Swimming Biomechanics and Injury Prevention

New Stroke Techniques and Medical Considerations

James N. Johnson, MD
Jason Gauvin, PT, ATC
Michael Fredericson, MD

THE PHYSICIAN AND SPORTSMEDICINE - VOL 31 - NO. 1 - JANUARY 2003

In Brief: Shoulder injuries are common in swimmers of all ages and abilities. Advances in the understanding of biomechanics help identify and correct stroke flaws to prevent shoulder injury. Physicians can demonstrate correct pull patterns and body alignment in an office setting, and proper coaching can help correct mistakes made in the water. If injury occurs, swimmers can employ rehabilitation techniques, including preventive scapular stabilization exercises, to prevent recurrence. The treating physician and physical therapist who understand stroke technique and prevention concepts may help decrease the incidence of swimming-related shoulder injuries.

Summer "splashers" account for a large portion of the 100 million to 120 million Americans who enjoy recreational swimming,[1,2] but a significant number are coached, competitive swimmers. USA Swimming has recently surpassed 250,000 registered swimmers from preschool through college age, and United States Masters Swimming has more than 38,000 members ages 19 to 100+. High school and summer league swimming participation is roughly estimated at 5 million over and above the USA Swimming membership.[3-6]

Competitive swimmers train 10,000 to 20,000 yards or meters per day, using the freestyle arm stroke for most of the distance. At an average of 8 to 10 arm cycles per 25 yards, a swimmer completes more than 1 million shoulder rotations each week.[6] Swimmers are obviously at risk for overuse injuries, especially to the shoulder.

With new biomechanic developments and subsequent new teachings, shoulder injury incidence may be on the decline, but it remains a common problem. Sports medicine professionals can implement new prevention strategies and coaching techniques by understanding the new biomechanics and pathomechanics of the freestyle stroke. By using prevention and rehabilitation strategies for shoulder impingement, physicians may prevent progression of the initial injury to a rotator cuff tear, worsening capsular laxity, or glenoid labral tear.

Common Injuries

Shoulder impingement and overuse injuries are still common because of the sheer number of arm strokes each swimmer makes in a given week. In a study by Cole et al[7] during the 1996-97 season, shoulder injuries in 325 swimmers occurred at a rate of 30%

of all injuries per year. A Dutch study[8] from the 1986-87 season revealed that 38% of swimming injuries per year were in the shoulder. McMaster and Troup[9] reported a lifetime shoulder injury incidence of 47% to 73% for competitive swimmers; Stocker et al[10] reported a 47% lifetime incidence in collegiate swimmers and 48% in masters swimmers. Fewer injuries in the more recent studies, such as Cole et al,[7] reflect a positive trend. It is hoped that shoulder injury rates will continue to decline as the knowledge gained in biomechanics is applied to the way in which the freestyle stroke is taught.

'New' Biomechanics

Much has been written regarding swimming biomechanics and shoulder injury prevention, but new theories and coaching techniques have developed in the last decade. Counsilman's[11] two-dimensional biomechanic analysis in 1971 showed that freestyle swimming propulsion was primarily due to lift forces based on Bernoulli's Principle of Hydrodynamic Forces. From these data, the description of an S-shaped pull was developed.[12] However, in 1994 Rushall et al[13] disproved this theory with a computer-aided, three-dimensional biomechanic analysis. They found that freestyle propulsion was primarily attributable to drag forces based on Newton's Third Law of Motion. The presumed S-shaped stroke developed in the two-dimensional model failed to consider body rotation. The Rushall analysis took body roll into account and thus developed the concept of the "straight-through" pull that caused coaches to rethink their paradigm of the freestyle arm stroke.

Bill Boomer, pioneer stroke technician, and Richard Quick, US Olympic coach, picked up on these new teachings, even before publication of the Rushall paper, and considered the importance of the current "buzz words" (ie, body rotation, balance, and core strength).[14] New theories and coaching techniques, developed in the last decade, are carryovers of common teachings in throwing and swinging sports.

In 2001, further studies by Riewald[15] in the biomechanics lab at USA Swimming have shown that propulsive drag forces, produced by the hand, stop before the hand reaches the hip and that propulsive lift forces are negligible throughout the stroke. The "new" coaching practice is supported with biomechanic analysis; the swimming stroke is now taught as an early catch with an early exit. Thus, a new competitive freestyle uses the key principles of equal body rotation and balance in the water with core strength to support these goals, along with an early catch, early exit, straight-through pull arm stroke.

Freestyle Biomechanics

Souza[16] describes the freestyle stroke as early pull-through, late pull-through, and recovery—more simply explained in the swimming community as catch, pull, and recovery. Pink et al[2] studied the normal freestyle arm stroke with fine-needle electromyography (EMG). The normal "catch" occurs when the forward hand enters the water as the upper trapezius elevates and the rhomboids retract the scapula. The serratus anterior protracts, rotates the scapula up, and is highly active from this point in the catch and through the pull. These opposing actions hold the scapula in place. Just after the catch, the pectoralis major fires and adducts and extends the humerus while internal rotation is balanced by the antagonistic external rotation of the teres minor. The latissimus dorsi fires in concert with the subscapularis from the mid pull-through until the beginning of recovery. The deltoid and supraspinatus are the prime movers through recovery.

EMG studies by Pink et al were done on the "old" freestyle stroke, but the muscle firing patterns are similar; therefore, these studies remain an accurate and reliable description of the normal stroke patterns and can help to explain the painful "swimmer's shoulder."

Freestyle Pathomechanics

The cause of the painful shoulder in swimmers can be attributed to a myriad of stroke flaws. A hand entry that crosses the midline of the long axis causes mechanical impingement in the anterior shoulder, including the long head of the biceps and the supraspinatus (figure 1A). This is exacerbated by a thumb-first entry that further stresses the biceps attachment to the anterior labrum. A crossover pull-through usually results from a crossover entry (figure 1B) and increases the time in the impingement position. Proper body roll, however, can resolve most of the impingement risks, unless the athlete has glenohumeral instability or anterior capsular laxity and concomitant anterior subluxation.

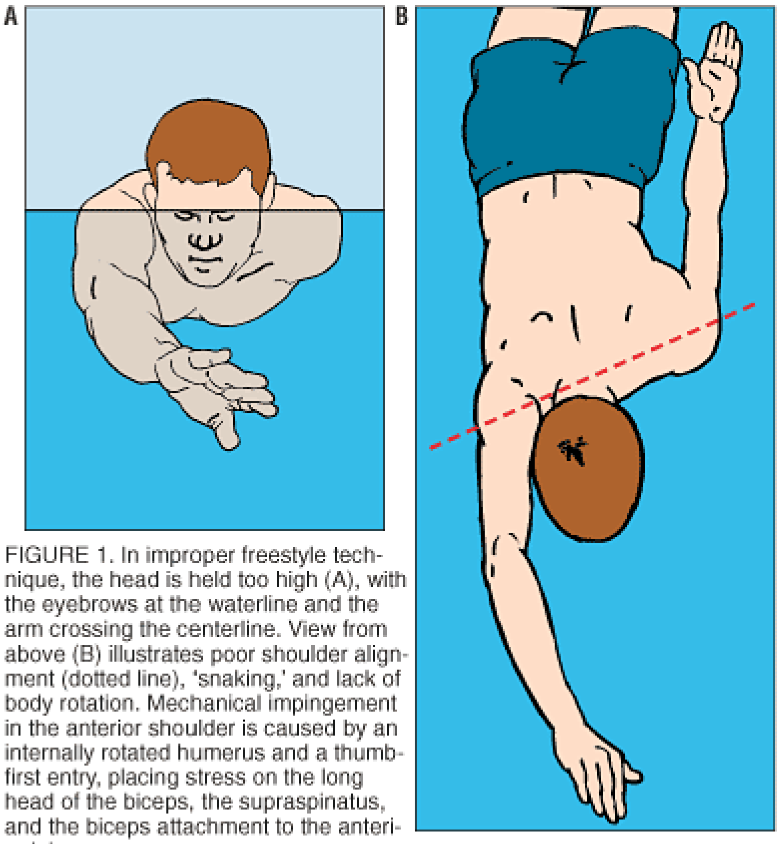

FIGURE 1. In improper freestyle technique, the head is held too high (A), with the eyebrows at the waterline and the arm crossing the centerline. View from above (B) illustrates poor shoulder alignment (dotted line), 'snaking,' and lack of body rotation. Mechanical impingement in the anterior shoulder is caused by an internally rotated humerus and a thumb-first entry, placing stress on the long head of the biceps, the supraspinatus, and the biceps attachment to the anterior labrum.

Asymmetric body roll or unilateral breathing may increase impingement by causing a compensatory crossover pull-through on the side with less roll or on the nonbreathing side. Improper head position, forward-sloping shoulders, and scapular instabilities are also implicated in arm, shoulder, upper-back, and neck pain that may or may not be associated with neurologic signs and symptoms.[16]

EMG analysis by Pink et al[2] in swimmers with painful shoulders revealed that the most prominent abnormality is a weakness of the serratus anterior and increased activity of the rhomboids during the pull. The resulting mechanical imbalance ("floating scapula") increases anterior impingement of the biceps and supraspinatus tendons.[2] EMG studies by Pink et al and resulting therapy recommendations for scapular stabilization are now widely accepted and used in the rehabilitation of shoulder injuries.[17]

Kibler[18] maintains that shoulder injury is prevented first by core stabilization and then by scapular stabilization. He describes the scapula as the link in the kinetic chain from the legs and trunk to the shoulder. Coaches and physical therapists are beginning to recognize the importance of strengthening the entire kinetic chain for the prevention and treatment of shoulder injuries.

Evaluating the Injury

First, the sports medicine professional must take a thorough history. Relevant historical data include number of years swimming, number of practice sessions per week (both swimming and strength training or calisthenics), whether the athlete breathes to one or both sides, any technique flaws that may have been pointed out by the coach, any recent stroke technique changes, any recent changes in volume or intensity of swimming, and, finally, the types of weight room exercises the athlete is performing and any associated shoulder pain. Characterizing the location, duration, and causative factors of pain are as important as with any other injury.

A complete neck and upper-extremity neurologic exam should rule out causes of referred pain from the neck. Next, a shoulder exam should look specifically for rotator cuff injury, anterior and posterior impingement signs, labral pathology, and glenohumeral instability.

Appropriate imaging includes plain films and/or magnetic resonance imaging (MRI), with or without an arthrogram. If, after a complete evaluation, the working diagnosis is impingement syndrome, the physician may be able to provide some salient rehabilitation techniques and, ultimately, preventive tips.

Quick Office Tips

Many coaches are beginning to incorporate the new biomechanics. After performing a complete evaluation of a swimmer who has shoulder pain, physicians can pass along some of these techniques if they understand the mechanics of the swimming stroke and translate it into terms the swimmer will understand.

Climbing the ladder. The early catch phase of the freestyle arm stroke may be explained as a pinky- or fingers-first entry (not thumb-first) with water exit just above the beltline. This technique will keep the swimmer in the impingement range for as short a period as possible by avoiding excessive internal rotation. The stroke is a straight line, not S-shaped. A good description is to imagine that a long stepladder is just beneath the surface, and swimmers are trying to grab each rung and pull themselves down the length of the ladder with equal body rotation. Paddling on surfboards may help swimmers establish the correct hand pattern and keep the scapulohumeral link at 180°.

Rotating on the axis. The correct stroke pattern must be accompanied with equal body rotation to avoid injury. The body must rotate at least 45° from its long axis equally in both directions. The head position should be neutral on the spine as if the person were standing on a flat surface in good alignment (figure 2). Many coaches and physicians had formerly taught the "eyes forward" head carriage, which increases impingement by impeding normal scapulothoracic motion. The swimmer should be taught that correct body roll should feel as if one were rotating on a barbecue skewer that goes through the top, center of the head and extends the length of the spine to between the ankles. Using a pull-buoy (a foam device held between the thighs) or breathing every third stroke (or other alternate pattern) can help a swimmer practice body rotation.

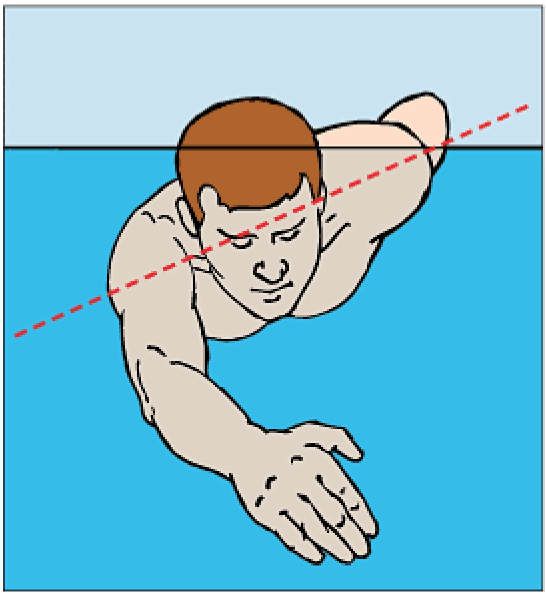

FIGURE 2. When using proper technique, the body rotates 45° along the longitudinal axis (dotted line), and the fingers enter the water first. The neck is held in the same position as when standing erect on dry land, with the waterline in the middle of the top of the head.

Floating the legs. Body balance is difficult to learn and explain but is the most important skill in linking the kinetic chain from the legs and trunk through the scapula into the shoulders. The body's center of mass is around the pubis, but the center of buoyancy is at the sternum. The lungs filled with air float the body, but the mass and density of the legs tend to bring the body down feet first. The swimmer must use the counterbalancing weight of the head and press the center of buoyancy (sternum) into the water to float the legs. Essentially, the swimmer must experiment with balance in the water and try to find the best dynamic position to maintain the whole "vessel" at or near the surface on the same horizontal plane. Floating drills with the hands at the side are the best way to learn this technique.

Conditioning and flexibility. Developing core strength from the pelvic girdle to the scapular stabilizers is the common denominator to mastering all these skills. Encouraging the young athlete to participate in a variety of activities that help develop total-body conditioning, muscular strength, and muscular endurance is essential. As an athlete reaches adolescence and focuses more specifically on swimming, a scapular- and trunk-stabilizing program should be added. The mature athlete should add flexibility activities, such as yoga, and strengthening exercises that specifically address scapular and abdominal muscles.[12,14,19]

Preventive Rehabilitation

The sports medicine professional should find out what coaches are already doing to prevent injury. First, coaches' injury prevention programs should be evaluated for safety; then those exercises that are safe and effective should be incorporated into the practitioner's own prevention program. As relationships develop with injured athletes and their coaches, the physician can volunteer to give educational talks to the team. Also, some preventive physical therapy techniques, including a basic scapular stabilization program and additional core stabilization exercises, can be taught to injured athletes and their coaches.

Successful prevention of shoulder injuries in swimmers can be accomplished by establishing proper muscular balance. The development of muscular balance allows for rhythmic scapular motion instead of the dyskinetic motion seen in injured swimmers.[18] Swimmers tend to have an imbalance manifested by rounded shoulders that develop because of tight internal rotators and adductors and overstretched, weak external rotators and abductors. A preventive rehabilitation program should include strengthening the scapular stabilizers, appropriate stretching, and spinal stabilization with core strengthening.

Strengthening exercises should focus on endurance training of the serratus anterior, lower trapezius, and subscapularis muscles.[20] The four most widely accepted and effective exercises used in clinical practice are scapular elevation (scaption), push-ups with a plus, rowing, and press-ups[17] (see the Patient Adviser, "Stronger Shoulders for Swimmers"). These exercises can be incorporated into a dryland training program for swimmers and should be progressed to three sets done to fatigue.[21] If the equipment is available, upper-body ergometry can greatly enhance the endurance component of the strengthening of the scapular stabilizers.[2] The traditional rotator cuff elastic band exercises are particularly effective for strengthening the external rotators and supplement the previous exercises. Strength training is most effective when done after swimming or as an isolated workout session. Strengthening exercises done before swimming can fatigue the rotator cuff and possibly increase the risk of injury.

Stretching should complement the strengthening program. Swimmers tend to lack range of motion in internal rotation and horizontal adduction, which may predispose them to anterior impingement. Isolated stretches of the pectoralis major and minor, posterior capsule, and latissimus dorsi are most effective.[22] The traditional swimmer's partner stretch may actually exacerbate impingement by overstretching anterior structures that are already overstretched. Though the data are mixed, these stretches may be more effective if done after swimming.

Core strengthening provides the final link in the prevention plan. Lower-abdominal strengthening should be emphasized in the dryland conditioning program for swimmers. The goal of abdominal strengthening is to develop increased control of the pelvis by avoiding excessive anterior pelvic tilt and lumbar lordosis. Exercises should be done with the pelvis in a neutral position and the spine in good alignment. Development of muscular endurance is also one of the goals of core strengthening, because swimmers must support their body in the water for long periods of time while training. Abdominal exercises to build core strength may be part of a separate strength training session or may be effectively accomplished without untoward injury risk just prior to or just after swimming.[16,20,21]

Preventive exercise can be an important addition to a training program if done correctly. These exercises may not be appropriate as treatment for swimmers who have a preexisting injury. Those swimmers should be evaluated before they begin a rehabilitation program—which may or may not include the above exercises, depending on the nature of the injury. With the "new" freestyle techniques that emphasize body rotation and balance, scapular stabilization, appropriate stretching, and core strengthening become even more important for injury-free swimming and, ultimately, more effective technique.

Promoting Safe Technique

Shoulder pain is the most common complaint in swimmers. Understanding the freestyle stroke and common injury patterns may help identify an underlying biomechanic or training-related cause of injury. In addition, some quick office tips on stroke technique and a few specific strengthening and stretching exercises may help prevent new injuries or prevent recurrence in a patient who has a history of shoulder problems.

References

1. Murphy T: Shoulder injuries in swimming, in Andrews JR, Wilk KE: The Athlete's Shoulder. New York City, Churchill Livingstone, 1994, p 411
2. Pink M, Jobe F: Biomechanics of swimming, in Zachazewski JE, Magee DJ, Quillen WS: Athletic Injuries and Rehabilitation. Philadelphia, Saunders, 1996, p 317
3. USA Swimming Web site: http://www.usa-swimming.org/. Accessed October 25, 2002
4. United States Masters Swimming Web site: http://www.usms.org/. Accessed October 25, 2002
5. National Collegiate Athletic Association Web site: http://www.ncaa.org/. Accessed October 25, 2002
6. Kammer CS, Young CC, Niedfeldt MW: Swimming injuries and illnesses. Phys Sportsmed 1999;27(4):51-60
7. Cole A, Johnson JN, Fredericson M: Injury incidence in competitive swimmers. Presented at USA Sports Medicine Society and American Swim Coaches Association meeting; September 7, 2002; Las Vegas
8. Bak K, Bue P, Olsson G: Injury patterns in Danish competitive swimming. Ugeskr Laeger 1989;151(45):2982-2984
9. McMaster WC, Troup J: A survey of interfering shoulder pain in United States competitive swimmers. Am J Sports Med 1993;21(1):67-70
10. Stocker D, Pink M, Jobe FW: Comparison of shoulder injury in collegiate- and master's-level swimmers. Clin J Sport Med 1995;5(1):4-8
11. Counsilman JE: Competitive Swimming Manual for Coaches and Swimmers. Bloomington, IN, Counsilman Co, 1977
12. Maglischo EW: Swimming Even Faster. Mountain View, CA, Mayfield Publishing Company, 1993

13. Rushall BS, Sprigings EJ, Holt LE, et al: A reevaluation of forces in swimming. J Swimming Research 1994;10(fall):6-30
14. Boomer B, Nelms M: The Boomer Chronicles [Videotape Series]. Colorado Springs, CO: USA Swimming; 2000
15. Riewald S: Biomechanical forces in swimmers. Presented at USA Sports Medicine Society; April 15, 2002; Colorado Springs
16. Souza TA: The shoulder in swimming, in Sports Injuries of the Shoulder: Conservative Management. New York City, Churchill Livingstone, 1994, pp 107-24
17. Moseley JB Jr, Jobe FW, Pink M, et al: EMG analysis of the scapular muscles during a shoulder rehabilitation program. Am J Sports Med 1992;20(2):128-134
18. Kibler WB: The role of the scapula in athletic shoulder function. Am J Sports Med 1998;26(2):325-337
19. Laughlin T, Delves J: Total Immersion: The Revolutionary Way to Swim Better, Faster, and Easier. New York City, Simon and Schuster/Fireside, 1996
20. Scovazzo ML, Browne A, Pink M, et al: The painful shoulder during freestyle swimming: an electromyographic and cinematographic analysis of twelve muscles. Am J Sports Med 1991;19(6):577-582
21. Rodeo S, Johnson JN, Ellison P, et al: USA Swimming Shoulder Injury Task Force: Summary of findings. Presented at USA Sports Medicine Society; April 11, 2002; Colorado Springs
22. Wilk KE, Arrigo C: Current concepts in the rehabilitation of the athletic shoulder. J Orthop Sports Phys Ther 1993;18(1):365-378

Dr Johnson is a team physician for Stanford University in Stanford, California, and for the USA Swimming National Team. Mr Gauvin is a physical therapist and athletic trainer in the Stanford University Department of Athletics. Dr Fredericson is the director of sports medicine in the division of physical medicine and rehabilitation at Stanford University School of Medicine and a Stanford team physician. **Address correspondence to** James N. Johnson, MD, Stanford Sports Medicine, Arrillaga Family Sports Center, 641 Campus Dr, Stanford, CA 94305; e-mail to: jimdocswim@aol.com.

Disclosure information: Dr Johnson, Mr Gauvin, and Dr Fredericson disclose no significant relationship with any manufacturer of any commercial product mentioned in this article. No drug is mentioned in this article for an unlabeled use.