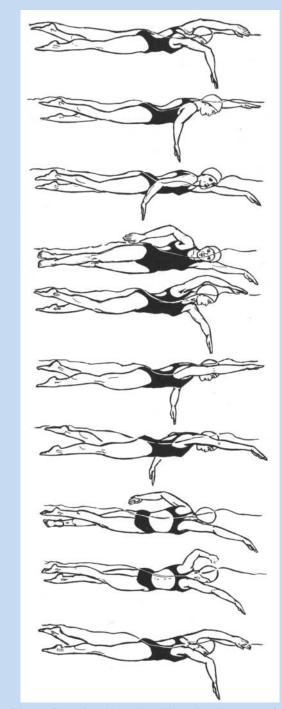


Figure 1. Freestyle stroke cycle pull-through and recovery of the right arm during a single stroke. (Used with permission from Colwin CM. *Breakthrough Swimming*. Champaign, IL: Human Kinetics; 2002:50-70.)

The glide phase of the stroke begins as the right hand enters the water, with the elbow held slightly higher than the hand.⁹ During the glide phase, the arm is held forward and lateral to the head with variability, from slightly medial to the shoulder to slightly lateral. During the glide, the upper trapezius, rhomboids, and serratus anterior show increased activity to stabilize and rotate the scapula upward to allow clearance of the humeral head.²³ The rhomboid muscle acts to anchor the superior angle of the scapula so that the upper trapezius and serratus anterior can provide leverage for upward rotation.

The pull-through phase of the freestyle stroke can be divided into 3 parts. The early pull-through phase occurs from the end of glide, at the point when the hand reaches maximum forward extension and begins a downward motion, to the time when the humerus is approximately 90° flexed in front of the body or perpendicular to the long axis of the body, with the arm pointing straight down to the floor of the pool. The midpull-through occurs when the forearm is pointing down to the floor of the pool. It is a transition between early and late pullthrough phases, and it has specific associated muscle action. The late pull-through phase occurs from 90° flexion to the time when the hand exits the water. During early pull-through, the elbow remains high, toward the surface of the water, as the shoulder moves into internal rotation, extension, and adduction at the glenohumeral joint. This can be seen as if the swimmer is grasping a point in the water and pulling his or her body over top (closed kinetic chain mechanics). A swimmer tries to pull directly backward (toward the feet); the rotation of the body on this long axis causes the hand and forearm to move laterally or medially under the torso. The high elbow position enables the swimmer to combine the strength of the arm rotators with that of the larger muscles of the torso as the body moves forward using the shoulder as the fulcrum.⁹ During early pull-through, the pectoralis major and teres minor work as a force couple to extend, adduct, and internally rotate the humerus.²³ During late pull-through, the latissimus dorsi increases its activity to extend the glenohumeral joint and assist the subscapularis with internal rotation.²³ Throughout early and late pull-through, the serratus anterior, pectoralis major, and latissimus dorsi are active to move the body forward over the relatively fixed hand (Figure 2).

At the end of the pull-through phase in transition to the recovery phase, the elbow remains slightly flexed as it exits the water before the hand. The posterior deltoid, middle deltoid, and supraspinatus work in a sequence to assist in extension and abduction of the humerus. The rhomboids muscles retract the scapula and initiate body roll to the opposite side in preparation for opposite-arm pulling and same side-arm recovery. The upper trapezius and serratus anterior increase their activity to rotate the scapula upward. The deltoid muscle sequentially fires during recovery, with the posterior deltoid initiating extension and the middle deltoid abducting, which is followed by the anterior deltoid flexing the shoulder in preparation for hand entry.²³ The recovery phase has a much shorter duration compared with that of the pull-through phase of the freestyle stroke because there is no water resistance to slow the movement of the arm.

The freestyle kick, or flutter kick, is performed continuously throughout the freestyle stroke. It is divided into upward and

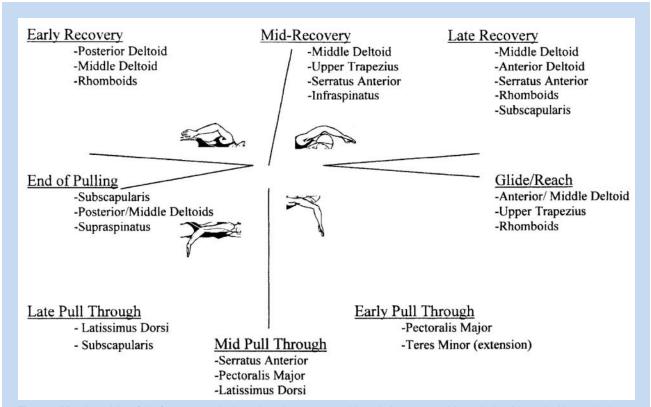


Figure 2. Muscle activity of the freestyle stroke based on electromyographic and cinematographic analysis. (Adapted with permission from Colwin CM. *Breakthrough Swimming*. Champaign, IL: Human Kinetics; 2002:50-70.) Figure copyright Scott Heinlein.

downward beats, primarily using the hip flexors and extensors, with less propulsive force generated from knee flexion and extension. The ankles remain in a plantar-flexed, slightly inverted position throughout the kick. There is some lateral movement of the legs during kicking, which is caused by the roll of the body. The number of downward beats during a full stroke defines kicking pace. A 2-beat kick is 1 downward beat of each leg with each arm stroke. It is more energy efficient in limiting lower extremity movement and muscle activity, but it provides less propulsion. A 6-beat kick requires 3 downward beats per arm stroke; it is primarily seen in sprinting and is less energy efficient, but it provides more propulsion.

VARIATIONS IN FREESTYLE MECHANICS IN THE PRESENCE OF PAIN

In 1991, Scovazzo et al²⁸ studied the painful shoulder in freestyle swimming. With impingement, the arm was placed farther from the midline on hand entry, with the humerus lower, in a dropped elbow position, with decreased anterior and middle deltoid, upper trapezius, and rhomboid activity. Cools et al¹⁰ showed late recruitment of upper trapezius in shoulders with impingement syndrome. During the pull-through phase, there was decreased serratus anterior activity with increased rhomboids activity, causing a net loss of scapular upward rotation and protraction. At the end of the pull-through,

the symptomatic swimmers demonstrated an early hand exit, presumably to avoid the extremes of internal rotation.²⁸ The rhomboids showed increased activity to retract and elevate the scapula. During recovery, there was decreased anterior deltoid activity, which limited forward flexion, causing a more lateral entry of the hand. Yanai et al³³ reported that the hydrodynamic force exerted on the hand during entry could forcibly elevate the arm beyond normal maximum active flexion, placing the shoulder in a position of hyperflexion, causing impingement. Mean duration of impingement positioning during the freestyle swimming stroke was up to 24.8% of the entire stroke, with 14.4% of this occurring during pulling and 10.4% occurring during recovery.33 Yanai found that swimmers experienced impingement on some stroke cycles and avoided it on others. Swimming technique was inconsistent in painful conditions, and shoulder actions were used in each stroke phase to prevent impingement.^{32,33} It is unknown whether the stroke alterations seen in swimmers with symptomatic shoulders are the cause or a consequence of the pain.

THE BUTTERFLY STROKE

The butterfly stroke uses the hips as a fulcrum for a characteristic teeter-totter motion of the body. It is similar to the freestyle, but the arms are used synchronously (Figure 3). Muscular activity during the butterfly is similar to that of the

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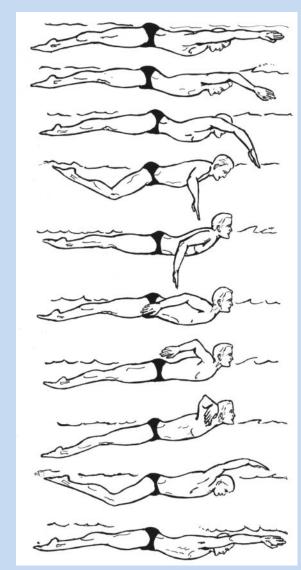


Figure 3. Butterfly stroke cycle pull-through and recovery. (Used with permission from Colwin CM. *Breakthrough Swimming*. Champaign, IL: Human Kinetics; 2002:50-70.)

freestyle stroke, with some exceptions. As the hands enter the water, the palms are turned outward (internal rotation with full pronation), and the upper trapezius, supraspinatus, and infraspinatus have high activity, along with the anterior, middle deltoid, and rhomboids.²² The elbows bend as the arms spread outward to position the hands and forearms to the high elbow position. This high elbow position provides leverage and a large surface area to pull the body through the water.⁹ The hands may move closer together under the shoulders as the arms move toward a 90° forward-flexed position in front of the body, perpendicular to the body's long axis, with the arm pointing straight down. As in freestyle, the pectoralis major, latissimus dorsi, and serratus anterior perform the majority of the pulling, with peak subscapularis and teres minor activity

at this mid-pull-through phase.²² The swimmer will flex the knees simultaneously and begin a downward kick, assisting in propulsion and hip position. From the 90° flexed position of the shoulders, the arms are rapidly drawn toward the midline and backward toward the feet, thrusting the hand backward to complete the stroke. The latissimus dorsi, posterior deltoid, and rhomboids perform this end-of-pulling phase.²² With the final thrust of the arms and the double-leg kick, the head and shoulders lift above the surface of the water for recovery. In contrast to freestyle, where breathing is to the side, in butterfly the breathing is generally performed forward. The arms recover with the elbows slightly bent, and the head submerges just before the hands enter the water. The bent-elbow recovery reduces the moment arm to improve stroke efficiency, and it reduces strain on the upper back and arm muscles. Because both scapulae and arms must be simultaneously elevated, upper trapezius activity peaks as the hands exit the water, and rhomboid activity peaks at midrecovery.²² All other muscle activity during recovery matches that of the freestyle stroke.²²

VARIATIONS IN BUTTERFLY MECHANICS IN THE PRESENCE OF PAIN

Pink et al²¹ studied the painful shoulder attributed to butterfly swimming and reported wider hand entry. During the early pull-through phase, there was a significant increase in posterior deltoid activity to abduct and extend the shoulder.²¹ At hand entry, there was decreased activity in the upper trapezius and serratus anterior at hand entry, with no change in the rhomboids, resulting in a net downward rotation of the scapula.²¹ The decreases in the supraspinatus and teres minor activity were attributed to painful impingement owing to scapular malpositioning. The latissimus dorsi and pectoralis major activity were largely unchanged during pull-through, whereas the serratus anterior activity remained significantly lower. It is unclear if the serratus was less active because of fatigue. The last significant change was the increased infraspinatus activity at hand exit, which may depress the humeral head to avoid further impingement.²¹

THE BACKSTROKE

The backstroke is similar to the freestyle, with the exception of the face not being submerged and with the arms to the side rather than in front of the body. The arm enters the water above the shoulder, with the elbow straight and with the little finger first (Figure 4). Rolling the body toward the arm enables the large trunk muscles to pull. The elbow bends, reaching maximum flexion approximately midway through the pulling phase. Even with the elbow flexed, the hand does not break the surface of the water, because of the body roll to the same side. The arm continues pushing down toward the feet, finishing the stroke with wrist flexion, as if dribbling a basketball next to the hip. The opposite arm enters the water a split second before the first arm finishes pulling. With the shoulder leading, the first arm moves into recovery, out of

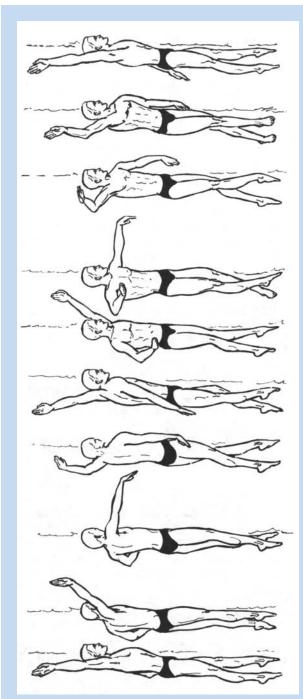


Figure 4. Backstroke cycle pull-through and recovery of the right arm. (Used with permission from Colwin CM. *Breakthrough Swimming.* Champaign, IL: Human Kinetics; 2002:50-70.)

the water and in front of the body, in straight vertical flexion, overhead at the shoulder and coupled with internal rotation, allowing hand entry with the little finger first. At hand entry, the arm should form an imaginary straight line from the fingertips to the lower corner of the scapula. This position is attained by adduction of the scapula, which enables the

entire arm to easily enter the water.⁹ As in freestyle, the kick is constant during backstroke, with most swimmers using a 6-beat flutter kick.

THE BREASTSTROKE

The arm motion in the breaststroke initially resembles the beginning pull of a butterfly stroke. However, the breaststroke pull does not continue with the forearms passing under the body to the level of the hips, as in the butterfly stroke (Figure 5). Starting from a shoulder-flexed posture with elbows extended straight ahead and eyes forward, the swimmer turns the palms outward and slightly upward in ulnar deviation to the oncoming water.⁹ Keeping the elbows high, the swimmer supinates the hands to get set for the pull-through phase. The shoulders are moved through internal rotation, adduction, and, finally, extension as the swimmer pulls forward in the water. The streamline position of the body is maintained as the knees flex and subsequently spread the feet slightly apart in a frogkick position. The head, shoulders, and upper body are lifted above the surface of the water as the shoulders adduct, with hands slightly in front of the chest.⁹ The hips are externally rotated and flexed approximately 35°; the knees are flexed 90°; and the feet are everted and dorsiflexed as the swimmer lunges forward. This takes place between the pull and the kick such that the rhythm becomes pull \rightarrow lunge \rightarrow kick. The swimmer then begins a powerful kick directly backward, keeping the feet everted to provide more propulsion to move the body forward. This kick is a powerful hip adduction motion; the hips and knees are forcefully extended, returning the swimmer to the original streamline position. Pink²³ and Scovazzo et al²⁸ studied 2 general distinctions between the breaststroke and the freestyle: The breaststroke has a longer recovery phase, and the freestyle, a much longer pulling phase. In breaststroke, the shoulders stay in a high degree of humeral elevation compared with that of freestyle, and similar muscle activity is found with pull-through on the nonpainful shoulder.

VARIATIONS IN BREASTSTROKE MECHANICS IN THE PRESENCE OF PAIN

Ruwe et al²⁶ studied electromyographs in swimmers with normal and painful shoulders while performing breaststroke. Those with painful shoulders showed greatly increased latissimus dorsi, upper trapezius, and subscapularis activity during pull-through.²⁶ During recovery phase, swimmers with painful shoulders showed decreased upper trapezius and supraspinatus activity. A decrease in scapular upward rotation during recovery may predispose the shoulder to impingement as the arms move into position to begin the pull phase, namely because of diminished serratus anterior and upper trapezius activity.²⁶

PHYSIOLOGIC CONSIDERATIONS IN SWIMMER'S SHOULDER

Supraspinatus tendinopathy is the most common cause of pain in the swimmer's shoulder.²⁹ In a study of 52

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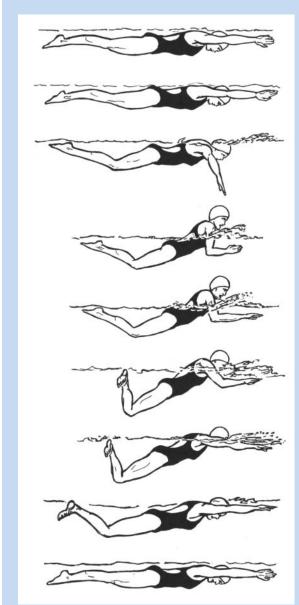


Figure 5. Breaststroke cycle pull-through and recovery of the right side during a single stroke. (Used with permission from Colwin CM. *Breakthrough Swimming*. Champaign, IL: Human Kinetics; 2002:50-70.)

elite swimmers, 36 (69%) showed evidence of tendinosis on magnetic resonance imaging (MRI). Increased swim time and weekly distance correlated significantly with supraspinatus tendinopathy, as evidenced by tendon thickening. ^{29,30} There was excellent correlation between MRI results and clinical signs of impingement. In a study of 80 young elite swimmers, Sein et al³⁰ found that 91% had painful shoulders and 84% had clinical signs of impingement. Of the 52 swimmers who had an MRI, 69% had supraspinatus tendinopathy. ^{29,30}

In contrast to rotator cuff pathology, there is little information regarding labral lesions in swimmers. In one retrospective analysis of 18 swimmers, Brushøj et al⁷ found labral pathology in the shoulders of 11 swimmers who underwent arthroscopy following a failed course of conservative treatment for chronic shoulder pain. Of these 11 shoulders, 5 had posterior superior labral pathology, 3 had superior lesions, 1 was anterior inferior, and 2 were undefined. Furthermore, of these 11 shoulders, 8 were debrided, 2 were left alone, and 1 was repaired. Only 6 of the 11 swimmers returned to competition. It was unclear what the indications for debridement or repair were. The variable location of the labral tears suggests a multifactorial cause. Optimum treatment for labral lesions in swimmers remains unclear. The results of surgical treatment have been less than optimal.

Excessive glenohumeral joint laxity is a major concern in swimmers. Because of the relatively shallow glenoid, the labral, ligamentous, and muscular structures play a crucial role to the stability of the normal joint. 11,13 Repetitive stress on the static, stabilizing structures may lead to adaptations, including anterior inferior capsular laxity.^{11,15,31} McMaster et al18 showed a significant correlation between shoulder laxity and shoulder pain in swimmers. Microinstability is a wellknown cause of secondary impingement. 1,2,11,13,15,31 In a study using the Beighton score as an indication of generalized joint laxity, higher scores did not correlate with increased range of motion.³ Jansson et al¹⁴ found higher general joint laxity in male swimmers aged 9 and 12 years, but a decreased total range of rotation. Zemek and Magee³⁴ found increased laxity of the glenohumeral joints in elite swimmers compared with recreational swimmers. Sein et al³⁰ found laxity weakly correlated with impingement pain and not associated with supraspinatus tendinopathy. The relationship between laxity and pain is not clear.^{3,6,30} Borsa et al⁶ showed that the joint laxity of elite swimmers with shoulder pain was not significantly different from those without shoulder pain. Together, these studies seem to indicate that the glenohumeral laxity is probably not a primary cause of pain.

The painful swimmer's shoulder should be considered in the context of the entire kinetic chain. This approach allows identification of a weak link, which may contribute to the functional problem. For example, a proximal muscle weakness may put extra stress on a distal joint, which often results in dysfunction, pain, or injury. Sciascia²⁷ coined this phenomenon *catch up*: "changes in interactive moments altering forces on distal segments." Whereas the functional manifestation may present as shoulder pain, the underlying cause may be periscapular muscle fatigue or core weakness. The relationship between the function of the shoulder girdle and the rest of the body is well recognized in throwing athletes^{8,17} and is relevant to the successful treatment of shoulder pain in swimmers.

The avoidance of impingement through neuromuscular activation, prevention of superior humeral migration, proximal muscle coordination, and strength or by cessation of the

activity before fatigue becomes crucial in managing pain and protecting the rotator cuff.

CONCLUSION

Because of the great number of stroke repetitions and the propulsive force generated through the upper extremity, the shoulder is vulnerable to injury in the swimmer. Similar to the throwing shoulder, the swimmer's shoulder is at increased risk when the muscles of the proximal segments of the kinetic chain fatigue.^{8,17} Comprehensive evaluation should include the entire kinetic chain, including trunk strength and core stability.

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