

[Orthopaedic Surgery]

Epidemiology of Injuries and Prevention Strategies in Competitive Swimmers

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Context: Competitive swimmers are predisposed to musculoskeletal injuries of the upper limb, knee, and spine. This review discusses the epidemiology of these injuries, in addition to prevention strategies that may assist the physician in formulating rehabilitation programs for the swimmer following an injury.

Evidence Acquisition: A literature search was performed by a review of Google Scholar, OVID, and PubMed articles published from 1972 to 2011.

Results: This study highlights the epidemiology of injuries common to competitive swimmers and provides prevention strategies for the sports health professional.

Conclusions: An understanding of swimming biomechanics and typical injuries in swimming aids in early recognition of injury, initiation of treatment, and design of optimal prevention and rehabilitation strategies.

Keywords: competitive swimmer; injury; prevention; shoulder; knee; spine

Swimming is a unique sport that combines upper and lower extremity strength exercises with cardiovascular training in a nonweightbearing environment. Four strokes are recognized in competitive swimming: freestyle, butterfly, backstroke, and breaststroke. Regardless of the stroke performed in competition, swimmers spend a considerable amount of their training time swimming freestyle. The highly repetitive motion that occurs in the normal swimming stroke can predispose elite swimmers to musculoskeletal injuries of the upper limb, knee, and spine.

A 5-year survey from the National Collegiate Athletic Association (NCAA) revealed that overall elite swimmer injury rates were 4.00 injuries per 1000 hours training for men and 3.78 injuries per 1000 hours training for women.⁴⁹ Shoulder injuries are the most common injuries, with prevalence between 40% and 91%.^{2,3,7,10,20,24,38,42}

The knee is a significant cause of morbidity in the competitive swimmer. One study reported knee problems in 34% of the 35 members of the 1972 Canadian Olympic swimming team.¹⁹ A survey of 36 competitive swimmers found that 86% reported at least 1 episode of knee pain.³⁷ Many studies have reported a greater incidence of knee pain among breaststroke swimmers; the “breaststroker’s knee” has been well described in the literature.^{21,46}

The spine is also a recognized site predisposed to injury in the elite swimmer. Capaci et al reported that 33.3% of butterfly swimmers and 22.2% of breaststroke swimmers experienced low back pain.⁹ Mutoch found a 37% incidence of pain for butterfly swimmers, while Drori et al found a 50% incidence of pain for butterfly swimmers and 47% for breaststroke swimmers.^{12,27}

EPIDEMIOLOGY

Shoulder

Injuries of the shoulder. Shoulder pain is the most frequent orthopaedic injury in swimmers, with a reported prevalence between 40% and 91%.^{2,3,7,10,20,24,38,42} In contrast to most other sports, where the legs initiate the propulsive force, swimming athletes primarily use their arms to generate forward thrust.³² Swimmers at the elite level may swim up to 9 miles per day (more than 2500 shoulder revolutions).^{32,36} Muscle fatigue of the rotator cuff, upper back, and pectoral muscles caused by repetitive movement may result in microtrauma due to the decrease of dynamic stabilization of the humeral head.^{32,42}

Kennedy and Hawkins coined the term “swimmer’s shoulder,” for which they described anterior shoulder pain during and after workouts.²⁰ Originally, the cause of pain was thought

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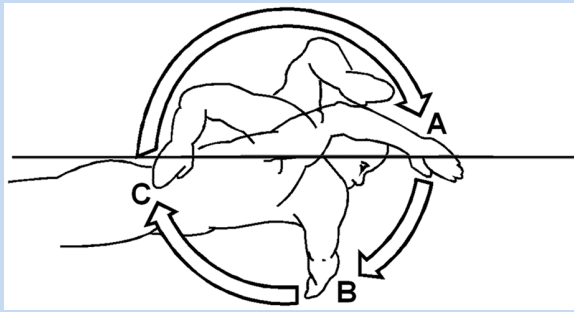


Figure 1. Freestyle swimming stroke. A, hand entry; A to B, early pull-through phase; B to C, late pull-through phase; C, hand exit; C to A, recovery phase. Reprinted with permission and adapted with permission from Pink et al.³¹

to be impingement of the rotator cuff tendons under the coracoacromial arch (outlet impingement).³² However, with continuing analysis of shoulder pain, it became evident that the cause is multifactorial, including (1) stroke biomechanics and/or (2) overuse and fatigue of muscles of the shoulder, scapula, and upper back and/or (3) glenohumeral laxity with subsequent shoulder instability.^{36,38,51}

Shoulder impingement. Impingement in the competitive swimmer is typically caused by altered kinematics (nonoutlet impingement) due to muscle fatigue or laxity rather than subacromial pathological changes, which are observed in other patient populations (outlet impingement).³⁶ Subacromial or intra-articular impingement may occur in various positions during the swimming stroke. In the former, the bursal surface of the rotator cuff impinges against the anteroinferior acromion, while in the latter, the rotator cuff tendons and/or biceps tendon impinges on the anterosuperior glenoid and labrum.³⁶

A characteristic position for subacromial impingement is forward flexion and internal rotation of the glenohumeral joint during the recovery phase (above-water portion) of the stroke (Figure 1). At the point when the hand enters the water, the hydrodynamic force applied on the hand generates a large moment in the shoulder joint, causing elevation of the humeral head and subsequent impingement.⁵⁰ The hyperextension of the upper extremity at the late pull-through phase (underwater portion) of the stroke pushes the humeral head anteriorly and rotates internally, possibly aggravating an impingement when muscle fatigue is present.^{36,40} A hand entry that crosses the midline of the long axis of the body causes impingement of the supraspinatus and the long head of the biceps.

In a recent study, 91% out of 80 young elite swimmers (13–25 years old) reported an episode of shoulder pain. Eighty-four percent demonstrated a positive impingement sign, and 69% of the 52 swimmers examined with magnetic resonance imaging

(MRI) demonstrated signs of supraspinatus tendinopathy.⁴² Interestingly, the level of competition has been correlated with supraspinatus tendinopathy, with a higher proportion of swimmers at the higher competition level having radiographic signs of tendinopathy.

Muscle Overuse and Fatigue. The shoulder is an inherently unstable joint; therefore, muscle forces are critical for maintaining stability, proper motion, and painless function.³⁶ The greatest propulsive force in swimming is generated by adduction and internal rotation of the upper extremity.^{2,3,28,31} The 2 major muscles involved are the pectoralis major and the latissimus dorsi.³² The training-induced adduction and internal rotation strength in swimmers can lead to imbalance and, thus, reduced glenohumeral stability.^{25,48} The teres minor muscle provides an external rotation force and stabilizes the humeral head in conjunction with the pectoralis major. The serratus anterior and subscapularis are active throughout the entire swimming stroke. The serratus anterior helps to position and stabilize the scapula, and the subscapularis muscle acts as an internal rotator throughout the stroke. Their repeated contraction during swimming makes them prone to fatigue³¹ (Table 1). Female swimmers, on average, have shorter arm strokes than those of their male colleagues and are, from a biomechanical perspective, at a greater risk of suffering an overuse injury, due to more arm revolutions per lap.³

Laxity. Excessive translation of the humeral head is prevented by the static stabilizers (the glenoid labrum and capsular ligaments), as well as the active stabilizers (the rotator cuff and scapular muscles). In many competitive swimmers, shoulder laxity with increased translation of the humeral head can be observed.^{38,51} A genetic component may play a role, but only 20% of the swimmers meet the criteria for generalized ligamentous laxity.³² Laxity may increase over time due to continual overuse in competitive swimming.³⁸ Up to a certain degree, glenohumeral laxity may be advantageous by allowing a swimmer to achieve both a body position that reduces drag and a greater stroke length, correlating directly with speed.^{36,48} The decreased passive stability provided by the glenohumeral ligaments in more lax shoulders necessitates a greater contribution of the rotator cuff muscles to control the glenohumeral translation. This may result in muscle overload and subsequent muscle fatigue.³⁶ Several studies have found an association between increased shoulder laxity and shoulder pain in swimmers.³⁵

Backstroke swimmers generally experience isolated anterior glenohumeral instability due to the position of the arm in overhead elevation and external rotation at hand entry.³

Differential diagnosis. Differential diagnoses should be considered, such as labral tears, subluxation, and intra-articular impingement of the anterosuperior labrum. Rotator cuff tendon tears are uncommon but should be considered in the older athlete. Biceps tendon pathology often coexists with rotator cuff pathology.³⁶

Table 1. Phases of the freestyle stroke, shoulder position, and muscle activation.

Stroke Phase	Shoulder Position	Muscle Activity
Hand entry	Abduction, flexion, internal rotation	Upper trapezius, rhomboids, supraspinatus, anterior and middle deltoids, serratus anterior
Early pull-through phase (maximum forward extension to 90° flexion)	Adduction, extension, neutral rotation	Pectoralis major, teres minor, serratus anterior
Late pull-through phase (90° flexion to hand exit)	Full adduction, extension, internal rotation	Latissimus dorsi, subscapularis, serratus anterior
Recovery phase	Extension, abduction, internal rotation	Anterior middle posterior deltoid, supraspinatus, subscapularis, rhomboids

Physicians treating competitive swimmers should also be aware of several less common injuries, including thoracic outlet syndrome,¹ sternoclavicular joint subluxation,¹³ os acromiale,⁶ proximal vascular obstruction due to muscle hypertrophy,⁴⁷ rib stress fractures,⁴⁵ and exertional compartment syndrome of the forearm.⁴¹

Knee

Injuries of the knee. The knee is the second-most-reported source of pain in competitive swimmers.³⁶ The prevalence of knee problems requiring an orthopedic consultation was 34% among the 35 members of the 1972 Canadian Olympic swimming team.¹⁹ A greater incidence of knee pain occurs in breaststroke swimmers than in other swimming techniques.^{19,21,46} A survey of 36 competitive breaststroke swimmers found that 86% had at least 1 episode of breaststroke related knee pain.³⁸

Quantifying the true prevalence of swimming-associated knee injuries is challenging, as structural abnormalities do not always correlate with painful symptoms and vice versa. Swimmers may have a number of knee abnormalities that take many years to become symptomatic, if ever. A MRI study compared knees of asymptomatic adolescent elite swimmers to age- and sex-matched controls who did not practice any impact sports regularly.⁴³ Swimmers had a significantly higher incidence of imaging abnormalities (69.2%) compared with age- and sex-matched controls that do not regularly practice any impact sports. The most common MRI abnormalities were infrapatellar fat pad edema (53.8%), bone marrow edema (26.9%), prefemoral fat pad edema (19%), and joint effusion (15.3%). One limitation of the study is that these MRI findings also correlate with the dry land training included in the training regime. Asymptomatic MRI abnormalities in elite swimmers may be benign, which raises questions about treatment.

Biomechanical factors affecting knee injuries. Like most swimming pathology, overuse is the primary factor in causing

knee pain and injuries.¹⁶ Repetitive hydrodynamic forces result in cumulative stresses that increase the risk of soft tissue injuries. Pain predominantly affects the medial compartment of the knee, although anterior knee pain is also common.

Breaststroke swimmers have a fivefold higher risk of knee pain (relative risk, 5.1), although most occurs in the medial compartment, whereas freestyle has a reduced relative risk (0.5) for knee pain.²³ The biomechanics of the breaststroke generates high valgus loads due to the adducted hip position. Extreme hip abduction angles at kick initiation can be detrimental. For example, a study of 21 competitive swimmers reported that hip abduction angles of less than 37° or greater than 42° were associated with a higher knee injury rate.⁴⁶

Increased varus and valgus loads also occur in the knee in addition to rapid knee extension. Due to the kick style in the breaststroke technique, increased tension across the medial compartment and increased compression of the lateral compartment occur.³⁴ Clinical and arthroscopic examination of 9 breaststroke swimmers with medial knee pain found medial compartment synovitis in 7 swimmers.²¹ Rovere and Nichols proposed that inflammation and fibrosis of the synovial plica cause medial knee pain; they found thickened and tender medial plica in 47% of breaststroke swimmers with medial knee pain.³⁷

There is increased strain of the medial collateral ligament (MCL) due to high valgus loads during the whip kick, which can present with tenderness of the femoral or tibial origin of the MCL.¹⁹ Repetitive valgus loads may result in pes anserinus tendinitis or bursitis.³⁵ Strain injuries of the hip flexors and adductors (particularly adductor magnus and brevis) occur in breaststroke swimmers.³⁵

The flutter kick in freestyle swimming requires repetitive quadriceps contraction, which may result in patellofemoral overload.³⁵ Increased patellofemoral contact stresses resulting in anterior knee pain also occur during wall push-off, due to forceful quadriceps contraction with the knee in a high degree of flexion, or during starts and turns when the knee is in a partial squat position.³⁵ These motions may present with patellar tendinitis.

Abnormal kicking mechanics are often present in swimmers with knee pain. Underwater videos of breaststroke swimmers showed that symptomatic swimmers complaining of MCL tenderness had different whip kick patterns.⁴⁴ Swimmers with medial patellar facet pain keep their hips in more abduction and demonstrate greater hip and knee flexion, which cause medial facet contact on the intercondylar ridge. In contrast, those with MCL pain derotated and plantar flexed the ankles as the knees extended. A video analysis of breaststroke mechanics in patients with knee pain showed high angular velocities at the hip and knee, as well as increased external tibial rotation.²¹

Extrinsic factors. Overuse in breaststroke swimmers contributes to knee pain and injuries. Knee pain in breaststroke swimmers correlates with the number of years of training, the volume of training, the caliber of the athlete, and increasing age.³⁸ A substantial increase in training volume and intensity in freshmen swimmers competing in the NCAA Division I contributes to the risk of sustaining swimming injuries. Freshmen swimmers suffer the most injuries compared with more experienced swimmers.⁴⁹ A survey of 341 elite swimmers showed the rate of knee injuries was 0.17 for every 1000 hours of swimming.²³ A survey of NCAA Division III college swimmers showed that females had significantly more knee injuries, as well as back/neck, shoulder, hip, and foot problems ($P < 0.01$).³⁹

Intrinsic factors. Intrinsic factors can contribute to the biomechanical stresses on the knee and subsequent development of patellofemoral pain. Quadriceps muscle abnormalities may predispose to patellar maltracking due to impaired strength, endurance, and flexibility. Swimmers may experience patellofemoral pain as a consequence of patellar instability, subluxation, or maltracking.

Spine

Muscle strength, endurance, and flexibility protect against low back pain and/or injuries. Mechanical loading of the spine in competitive sports results in lumbar intervertebral disk degeneration.^{4,8,26,33}

A significantly greater proportion of swimming athletes had degenerative disk changes at one or more disk levels compared with a control group.¹⁴ Sixty-eight percent of 56 elite swimmers (mean age, 19.6 years) and 29% of 38 recreational swimmers (mean age, 21.1 years) demonstrated degenerated disks at various levels.¹⁸ There were no significant sex differences in the rate or among swimming strokes.¹⁸ The main variables were training intensity, duration, and distance, suggesting that competitive swimming amplifies lumbar intervertebral disk degeneration. The L5-S1 levels are more frequently involved in elite swimmers.¹⁸

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All swimming strokes maintain hyperextension of the lower back to achieve a streamlined position; this position is exaggerated in the “undulating” style of breaststroke and butterfly. The high intensity and repetitiveness of these strokes load the posterior structures of the lumbar spine, which can result in spondylolysis and possible spondylolisthesis.²⁹ Increased intensity can increase the risk of damage. Muscle and ligament sprains can occur but settle rapidly with core stability programs and manual therapies.¹⁵ Additional risk factors for the development of low back pain in competitive swimmers are training devices such as fins, kick boards, or pull buoys. These produce excessive hyperextension of the lumbar spine.²⁹

ALGORITHM FOR INJURY PREVENTION

The incidence of pain and injury is greater in athletes with a poor stroke technique.³⁶ The goal of athletes, coaches, and physicians must be a biomechanically sound stroke technique to prevent injuries. The correct stroke pattern should be accompanied by correct body roll to reduce the scapular protraction needed to maintain proper alignment of the glenohumeral joint. This reduces the demand on the serratus anterior and the other scapular muscles.^{30,48}

Recognize Stroke Alterations

Athletes, trainers, and team physicians should constantly be aware of and identify early signs of shoulder injuries. Stroke alterations occur in the swimmer with a painful shoulder. A dropped elbow in the recovery phase of the freestyle stroke is a sign of injury. By dropping the elbow, the swimmer decreases the degree of humeral internal rotation (avoiding the pain caused by subacromial impingement).^{32,40} A wider hand entry occurs, which decreases scapular upward rotation and humeral forward flexion.³² An early hand exit decreases humeral hyperextension and the extremes of internal rotation; anterior translation of the humeral head results and possible impingement.^{32,40}

Prevention Strategies

An extensive program of stretching, strengthening, and endurance training, in addition to stroke-specific mechanics instruction, should form the foundation of an elite swimmer's training regimen. Musculoskeletal injuries in this population usually result from cumulative, repetitive trauma. Careful monitoring of training volume, intensity, and duration by coaches and physicians will minimize overuse injuries and identify athletes at risk.³⁶

Endurance training of core muscles (strengthening, stabilization, and flexibility) is an essential component in any injury prevention program. Abdominal and scapular muscle strengthening should be emphasized in the dry-land training program. The goal of core and abdominal strengthening is to develop increased control of the pelvis by avoiding excessive anterior pelvic tilt and lumbar lordosis.^{17,22}

An endurance training and strengthening program for the shoulder and periscapular muscles, with emphasis placed

Table 2. Strength training exercises for the competitive swimmer.^a

Muscle Group	Type of Training Exercise
Primary rotator cuff muscles ^b	External rotation using Thera-Band®—facilitates bilateral strengthening. <i>Strengthens:</i> Teres minor. Full can straight arm lifts. <i>Strengthens:</i> Supraspinatus. Ball on the wall—one arm extended, rolling a ball in circles. <i>Strengthens:</i> Stabilizers of the rotator cuff and scapulae.
Scapular muscles	Seated row using Thera-Band®—scapulae maintained in retraction using looped Thera-Band. <i>Strengthens:</i> Rhomboids. Hitchhiker—performed lying on the stomach; initially, only the weight of the arm is used, but as strength develops, 1- or 2-lb weights may be used. <i>Strengthens:</i> Teres minor, rhomboids. Push-ups with a plus—initially performed against a wall while standing, then on the knees, finally in a traditional push-up position. <i>Strengthens:</i> Serratus anterior.
Abdominal and lower back muscles	Dead bug—performed lying flat on the back with hands under the pelvis back lightly “flutter kicking” the legs before progressing to a similar motion with the arms. <i>Strengthens:</i> Abdominal muscles. Quadruped—performed in a kneeling position with upper body level to the floor and hands touching the floor with the back kept flat; the right arm and the left leg are lifted and held for 1 second, then the contralateral sides performed in an alternating pattern; exercise can be performed with eyes closed, which emphasizes the use of the postural muscles to a greater degree to develop balance and stability. <i>Strengthens:</i> Lower back.

^aFor all these exercises, the goal is to perform 3 sets of 2 minutes, with 30 seconds of rest between sets (the athlete may initially fatigue before the 2-minute point).

^bPerformed in standing position, scapulae maintained in retraction.

on the serratus anterior, rhomboids, lower trapezius, and subscapularis, may help prevent injuries.^{31,36} Individual swimmers should be evaluated to determine strength, endurance, or flexibility deficits. A comprehensive program can be performed with minimal equipment (Table 2).

Rehabilitation Exercises

As soon as the athlete experiences increased pain, warm-up should be long and slow prior to training with intensity, distance, and frequency adjusted. Temporary avoidance of painful strokes or positions (typically, freestyle and butterfly) is recommended; absolute rest is rarely indicated because it often results in rapid deconditioning of the elite swimmer.¹¹

Hand paddles and pulling sets are discouraged because they stress on the shoulder and can exacerbate the injury.³⁰ A kickboard may be used with the elbows flexed to prevent shoulder impingement. This position may need to be modified to avoid forward shoulder elevation. Fins may also be used to maintain good body position while decreasing upper body stress. A pull buoy may change the position of the shoulder in the water and reduce drag. Athletes may tolerate breaststroke swimming without pain. Dry-land upper extremity weight training should be modified or eliminated. A strap around the upper arm over the biceps muscle (counterforce strap) may diminish the stress on the tendon.³⁶

The prevention strategy for knee pain in swimmers focuses on quadriceps strengthening (vastus medialis obliquus) and stretching. Hamstring stretching may also be advantageous. Athletes with inadequate hip internal rotation also benefit from flexibility exercises.³⁵ Butterfly swimmers require hip external rotators to power their kick from the gluteus medius and piriformis.

During periods of relative rest, ice should be used judiciously and short courses (up to 1 week) of nonsteroidal anti-inflammatory medication may be beneficial. Injection of corticosteroid into the subacromial bursa is a controversial option and should be limited to swimmers with constant pain.

The most beneficial duration of relative rest is not known; resumption of training should be gradual and closely monitored. If pain persists, a 3-day period of absolute rest is recommended, and the athlete should then be reassessed prior to returning to the water. If pain persists upon the resumption of training, an evaluation by a physician is indicated.

CONCLUSIONS

Musculoskeletal overuse injuries are a common source of pain in competitive swimmers. Correct stroke technique may help prevent injuries. Coaches should identify stroke alterations that may cause or alter pain. Abdominal, core, scapular, and rotator cuff muscle strengthening exercises should be emphasized for

prevention of pain. Lower extremity muscle strengthening and flexibility exercises should be routinely included for breaststroke swimmers. As soon as the athlete experiences pain, training intensity, distance, and frequency should be adjusted.

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