Biomechanics and Management of Shoulder Injuries in Volleyball: From Risk Factors to Prevention and Rehabilitation

Dingchang Yang *

School of Physical Education, Chengdu University, Chengdu, 610000, China

* Corresponding Author Email: 202211301218@cdu.edu.cn

Abstract. Volleyball includes repetitive overhead movements such as spiking and serving, which place extremely high demands on the shoulder joint, leading to a high incidence of injuries. This article reviews the specific biomechanical loads, epidemiological characteristics, training-related risk factors, injury mechanisms and prevention strategies of shoulder injuries in volleyball players. During the puncture, the shoulder joint undergoes significant external rotation and abduction, accompanied by high impact forces, increasing the risk of chronic and acute injury. Clinical manifestations usually include pain, limited movement and loss of strength, and are diagnosed as impingement syndrome, rotator cuff tear and lip lesions. Epidemiological evidence indicates that the incidence of shoulder pain in volleyball and other overhead sports is very high. Due to the large volume of training and insufficient recovery, the risk is particularly high among outstanding athletes and young people. Training volume, technical errors, muscle imbalance and insufficient recovery will further increase the risk of injury. Effective prevention requires a multi-faceted approach, including strength training, scapular stability exercises and dynamic chain optimization. This review integrates current evidence on sports biomechanics, training load, and clinical outcomes to clarify the mechanism of shoulder joint injuries in volleyball and propose targeted prevention and rehabilitation strategies.

Keywords: Shoulder injury, volleyball, biomechanics, rehabilitation.

1. Introduction

As a highly technical and competitive net sport, volleyball puts forward extremely high requirements for the stability and flexibility of the shoulder joint, especially in the overhead movements such as serving and spiking. The shoulder joint is the joint with the largest range of motion in the human body and has a complex anatomical structure, including the rotator cuff muscles, shoulder joints, and acromioclavicular joints. In the high-speed arm swings, powerful spikes and powerful jump serves, the shoulder joint is subjected to tremendous biomechanical pressure, making it one of the most vulnerable areas for volleyball players. In recent years, with the continuous improvement of the competitive level of volleyball and the increase in training intensity, shoulder injuries have become one of the most common sports injuries among athletes, especially in positions such as playing outside and playing against each other. Studies show that shoulder injuries among volleyball players exhibit a high incidence rate, chronic progression and multiple factors. Shoulder joint injuries account for 8% to 20% of all volleyball-related injuries, most of which are chronic injuries accumulated from long-term training, while some are due to acute sports injuries [1]. Whether chronic or acute, these injuries can cause shoulder pain, thereby affecting training and competitions. This not only seriously affects the performance and career of the athletes, but also imposes a heavy burden on the team's medical support system.

The typical manifestations are pain, limited movement and weakened strength. Common symptoms include post-exercise pain, pain at night or in position, limited abduction and external rotation, difficulty in head movement and joint instability. Some athletes may also experience muscle weakness, joint clicking sounds or tenderness in the rotator cuff area. Chronic injuries are usually progressive, while acute injuries typically present as sudden, severe pain and functional impairment. The clinical diagnoses mainly include rotator cuff tear, subacromial impingement syndrome, labral tear and joint instability. The injury mechanism of shoulder pain is relatively complex, and most of the pain is caused by the repeated spiking and serving training of volleyball players. Internal impingement syndrome is relatively common among volleyball players in shoulder joint pain.

Repeated abduction and external rotation of the shoulder cause continuous contact and friction between the rotator cuff joint surface and the posterior pelvis margin, thereby leading to local inflammation and pain. Insufficient strength of the rotator cuff muscles, reduced dynamic stability of the scapula, mild upward displacement of the humeral head and soft tissue degeneration will exacerbate this process. These anatomical and functional factors interact with high-intensity training loads and insufficient rehabilitation, resulting in shoulder injuries characterized by multiple overlapping factors. Therefore, systematically studying the etiological mechanism of shoulder joint injuries in volleyball players is of great significance for improving the sports injury research system and optimizing prevention and treatment strategies [2]. This review examines the underlying causes of shoulder injuries in volleyball, emphasizing the roles of shoulder anatomy, biomechanical loading, training demands, and movement-specific risks. It proposes evidence-informed prevention and rehabilitation approaches aimed at protecting athlete health, sustaining career longevity, and optimizing performance.

2. Biomechanical Demands and Loading Characteristics of the Shoulder in Volleyball

The shoulder joint, possessing the greatest range of motion in the human body, has a complex anatomical structure comprising the rotator cuff muscles, glenohumeral joint, and acromioclavicular joint. During high-speed arm swings, powerful spikes, and jump serves, the shoulder must not only perform extensive rotation and abduction but also withstand substantial tensile and impact loads, making it one of the most injury-prone regions in volleyball players.

Kinematic analyzes show that overhead actions such as spiking and serving involve repeated movements within extreme joint ranges. During the spike preparation phase, the shoulder reaches an average external rotation of 174° ± 36%, abduction of 70° ± 28%, and horizontal adduction of 109° ± 26%, reflecting the highly complex joint configurations required for force generation. At impact, external rotation (-83°) and abduction (122°) are maximized, with horizontal adduction approaching a neutral position (12°), imposing considerable stress on joint stability.

The mean impact force during ball contact reaches 416 ± 99 N, peaking at 681 N, which induces substantial fluctuations in internal shoulder torque and may even reverse its direction. To counteract this reaction force, the subscapularis, pectoralis major, and latissimus dorsi generate additional torque to stabilize the motion, markedly increasing joint load and injury susceptibility. These biomechanical characteristics underscore the inherent high-risk nature of volleyball movements, predisposing athletes to chronic shoulder overuse injuries through prolonged training and competition [3, 4].

3. Classification and Epidemiological Features of Shoulder Injuries

Typical symptoms of shoulder joint injuries include pain, limited range of motion, and decreased strength. Athletes commonly report post-exercise soreness, nighttime or positional pain, restricted abduction and external rotation, difficulty with overhead movements, and joint instability [5]. Some cases also present with muscle weakness, joint clicking, or tenderness in the rotator cuff region. Chronic injuries typically manifest as progressively worsening shoulder pain and functional decline, while acute injuries often present as sudden severe pain and loss of function.

Clinical diagnosis indicates that shoulder joint injuries can be classified into multiple types, as shown in Table 1. Subacromial impingement syndrome is often associated with tendinopathy, partial rotator cuff tears, or bursitis. Internal posterior-superior impingement primarily occurs during abduction and external rotation, involving repeated contact between the greater tubercle of the humerus and the posterior-superior labrum. Biceps-labral complex injuries include the classic SLAP lesion, often associated with repetitive overhead activities. Rotator cuff injuries involve varying degrees of tendon pathology or tears, most commonly affecting the supraspinatus muscle. Anterior

instability is frequently seen in athletes with a history of dislocation or repetitive microtrauma, presenting as subluxation or a sensation of instability.

Table 1. Classification and Key Features of Shoulder Injuries

Type of Injury	Key Features
Subacromial Impingement Syndrome (SIS)	Pathology within the subacromial space, including tendinopathy, partial rotator cuff tears, or bursitis, typically aggravated by shoulder elevation and rotation.
Internal Posterosuperior Impingement	Seen in overhead athletes, caused by repetitive contact between the humeral greater tubercle and the posterosuperior glenoid during extreme abduction and external rotation.
Biceps-Labrum Complex Injuries	SLAP lesions, superior labrum tears extending from anterior to posterior, involving the biceps tendon anchor.
Rotator Cuff Injuries	Tendinopathy or partial-to-full thickness tears, most frequently affecting the supraspinatus tendon.
Anterior Instability	Often following prior dislocation or repetitive microtrauma, presenting as anterior subluxation and recurrent pain.

From an epidemiological perspective, shoulder joint injuries exhibit high incidence and prevalence across various overhead sports. Studies indicate that 23%–38% of swimmers sustain shoulder injuries within a year, while 23% of volleyball players experience shoulder pain during the season. Between 44% and 75% of elite handball players report a history of shoulder pain, with 20%-52% experiencing persistent shoulder pain, 28% experiencing weekly shoulder pain, and 12% having a history of severe shoulder injury. Baseball and water polo similarly exhibit high shoulder injury rates, with specific figures varying according to factors such as athlete age, gender, and competitive level.

Regarding injury mechanisms, acute injuries result from transient high-energy transfer events such as falls or direct impacts. Chronic or overuse injuries stem from the cumulative effect of repetitive low-energy loading, exemplified by repeated overhead movements. Mixed injuries arise from sudden exacerbation during repetitive actions, such as acute pain during throwing motions. High-risk populations include adolescent and young adult athletes, as well as participants in overhead sports such as swimming, volleyball, handball, baseball, and water polo. Elite athletes with high training intensity and repetitive motion exposure are particularly vulnerable. Frequently implicated movements comprise throwing actions in baseball and handball, spiking and serving in volleyball, swimming strokes, ring and bar exercises in gymnastics, and overhead lifts in weightlifting, including the snatch and clean and jerk [6, 7].

4. Training Load and Injury Risk

Shoulder joint injuries in volleyball are closely linked to sport-specific training loads. The mechanisms underlying shoulder pain are complex, with most cases stemming from repeated spiking and serving drills in volleyball players. Spiking constitutes the most frequent scoring technique in volleyball, with approximately 80% of shoulder pain among volleyball players associated with this action. The spiking action requires athletes to execute the movement in mid-air without lower-body support, relying solely on upper-body and trunk power generation, thereby imposing substantial stress on the shoulder joint.

The impact of training load on injury risk manifests in multiple aspects. Repeated execution of spikes and serves positions the shoulder joint in extreme abduction, external rotation, and horizontal abduction, increasing stress on the rotator cuff and the biceps-labrum complex. Secondly, abnormal technical movement patterns significantly elevate risk. Players experiencing shoulder pain exhibit poor scapular retraction, increased internal rotation, heightened glenohumeral horizontal abduction, and reduced trunk lateral flexion during spikes. These biomechanical deficiencies compromise kinetic chain integration and exacerbate local structural strain. Furthermore, muscular strength and flexibility

imbalances are critical factors, with glenohumeral internal rotation deficiency (GIRD), rotator cuff strength asymmetry, and scapular dysfunction being common risk factors. Finally, training volume coupled with inadequate recovery cannot be overlooked. Athletes trained an average of 3.4 days per week for 3.3 hours daily; this high-frequency, high-intensity regimen, lacking sufficient recovery time, readily leads to overuse injuries. Painful training is prevalent, with 39.4% of athletes continuing to train despite baseline shoulder pain, thereby exacerbating injuries [8, 9].

5. Biomechanical Mechanisms of Shoulder Joint Injuries

As an overhead sport, volleyball shoulder injuries primarily stem from chronic overuse due to repetitive excessive loading. The core biomechanical mechanism involves internal impingement, particularly Posterosuperior Impingement (PSI). During the Late Cocking phase of the throwing motion, the shoulder joint assumes extreme abduction and external rotation (ABER), where the posterosuperior humeral head makes physiological contact with the posterosuperior glenoid labrum. However, repetitive high-velocity throws can transform this physiological contact into pathological collision, resulting in characteristic partial tears of the articular surface-side rotator cuff and damage to the posterosuperior labrum.

This process is closely associated with a series of adaptive pathological changes. Repeated exposure to substantial posterior shear forces during deceleration causes contraction of the posterior inferior joint capsule, resulting in GIRD. This forces the humeral head to undergo more pronounced posterior-superior displacement during external rotation, intensifying the impact and increasing stress on the biceps tendon insertion point, thereby triggering a superior labral anterior-posterior (SLAP) tear. Concurrently, fatigue of the scapular stabilizers and interruptions within the kinetic chain can precipitate scapular dysfunction, such as SICK scapula syndrome, which disrupts normal glenohumeral alignment and further compromises biomechanical stability. Moreover, during flexion, adduction, and internal rotation, the subscapularis tendon and biceps pulley system may undergo anterosuperior impingement (ASI) against the anterior superior glenoid rim, causing corresponding structural damage. Consequently, shoulder joint injuries in overhead athletes represent a multifactorial, complex biomechanical issue. Treatment should emphasize restoring the function of the entire kinetic chain, improving range of motion with particular attention to GIRD, and enhancing dynamic stability, rather than focusing solely on local impingement lesions [9, 10].

6. Prevention and Rehabilitation Strategies

Effective prevention and rehabilitation strategies should be based on systematic identification and targeted modification of risk factors. Current evidence of moderate strength highlights two non-modifiable determinants, namely playing position and sex, along with three modifiable factors, including deficits in rotator cuff strength, scapular dyskinesis, and insufficient implementation of shoulder-specific preventive training programs. Building a robust prevention framework therefore requires proactive screening of high-risk groups, such as female adolescent handball players or baseball pitchers, and the application of multidimensional interventions directed at modifiable risk profiles. A comprehensive prevention program integrating shoulder muscle strength training, scapular stability exercises, kinetic chain optimization, and thoracic flexibility training should be performed at least weekly as part of warm-up routines. During rehabilitation, alongside continuing the aforementioned preventative training, functional recovery and progressive load management should be tailored to individual injury mechanisms. Emphasis must be placed on synchronizing long-term adherence with enhanced athletic performance, thereby achieving seamless transition and systematic management from prevention to recovery [11].

7. Conclusion

The high-intensity, repetitive nature of volleyball-specific movements subjects the shoulder joint to substantial stress, resulting in a high incidence of injury. This review examines the anatomical and loading characteristics of the shoulder joint in volleyball players, outlines common injury types and epidemiological features, summarizes training loads and risk factors alongside biomechanical mechanisms, and proposes systematic prevention and rehabilitation strategies. Clinical practice demonstrates that optimizing technical movements, enhancing physical conditioning, implementing comprehensive prevention programs, and integrating personalized rehabilitation pathways can effectively reduce shoulder injury risk, improve athletic performance, and extend sporting longevity.

However, current research remains constrained. The majority of studies are confined to specific cohorts such as elite athletes, with a paucity of multicenter, large-sample longitudinal data. Injury mechanisms across different skill levels, sexes, and age groups are not yet fully delineated, and the evidence base supporting most preventive and rehabilitative interventions remains relatively weak. Future research should delve into the mechanisms of multifactorial interactions, develop personalized injury prediction and monitoring models, advance evidence-based rehabilitation protocols, and integrate wearable devices with motion capture technology to enable real-time monitoring and feedback of training loads. This will provide more scientifically grounded guidance for training and rehabilitation practices.

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