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Rotator Cuff Injury in Baseball: Causes and Mechanisms, Assessment, and Prevention

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Abstract. Baseball pitchers are subject to prolonged unilateral explosive rotational loading. Rotator cuff injuries are relatively common sports injuries in this group. They reduce athletic performance and shorten professional careers. Currently, China's system for preventing baseball-specific injuries is not well-developed, and traditional rehabilitation methods have not been adapted sufficiently to pitching mechanics. This paper studies the systematic prevention and management of rotator cuff injuries in baseball. It has investigated the reasons for the above injuries from three aspects: the different stages of pitching, joint function and kinetic-chain coordination. Three evaluation methods and their relevant physical therapy intervention plans are presented. The above methods are a risk-stratified management of subacromial impingement, targeted rehabilitation of the external rotator muscles and postoperative rehabilitation according to the stage of tendon healing. According to the force-producing features of pitching, these strategies can reduce the risk of injury and accelerate the recovery of shoulder function. Provide practical reference for the prevention and treatment of baseball-related injuries. However, long-term follow-up data from large samples remain insufficient. Future research will focus on the actual application of wearable monitoring technology in rehabilitation.

Keywords: Rotator cuff injury, baseball pitcher, kinetic chain, subacromial impingement, physical therapy

1. Introduction

Baseball is a representative unilateral explosive rotational sport. All links in the kinetic chain of a specific movement, such as pitching, swinging and batting, sequentially transmit force from the torso to the scapula and upper limbs. As the final power-generating unit in this series, the shoulder joint is located at the end. During the swing phase, rapid eccentric braking by the rotator cuff muscles is required for a large-amplitude movement of internal and external rotation at the shoulder joint. Therefore, the shoulder joint and the surrounding muscles are relatively weak. Rotator cuff injuries are relatively common chronic upper-limb injuries for baseball players, especially pitchers and batters. It is a reason for the decline in athletic performance and reduced professional life due to chronic relapse after rehabilitation. It can also affect the athletes' psychology and indirectly lead to injuries [1]. Targeted physical therapy of only the structures around the shoulder joint has had limited effects in practice.

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Rotator cuff injuries are causes of shoulder pain and restricted joint motion. These deficiencies will result in an unstable force-production path and reduced efficiency of force generation; thus, athletic performance will decline. Such injuries may also lead to chronic conditions in the muscles and joints that directly affect athletes' technical skills and careers. Epidemiological data on rotator cuff injuries show that the proportion of baseball pitchers injured is significantly higher than that of players in other positions. It also increases with an increase in the degree of matching, training intensity and training duration [2]. In recent years, baseball has gradually developed in China and the competition level has risen. However, the injury prevention system for this particular sport is not well-developed. The clinical assessment and physical therapy programs have not been adapted to the technical requirements and training model of baseball.

Research on rotator cuff injuries in baseball has studied several aspects of the problem in China. Research on the mechanism of injury has shown that the biomechanical features of pitching are directly associated with increased stress on the rotator cuff. The primary reasons for the technical errors, incorrect training methods and structural problems of poor scapular stability have been identified. Physical therapy and medical imaging are already widely used in clinical practice, but the criteria for assessment vary at different levels of assessment. There is no organised data available on the application of periodised exercise in baseball or rehabilitation programmes for returning to play after injury. This paper will investigate the reasons for injury, risk factors, diagnostic tests and different stages of recovery of rotator cuff injuries in baseball players, as well as the application of periodized rehabilitation exercises and return-to-play evaluations. Provide theoretical support for the construction of a rational and standardized rehabilitation system in this study.

2. Risk factors for rotator cuff injuries in baseball

2.1. Injury risks at different stages of pitching

The pitcher needs to rotate his upper body quickly and use a fast-eccentric contraction pattern of the rotator cuff. Based on the patterns of joint movement and types of muscle contraction, the three stages of pitching can be divided into the wind-up and arm-cocking phase, the acceleration phase of shoulder rotation, and the follow-through phase. The loading patterns and load intensities of the rotator cuff muscles in these stages are different, and thus the injury mechanisms vary. At the top of the arm-cocking movement, the shoulder is maximally externally rotated. Under high load, the rotator cuff muscles are elongated and need to keep the stability and positioning of the humeral head in the joint. Therefore, the tendon tissue is stretched and subjected to large stresses [3]. For instance, repeated compression of the supraspinatus tendon under the acromion, along with repeated stretching and contraction, can cause tendon strain and inflammation.

At the same time, during acceleration, the rotator cuff muscles contract concentrically and rapidly to perform internal rotation of the upper limb and provide force for pitching. The Tendons are extending along the pitch. If the load is too large, the tendon fibres will be torn or broken. The follow-through phase is the stage with a high incidence of rotator cuff injuries. At this time, the demand for the rotator cuff is relatively high. The rotator cuff muscles perform high-intensity eccentric contractions to rapidly inhibit internal rotation of the upper limb and regulate the trajectory of the ball after release. The stress on the tendons is much higher than in daily life, and they are therefore more likely to be damaged.

Repeatedly exercising hard for a long time will cause damage to muscles and tendons. Recurrent Injuries may develop into chronic diseases. A long-term high-load condition will lead to severe

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tearing or complete fracture of the above features over time. An increase in the frequency and duration of pitching during competition may also lead to injury [4].

2.2. Injury risks related to proximal and distal joint function

Force production and load transmission in the upper limb are achieved by a connected biomechanical chain. At the level of the proximal scapulothoracic and glenohumeral joints, as well as the distal elbow and wrist joints, force transmission occurs. Alterations in the Loading Conditions of the Scapula can increase the risk of Rotator Cuff injuries. At the proximal end of the kinetic chain, insufficient strength or abnormal activation patterns of the scapular muscles can lead to excessive scapular protraction and inadequate upward or downward rotation, thus resulting in abnormal movement patterns. The above changes may reduce the subacromial space and thus cause irritation or compression of the rotator cuff tendons at the acromion-coracoid process [5]. With time, this will cause tendon degeneration and inflammation, and in serious cases, a tear.

Reduced proprioceptive feedback from the glenohumeral joint and insufficient joint stability can lead to abnormal anterior, posterior, superior or inferior translation of the humeral head during pitching. Therefore, the rotator cuff muscles need to increase their compensatory activity by working with the surrounding muscles to stabilise the joint. The resulting rise in mechanical stress will increase muscle fatigue. Frequent braking of the tendon outside its normal range will also cause damage.

At the distal end of the kinetic chain, resistance to valgus stress during the pitching motion and maintenance of upper limb alignment are required. If the medial-stabilising structures of the elbow are weak or force transmission is inefficient, upper-limb alignment may deviate and increase shear stress at the shoulder joint due to compensation by the body. Additionally, a lower energy-transfer efficiency at the distal end of the kinetic chain will reduce the transmission of force generated by the lower limbs. Therefore, the rotator cuff muscles need to exert more force for compensation; as a result, the total stress on the shoulder is further increased.

2.3. Injury risks related to kinetic-chain function and muscle coordination

Pitching in baseball is a coordinated-force-production activity of the kinetic chain for both upper- and lower-body limbs. Rotator cuff injuries affect the efficiency of force transmission in this chain, interfere with coordination among the rotator cuff muscles, and reduce the ability of antagonistic muscles to control movement.

Firstly, a lack of cooperation among the kinetic links will raise the demand on the rotator cuff. Good Force Transmission Requires Stable Control of the Core Muscles. If the sequence of trunk rotation and upper-limb force production is incorrect, force transmission through the lower-limb kinetic chain from the stance leg to the push-off leg and then via arm cocking and arm swing may be interrupted. This reduces the efficiency of force transmission and increases the load on the rotator cuff muscles and tendons.

Second, weakness of the rotator cuff muscles may lead to shoulder instability. The Teres minor, Infraspinatus, Supraspinatus and Subscapularis work together to stabilise the head of the humerus and permit rotation of the shoulder joint. When a muscle group is weak, there may be restricted shoulder mobility due to overcompensation by other muscles. This will lead to an abnormal translation or rotation of the humeral head and concentrate the stress on a specific tendon. For instance, if the shoulder external rotators are weak, then the supraspinatus must take on a larger proportion of the stress that controls internal rotation, as well as controlling the rotation and

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displacement of the humeral head. Excessive superior displacement of the humeral head may increase the risk of subacromial impingement.

Thirdly, muscle and nerve fatigue during extended play or exercise may reduce eccentric strength and disrupt the coordination of muscle groups. Errors may occur at various links in the pitching process, and abnormal coordination of muscle-joint connections increases the risk of rotator cuff injuries.

Fourth, an imbalance in the strength of antagonistic and stabilizing muscles, along with abnormal muscle coordination, may result in incorrect shoulder rotation during pitching. Insufficiently stable downward control of the humeral head can also lead to subacromial impingement, for example. The deltoid muscle, supraspinatus tendon and others will be subjected to abnormal mechanical stress, interrupt the normal force transmission route, and thus increase the risk of rotator cuff injury [6].

3. Physical therapy assessment methods for rotator cuff injuries

3.1. Screening shoulder injuries in baseball pitchers using the KJOC score and park TIC

The purpose of the rapid screening protocol is to help identify subacromial impingement and early rotator cuff injuries in baseball pitchers promptly. The two assessment devices are the Kerlan-Jobe Orthopaedic Clinic (KJOC) score and the Park test-item cluster (Park TIC). A combination of self-assessment of function and clinical signs can be used to quickly screen without expensive equipment. The first is self-assessment of the athlete using the KJOC questionnaire. Ten items in the questionnaire cover all kinds of sports-specific attributes of pitching, such as pain during pitching, changes in ball speed, accuracy and endurance of pitching. The upper bound is 100, and a representative high-risk alarm level is taken to be around 90. A score below 90 indicates impairment of shoulder function in sports-specific activities.

Then the examiner will conduct the three manual tests of the Park TIC. Passive Positional Provocation Tests, observation of the arc of active motion and strength tests for external rotation are used to determine if subacromial impingement occurs. A greater number of positive tests indicates a higher risk of subacromial impingement syndrome. The two sets of results are used together. It will reduce the problem of subjective self-assessment and address the limitation of clinical signs in reflecting sport-specific performance. It is suitable for whole-team screening before the season and regular monitoring during training. Risks can also be divided according to the KJOC score and the number of positive test items for intervention. High-risk athletes can be selected for extra motion analysis and medical imaging [7].

3.2. Combined assessment of clinical signs in the rotator cuff external rotators and pitching-specific function

A method of evaluation based on rehabilitation intervention research for professional baseball pitchers. No special facilities or devices are required; otherwise, it cannot be held at the training site. The two components of the evaluation are manual clinical observations and sport-specific functional tests. The two kinds of manual tests are the external-rotation lag-sign test and the resisted external rotation test. Assess the range of motion and pain response of maximum external rotation with the arm in adduction under resistance for each athlete. Together, the results are used to evaluate the extent of inflammation and muscle-strength deficits in the infraspinatus and teres minor.

A 30-tooth maximum-effort straight-pitch functional test will be conducted for that sport. Record the accuracy of pitching and changes in ball speed at different times, and use a visual analogue scale

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(VAS) for pain. The above measures show the endurance capacity of the external rotators and the extent of functional impairment in sport-specific exercise. The angle of passive internal rotation is also measured with the athlete in the side-lying position. Quantification of the tightness in the posterior shoulder soft tissues and other structural factors that affect shoulder function [8] are also provided.

3.3. Dynamic rotator cuff assessment based on tendon healing stages and wearable sensors

Now there are no more single-time static clinical assessments. Based on the three biological stages of tendon healing, a multi-stage assessment system has been established to replace the previous approach of general clinical examination and sport-specific functional tests [9, 10]. In the first 6 weeks after surgery, during the inflammatory stage, attention should be paid to immobilisation compliance, pain changes at rest and with movement, and safe limits for passive range of motion. The above measures are suitable for the low-load tolerance of the tendon in the initial repair stage.

During the proliferative phase (weeks 7-12), there is a weekly increase in the range of motion after moving from passive to active exercise of the shoulder, as well as changes in the tightness of the soft tissues around the shoulder. The above measures determine the changes in tissue mechanics during the proliferative stage. In the remodelling stage (3-6 months after surgery and beyond), the focus of assessment shifts to the gradual improvement of muscle strength under increasing resistance and tolerance of daily living activities.

Wearable assessments are also available in the form of inertial measurement units (IMUs). Sensors are attached to the sternum and both humeri to continuously collect quantitative data about daily activities, such as the proportion of time spent moving the affected limb, peak angular velocity, and the ratio of activity between the affected and unaffected limbs. These indicators can replace some subjective self-assessments to quantify the kinematic changes resulting from different degrees of disability and aid in continuous remote monitoring at home post-surgery. They have added biomechanical data to address the previous deficiency of traditional clinical scores [11].

4. Physical therapy intervention strategies

4.1. Risk-stratified intervention for subclinical subacromial impingement

Risk levels for baseball pitchers are divided according to the KJOC functional score and the results of the Park TIC clinical screening, and the intensity of rehabilitation is adjusted according to each risk group. For the low-risk group (KJOC $\geq$ 90 and no positive TIC items), only preventive training is required. After each set of exercises, Scapular Stabiliser Activation Exercises and stretches for the back-of-the-shoulder soft tissues are performed. These exercises are done three times a week to keep the scapulohumeral rhythm normal and reduce the risk of subacromial impingement during pitching.

For the moderate-risk group (KJOC < 90 and one positive TIC item), maximum-effort pitching is temporarily suspended. Joint mobilisation techniques for the subacromial joint are used to increase the space available, and external rotation strengthening exercises are performed with the arm adducted and a rolled towel held in the axilla. The exercise aims to correct a compensatory movement pattern of superior translation of the humeral head.

For the high-risk group (KJOC < 90 and at least two positive TIC items), physical agents are used first to control inflammation and pain [12]. At the same time, pitching mechanics are corrected to reduce excessive scapular protraction in the arm-cocking phase. Resume sport-specific training gradually as the symptoms improve. Risk-stratified intervention can detect subclinical subacromial

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impingement 4-6 weeks earlier. Under the low-risk programme, the occurrence of symptoms during the off-season is reduced by 41%. The proportion of symptomatic relief for the medium- and high-risk groups is about 85%, and most athletes can resume exercising in 4-6 weeks.

4.2. Targeted rehabilitation for injuries to the rotator cuff external rotators

For baseball pitchers with injuries to the external rotators of the rotator cuff, such as the infraspinatus and teres minor, a rehabilitation program that combines stretching with strengthening and both concentric and eccentric training is used. The programme is a low-impact exercise system for everyone.

Daily stretching and strengthening exercises are conducted. A normal side-lying position is used for the stretch, the trunk is rotated back by 20-30 degrees, and the scapula is stabilised. Hold each position for 30 seconds and repeat five times to increase the range of motion of the back-of-the-shoulder soft tissues gradually.

The two components of exercise are: In the course of daily strength training, a light resistance of 1kg is used for three types of concentric exercises: external rotation with the arm abducted, external rotation with the arm adducted, and reverse-pitching movements. The number of times is gradually increasing each week. After training, additional eccentric contractions against manual resistance are performed to mimic the force-generation pattern of the external rotators during the deceleration phase of pitching.

Gradually increase the load over a 10-week period to balance the development of external rotator strength and flexibility. Endurance in pitching and passive shoulder internal rotation are also improved. The programme shows the irregular load conditions of pitching. In 10 weeks, the strength of external rotation increased by about 30% and the general efficiency rate reached 88%. The return-to-play time for sport-specific training is shortened by three weeks, and the risk of late relapse is also reduced.

4.3. Phase-specific rehabilitation after rotator cuff surgery

A three-stage rehabilitation program for tendon healing is based on the three biological periods of inflammation, proliferation and remodelling. The program matches the loading tolerance of the tissues at each stage to balance protection of the healing tendon with restoration of shoulder function.

During the inflammatory period (0-6 weeks after surgery), the main goal is protection via sling immobilisation, and cryotherapy is added to manage pain and inflammation. Only active movement of the elbow, wrist and hand, and gentle, limited passive shoulder external rotation are performed. The Range of Motion is relatively small. Proliferation Stage (Weeks 7-12): Gradual progression from passive exercise to active-assisted exercise in rehabilitation. Pulley exercises and table slides are employed to enhance joint mobility. Weekly increases in the range of motion are limited to prevent excessive stretching of the healing tendon.

Progressive resistance exercise therapy is applied during the remodelling period (3-6 months after surgery), and eccentric strengthening is added. Wearable devices containing inertial sensors have also been added to monitor the daily activity and movement-angle velocity of the injured limb [13]. Such data can show the extent of recovery and modify training intensity for individuals to reduce the risk of post-operative stiffness and re-tear. This phase-specific rehabilitation method follows the biological process of tendon healing. The early postoperative re-tear rate is less than 2%, and by six

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months, muscle strength has recovered to over 90% of that of the non-operated side. Wearable monitoring reduces the total length of rehabilitation by about 10% [13].

5. Conclusion

This paper will systematically introduce all the reasons for rotator cuff injury in baseball pitchers and provide a full-process physical therapy system covering risk screening, functional evaluation and personalised treatment. The three clinical cases are subclinical subacromial impingement, injury of the external rotator muscles, and postoperative rehabilitation. Based on the biomechanical features of baseball pitching, which include unilateral explosive rotation, this framework can help identify and correct early injuries. It can reduce the problem of shoulder pain, restore pitching-related functions, enhance athletic ability, and prolong the career of athletes. The framework also addresses the previous deficiency of sport-specific rehabilitation systems and their limited adaptability. At present, most research has a small sample size and the assessment standards of different evaluation tools vary. In the future, a large-scale prospective cohort study can be conducted to optimise wearable dynamic monitoring and establish a more standardised system for injury prevention and rehabilitation in baseball.

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