From Biomechanics to Clinical Translation: Mechanism Research and Prevention and Treatment Strategies for Shoulder Injuries of Swimmers

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Abstract: Recent years, competitive swimming has developed rapidly, and shoulder injuries among swimmers have become a key issue affecting their athletic performance and career development. This paper orderly combs through the biomechanics of the shoulder, analyzes common types and mechanisms of shoulder injuries, such as rotator cuff tendinitis, subacromial impingement syndrome, biceps brachii long-head tendinitis, and labral injuries. It also explores how to effectively treat shoulder injuries using physical therapy techniques without affecting the competitive ability of swimmers. Research shows that repetitive abduction and external rotation leading to overloading of the rotator cuff is the core mechanism of injury. This paper emphasizes the optimization of technical movements through biomechanical analysis to reduce the incidence of shoulder injuries among swimmers, this paper focuses on the targeted strengthening of the rotator cuff muscles and the development of coordinated training programs for related muscle groups, aiming to provide a theoretical basis and practical guidance.

1 INTRODUCTION

As people pay more and more attention to their physical health and develop the habit of daily exercise, swimming is considered a sport with relatively little physical damage due to its non - weight - bearing characteristics. However, for competitive swimmers, swimming can still cause some physical injuries. Especially in the current context, swimming occupies an important position in international competitions such as the Olympic Games and World Championships. The increasing emphasis on professional swimming training has promoted the global development of swimming and the improvement of competitive levels. Some sports injuries may follow as a result.

Previous studies have shown that the most common injury among swimming athletes is shoulder joint injury (Tan, Z. Z., 2019). Between 9% and 26% of swimmers report current shoulder pain, and 38% to 67% of swimmers state that they have had shoulder pain symptoms in the past (McMaster, W. C., 1993). Moreover, the likelihood of shoulder discomfort in athletes increases with the increase in the time of participating in competitions and training (McMaster, W. C., 1993). Even 47% of people say that they regularly take painkillers to control shoulder joint pain (Hibberd, E. E., 2013). In response to the shoulder joint pain of swimmers, in 1974, Kennedy and Hawkins proposed a broad term "swimmer's shoulder" to summarize the repeated shoulder abduction and forward flexion movements among swimmers cause the impingement of the supraspinatus tendon under the coracoacromial arch (De Martino, I., 2018). As the research becomes more profound, "swimmer's shoulder" has turned into a term that can signify multiple shoulder conditions, including but not limited to injury types such as rotator cuff tendinitis, subacromial impingement syndrome, long head of biceps tendinitis, and labral injury (De Martino, I., 2018; Tovin B. J., 2006).

In the field of competitive sports, swimming athletes have extremely high daily training intensity and exercise frequency. High-frequency overhead movements increase the likelihood of shoulder injuries. And daily training is an indispensable and important part of maintaining athletes' competitive state. Once they stop training due to injury or impaired competitive ability, it will not only affect the athletes' personal performance and development but

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also cause losses to the team and others. Therefore, although high-intensity swimming training can lead to shoulder injuries, swimming athletes still cannot reduce their training volume, which will form a vicious cycle. How to enable swimming athletes to reduce shoulder joint injuries and pain while ensuring their competitive state has become an issue.

At present, physical therapy techniques have shown that certain potential in the treatment of sports injuries. So far, the academic community still lacks systematic and comprehensive research and summary on the specific application effects, optimal usage methods, and possible risks of physical therapy among swimming athletes. Therefore, this article intends to summarize the causes and types of shoulder injuries in swimming athletes, and explore how to use physical therapy techniques scientifically, safely, and effectively on the premise of not delaying the athletes' daily training and not affecting the swimmers' competitive level, so as to help athletes maintain a good state during treatment of injuries and reduce the negative impact on their careers.

2 THE BIOMECHANICAL BASIS OF THE SHOULDER IN SWIMMING

Under different swimming strokes, the shoulder joint's anatomical structure is the basis for its biomechanical functions, which include a variety of biomechanical properties. In terms of skeletal structure, the humerus, scapula, and clavicle jointly form the shoulder joint. The proximal humerus and the glenoid cavity of the scapula constitute the glenohumeral joint, a ball-and-socket joint with an extremely wide range of motion. It diversifies the types of joint movements of the arm.

During freestyle swimming, the arm stroke is divided into four stages: entry, catch, pull, and exit. The shoulder extends forward, abducts, and internally rotates during the entry stage and the first part of the push stage, placing the humeral head beneath the anterior acromion and the coracoacromial ligament. Especially when the muscles are fatigued, the likelihood of impacting the supraspinatus muscle and the biceps tendon increases. During the act of swimming, in the latter portion of freestyle and butterfly strokes, the arms have to carry out abduction to get back to the position precisely in front of the head. If inward rotation or lateral horizontal abduction occur simultaneously in this time frame, the humeral head will make contact with the posterior edge of the acromion. Once the water - pushing phase is over, the shoulder enters a state of inward movement and internal rotation (Zhang, Y. J., 2022). Throughout the process, the shoulder joint exhibits an exceptionally broad range of motion, with its movement pathways and muscular force application patterns undergoing continuous variation throughout motion. It is necessary not only to generate propulsive force but also to maintain joint stability.

The scapula serves as a platform for the attachment of numerous muscles, and its position and movement have a significant impact on the overall function of the shoulder. The clavicle is like a bridge, connecting the upper limb and the trunk, playing an indispensable role in maintaining the stability of the shoulder.

The shoulder complex comprises four interdependent articulations - the glenohumeral, acromioclavicular, sternoclavicular joints and scapulothoracic articulation - which function in a coordinated manner to facilitate optimal joint mechanics. Owing to the shallow glenoid fossa and lax joint capsule, high mobility but poor stability is exhibited by the glenohumeral joint. During shoulder movements, the acromioclavicular and sternoclavicular joints fine-tune scapular positioning to facilitate multidirectional arm motion. Although not a true synovial joint, the scapulothoracic articulation assists in scapular elevation, depression, protraction, and retraction, serving as a critical stabilizer for normal shoulder kinematics. Repetitive overloading may lead to laxity of the anterior and posterior capsuloligamentous structures, accompanied by anterior joint instability, impingement-related shoulder problems (Rupp, S., 1995). In breaststroke and butterfly stroke, distinct biomechanical demands are observed. Breaststroke involves short, forceful arm movements characterized by alternating phases of shoulder abduction, adduction, and rotation, with coordinated activation of different muscle groups during propulsion and recovery. Butterfly stroke requires simultaneous bilateral arm motion, imposing extreme demands on shoulder flexibility and muscular endurance, thereby increasing susceptibility to fatigue and overuse injuries.

Muscle and musculotendinous components are pivotal in shoulder biomechanics. The deltoid muscle, divided into anterior, middle, and posterior bundles, governs shoulder flexion, abduction, and extension, respectively. During swimming movements, these muscles work in coordination. For

instance, the smooth entry of the arm during the freestyle stroke's water - entry phase is enabled by the contraction of the supraspinatus muscle and the anterior deltoid. In the catch phase, the pectoralis major and biceps brachii exert force to allow the arm to grip the water firmly. During the pull phase, the latissimus dorsi, pectoralis major, and other muscles contract synergistically to propel the arm to pull backward in the water. When the arm exits the water, the posterior deltoid and the rotator cuff muscles work together to complete the upward lifting motion of the arm.

In backstroke, due to the body lying on its back, the movement direction and force application mode of the shoulder joint are different from those of other swimming strokes. It is necessary to adapt to the body's position in the water and overcome the water resistance.

3 TYPES AND MECHANISMS OF SHOULDER INJURIES IN SWIMMERS

3.1 Rotator Cuff Tendinitis

The shoulder's rotator cuff musculature consists of four key components: the supraspinatus, infraspinatus, teres minor, and subscapularis. These muscles collectively form the primary stabilizing mechanism for glenohumeral joint integrity and rotational function. Swimming athletes suffer from muscle strain due to repetitive stroking movements, resulting in shoulder muscle weakness and poor stability during shoulder joint movement, which gradually leads to rotator cuff tendinitis (Meng, N., 1988). Its early symptoms mainly manifest as obvious tenderness under the acromion or at the greater tubercle of the humerus. Swimmers will feel deep pain during overhead movements, and the pain gradually intensifies. When continuously performing overhead movements, due to the friction among the tendon, ligament, and bone, the inflamed tendon is temporarily de-swollen, and the pain is relieved, enabling athletes to continue swimming. However, after stopping the exercise, when athletes move their shoulders above their heads, they will experience throbbing pain in the shoulders again (Meng, N., 1988). In the high-intensity stroking movements of freestyle and butterfly strokes, the shoulder joint is repeatedly abducted and externally rotated, causing friction between the rotator cuff tendon and the subacromial space, and long-term accumulation leads to micro-injuries.

3.2 Subacromial Impingement Syndrome

In most cases, the structural constriction of the subacromial space gives rise to subacromial impingement syndrome. The common symptom is the soft tissue impingement pain that occurs when the arm is raised. Compression between the acromion and the humeral head triggers chronic inflammation, tendon degeneration, or even tearing (Garving, C., 2017). During the catch phase of freestyle in swimming athletes' training, the high elbow catch requires the shoulder joint to be repeatedly and excessively abducted. Due to the narrowing of the subacromial space, the humeral head rubs repeatedly against the lower surface of the acromion. At the same time, due to the insufficient stability of the scapula, the scapula tilts forward, resulting in abnormal scapular movement, which further reduces the subacromial space. Therefore, it causes shoulder swelling, limited mobility, and local tenderness in swimming athletes. Moreover, due to the repetitive rotation movements of the shoulder joint, the incidence of subacromial impingement syndrome (SIS) in freestyle and butterfly swimmers is significantly higher than that in other swimming strokes (Matzkin, E., 2016).

3.3 Biceps Brachii Long-Head Tendinitis

The shoulder joint capsule provides attachment for the long head of biceps tendon, which contributes to joint stability while being prone to tendinitis development (Fu, J., 2011). Biceps tendonitis is commonly caused by the rotation of the shoulder joint beyond its normal range, which makes the biceps tendon in a subluxation state and causes friction. It can also often occur due to a sudden excessive stretch (Meng, N., 1988). When swimming athletes swim, the highly repetitive abduction and external rotation movements lead to the intertubercular groove of the humerus subjects the biceps brachii long - head tendon to repeated friction or overuse., affecting the proximal biceps brachii long-head tendinitis and its attachments to the superior glenoid tubercle and the labrum. This results in the typical characteristics of the biceps brachii long-head tendinitis, namely intermittent anterior or deep shoulder pain, and the pain intensifies during movement (Chalmers, P. N.,

2016). At the same time, during the stroke, Biceps brachii long-head tendinitis needs to bear a relatively large pulling force, which can also lead to inflammation.

3.4 Labral Injury

The glenoid labrum serves as an anchoring structure for both the joint capsule and associated shoulder ligaments. The superior labrum-biceps tendon complex plays an important role in providing shoulder stability, especially in resisting torsion and providing anterior stability (Rodosky, M. W., 1994). The main clinical manifestations are shoulder joint pain or instability. During the training process of swimming athletes, due to the instability of the shoulder, the movements in the entry stage cause the labrum to be repeatedly rubbed and stretched. The excessive external rotation and abduction of the shoulder joint lead to Superior Labrum Anterior to Posterior (SLAP) injury in the superior labrum.

4 PHYSICAL THERAPY STRATEGIES

During swimming, the shoulder joint needs to perform a large number of complex and high-intensity movements, such as stroking, entry, and exit. Shoulder instability leads to excessive stress on periarticular soft tissues (muscles, tendons, ligaments). Improving shoulder stability can make these tissues bear force more evenly and diminish the probability of sustaining an injury. Meanwhile, shoulder stability helps to maintain the movement of the shoulder joint in its normal anatomical position. Enhancing shoulder stability necessitates strengthening and improving neuromuscular coordination of the periarticular musculature.

Therefore, the main purpose of the exercise therapy for shoulder injuries in swimming athletes is to enhance the stability of the shoulder joint. Through targeted strength training, such as weight-bearing exercises like dumbbell presses and barbell rows, it is possible to stimulate the growth of shoulder muscles and thus improve shoulder stability. For example, after physical therapy, it was observed that the range of flexion/extension rotation decreased by about 10 degrees, indicating that shoulder stability was improved and motor control was enhanced (Raffini, A., 2024).

At the same time, postural correction training cannot be ignored. Swimming athletes are prone to developing bad postural habits such as forward shoulder and hunchback during long-term training. These habits not only affect athletic performance but also increase the risk of shoulder injuries. Through postural correction training, it is possible to help athletes correct bad postures and improve shoulder posture and stability. For example, regular backward shoulder stretching can significantly improve the range of motion (ROM) of the athletes' shoulders (Chepeha, J. C., 2018).

Furthermore, dynamic stability training such as shoulder movement exercises on balance pads can also be combined to enhance the athletes' shoulder stability in unstable environments (Nie, D. Y., 2024).

In an attempt to reduce the shoulder pain of swimmers who got hurt, stretching exercises and manipulative treatments can be used in combination. That is, training the external rotators of the shoulder joint, the scapular retractors, and stretching the pectoralis major muscles are all helpful in relieving shoulder pain.

For example, a professional rehabilitation therapist conducts scapular mobilization treatment. The therapist drives the patient's shoulder joint through the movement of their own center of gravity, enabling the scapula to move in six directions: downward, upward, protraction, retraction, upward rotation, and downward rotation, once a day for half an hour each time. In a clinical study, 28 swimming athletes were randomly divided into a massage + scapular mobilization manual therapy group and a massage group. After 6 weeks of intervention, it was found that the swimming performance of the athletes could be improved by approximately 10%, and the functional score of the shoulder joint increased by about 19% (Liu, N., 2024).

By using different manual techniques such as swinging, rolling, sliding, and rotating, it is possible to achieve the effects of relieving pain, improving joint mobility, and increasing proprioceptive feedback. At the same time, electro-acupuncture can be combined with massage, and electro-acupuncture can be combined with physical therapy (dry needling therapy helps to relieve shoulder pain and improve function by directly stimulating specific muscles and connective tissues). Some studies have also shown that it can effectively improve the decrease in shoulder joint mobility caused by shoulder joint injuries, the decrease in the strength of the muscles around the shoulder joint, and alleviate the pain of shoulder joint injuries (Lei, L., 2024; Sun, R. Z., 2013).

Studies have shown that in terms of improving shoulder external rotation strength and endurance, open kinetic chain (OKC) training combined with a land-based program has more advantages than closed kinetic chain (CKC) training and aquatic training (Yoma, M., 2022). In addition, combining aquatic training with open kinetic chain exercises can also enhance the function of the shoulder's rotator muscles that reduce the risk of shoulder injuries in swimmers (Tavares, N., 2022).

Moreover, elastic band internal rotation and external rotation exercises are also effective treatment methods. Use a mini band, wrap it around the wrist, ensure that the muscles are always in a state of tight elastic band tension, push the scapula backward, squeeze the scapula, keep the elbows near the lateral torso when the hands are separated, contract the scapula, and repeat 5-8 times to enhance the strength of the rotator cuff muscles and stabilize the shoulder joint (Liu, N., 2024).

Owing to its features of causing no damage and having small toxic and side effects, ultrashort wave therapy finds wide use in treating various diseases. Most patients with "swimmer's shoulder" have symptoms such as inflammation of the shoulder joint, limited joint mobility, and shoulder joint dysfunction. Ultrashort wave therapy can effectively improve the above symptoms. The positive effects of ultrashort wave therapy on improving "swimmer's shoulder" include promoting blood circulation, sedation, pain relief, relieving muscle spasms, and promoting wound healing (Hu, M. X., 2022).

Shock wave therapy, as an emerging non-invasive treatment method, has a significant effect in relieving pain and promoting tissue repair. By effectively stimulating the nerve ending tissues with high-intensity shock waves, especially the effective stimulation of pain nerves, it can promote the decrease in nerve sensitivity, block nerve conduction, and rapidly improve the pain symptoms of patients. In a clinical study, 80 patients with periarthritis of the shoulder were included and randomly divided into a control group (conventional rehabilitation treatment, 40 cases) and an observation group (extracorporeal shock wave combined with conventional rehabilitation treatment, 40 cases). The treatment effects and shoulder joint mobility (CMS) scores of the two groups were compared. The results showed that the total effective rate (97.5% vs. 77.5%) and CMS score (59.37 vs. 55.26 points) of the extracorporeal shock wave combined with conventional rehabilitation treatment group were better. Although the subjects were not swimming athletes, it also shows that the combination of extracorporeal shock wave and conventional rehabilitation treatment can significantly improve the treatment effect (Huang, Q. P., 2024). This treatment method directly acts on the damaged tissues by using high-energy sound waves, so as to achieve the purpose of relieving pain and promoting healing (Fu, J., 2011).

5 CONCLUSION

Shoulder injuries are quite common among swimming athletes. More than half of the excellent swimming athletes have been affected in their training due to shoulder pain, which has a negative impact on their athletic careers. The main types of injuries include rotator cuff tendinitis, subacromial impingement syndrome, biceps brachii long-head tendinitis, and labral injury, etc. These are usually caused by shoulder joint instability and frequent overhead movements, resulting in shoulder joint pain, limited joint mobility, and other problems.

Except for relatively severe shoulder injuries that require surgery, according to the situation of athletes' shoulder injuries, physical therapies such as exercise therapy, manual therapy combined with acupuncture, ultrashort wave, shock wave and other methods can be selectively used to relieve shoulder joint pain and improve joint mobility for swimming athletes. This can minimize the impact of injuries on athletes' careers. At the same time, it is recommended that athletes enhance their self-protection awareness and seek medical treatment in a timely manner after an injury occurs. In addition, medical staff should accurately diagnose the shoulder injuries of athletes, formulate personalized treatment plans considering the identity of the patient athletes, and adjust the treatment and rehabilitation plans in a timely manner.

However, due to the limitations of small sample sizes, limited data, and methodology in current studies, the quality of many studies on the limitations and safety of physical therapy for shoulder injuries of swimming athletes is relatively low, and no strong evidence can be provided. In the future, more multi-disciplinary, multi-center, and large-scale high-quality studies are needed to obtain different data, integrate and analyze them, and obtain individualized physical or combined treatment methods to reduce shoulder injuries, so as to provide more diagnosis and treatment strategies for clinical practice.

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