Proceedings of the 7th International Conference on Educational Innovation and Psychological Insights
DOI: 10.54254/2753-7048/2026.32750

Rotator Cuff Injury Exercise Rehabilitation Training Methods and Theoretical Optimization

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Abstract. Rotator cuff injury has a high incidence in populations performing repetitive overhead movements and athletes, and it is a major cause of shoulder joint pain and impaired quality of life. Studies have demonstrated that its prevalence is positively correlated with age. Based on a series of research studies, this paper puts forward rehabilitation recommendations tailored to different stages of rotator cuff injury and distinct populations. The biomechanical mechanism of the shoulder joint forms the foundation for formulating rehabilitation plans, while a systematic and standardized rehabilitation assessment is the prerequisite for implementing individualized and staged rehabilitation interventions. The early initiation and consistent implementation of neuromuscular re-education throughout the entire rehabilitation process of rotator cuff injury embody the advancements of modern rehabilitation in this field. This paper is intended to establish a direct correlation between rehabilitation assessment results and stage progression, minimize subjectivity in clinical rehabilitation practice to the greatest extent, and provide a scientific and operable theoretical and practical reference for the clinical rehabilitation of rotator cuff injury.

Keywords: Rotator cuff injury, exercise rehabilitation, rehabilitation protocol.

1. Introduction

Rotator cuff injury is a highly prevalent soft tissue disorder of the shoulder joint in the fields of clinical orthopedics and sports rehabilitation, and also the core cause of shoulder joint pain, limited joint mobility and dysfunction. Its epidemiological characteristics are reflected in a significant positive correlation between prevalence and age, as well as a marked clustering of incidence among occupational populations and professional athletes with prolonged overhead movements [1]. This injury not only directly impairs patients' physical motor function and reduces their activities of daily living and quality of life, but also severely undermines athletes' athletic performance and career development, while imposing corresponding resource burdens on the clinical medical and rehabilitation service system. As a core intervention for both conservative treatment and postoperative repair of rotator cuff injury, sports rehabilitation serves as a crucial means to promote the repair of injured tissues, reconstruct the biomechanical balance of the shoulder joint, restore the synergistic contraction pattern of the rotator cuff muscle group and reduce the incidence of secondary injuries, and its core status in the clinical diagnosis and treatment system of rotator cuff

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injury has been widely confirmed [2]. However, there remain prominent problems in the current clinical practice of sports rehabilitation training for rotator cuff injury: some rehabilitation protocols lack clear stage division and objective progression criteria, and there is a disconnection between rehabilitation assessment results and the adjustment of training parameters as well as stage transition; improper control of rehabilitation load and blind progression are prone to occur in clinical practice due to the dominance of subjective experience. In the meantime, the personalized adaptability of rehabilitation protocols for different injury severities, treatment methods and population characteristics is insufficient, and a rehabilitation training framework integrating structure, standardization and clinical practicability has not yet been established, making it difficult to fully meet the diverse clinical rehabilitation diagnosis and treatment needs.

Domestic research on sports rehabilitation for rotator cuff injury has gradually transformed from an experience-driven model to an evidence-based one, with the research focus centered on verifying the clinical effectiveness of staged rehabilitation protocols, and a series of evidence-based research results adapted to local clinical diagnosis and treatment needs have been formed. On this basis, domestic research has further expanded the intervention dimensions of rotator cuff injury rehabilitation. On the one hand, it actively explores the clinical application of the integrated traditional Chinese and Western medicine rehabilitation model, integrating traditional Chinese medicine manual therapies such as Tui Na with modern exercise therapy and physical factor therapy [3]. On the other hand, it deepens the translational practice of the neuromuscular control theory in rotator cuff injury rehabilitation, and researches the effects of relevant techniques such as proprioceptive neuromuscular facilitation training on the functional recovery of patients with rotator cuff injury [4]. In the meantime, specialized rehabilitation research has been carried out for special populations such as the elderly and athletes, which continuously enriches and improves the theoretical and practical system of sports rehabilitation for rotator cuff injury.

Overseas research on sports rehabilitation for rotator cuff injury has entered a stage of highly evidence-based and standardized development, and relevant research results continue to provide scientific evidence for the update and optimization of clinical guidelines. The latest clinical guidelines released by authoritative institutions such as the American Academy of Orthopedic Surgeons (AAOS) in 2025 have further established the status of physical therapy as a first-line basic intervention in the rehabilitation of rotator cuff injury, and clearly advocated the core rehabilitation principles of stepwise progression and personalized adaptation [5]. These guidelines have abandoned the traditional concept of prolonged postoperative immobilization and proposed the intervention strategy of scientifically implementing functional activities in the early postoperative period [6]. Meanwhile, they have incorporated patient education into the whole-process management system of rotator cuff injury rehabilitation, and improved patients' rehabilitation compliance through systematic health education, thus defining clear evidence-based basis and implementation criteria for the clinical practice of sports rehabilitation for rotator cuff injury.

This study aims to systematically sort out and integrate the relevant theories, evidence-based evidence and clinical practice methods in the field of sports rehabilitation for rotator cuff injury at home and abroad, condense the core principles and key technical points of sports rehabilitation for rotator cuff injury, attempt to construct a rehabilitation training framework for rotator cuff injury with a clear structure, definite stages and strong practicability, clarify the core intervention objectives, objective progression criteria and targeted training strategies for each rehabilitation stage, and propose personalized adjustment plans adapted to different injury types, treatment methods and population characteristics.

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The clinical practical significance of this study is reflected in the fact that the constructed rehabilitation training framework for rotator cuff injury can provide rehabilitation therapists with a structured evidence-based reference template and clear clinical thinking for formulating rehabilitation plans and offer scientific and standardized practical guidance for patients to carry out home-based rehabilitation training. By establishing a direct correlation between rehabilitation assessment and stage progression, as well as training adjustment, this framework can effectively reduce the subjectivity and bias in clinical rehabilitation practice and improve the standardization level of rehabilitation training for rotator cuff injury. In the meantime, this study provides operable theoretical support and practical reference for the clinical practice of sports rehabilitation for rotator cuff injury, which is conducive to promoting the precise implementation of clinical rehabilitation interventions and thus improving the overall rehabilitation effect of patients with rotator cuff injury.

2. Learning foundation: theoretical and assessment

As a major cause of shoulder disorders and functional dysfunction, the incidence of rotator cuff tears shows a significant positive correlation with age and is notably high in specific occupational groups and athletes performing frequent overhead movements [2]. It is a critical epidemiological parameter that would be a major clinical guideline rehabilitation therapists rely on when evaluating injuries in a first instance as well as assessing the patients within the first instance. Another theoretical basis that is essential to the creation of specific rehabilitation plans is the biomechanical mechanism of the shoulder joint.

2.1. Theoretical basis

The human shoulder is the most mobile joint with the relative lack of structural support because of poor structural support, offered by bony anatomy. Rather, shoulder stability is dynamic; it is based on a synergistic action by the four rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis), glenohumeral ligaments and the glenoid labrum. The main action of the rotator cuff muscles is to keep the central position of the humural head at the glenoid fossa and ensure the multi-axial motions of the shoulder joint [7]. The injury of rotator cuff directly interferes with this main mechanical equilibrium resulting in joint instability and movement pathology.

Remarkably, neuromuscular control theory is a fundamental theoretical foundation to present-day optimal rehabilitation. The theory is not restricted to just muscle strength increase but focuses on high regulation of the central nervous system rather than the timing, coordination patterns, and force control of the motor unit recruitment. The resulting processes of compensatory overactivation of some in relation to the inhibition selectively of others, which are caused by pain-induced selective muscle inhibition and distorted proprioceptive input, eventually leads to inappropriate movement patterns [4]. Thus, the modern tendency in the process of sports rehabilitation optimization is the provision of the neuromuscular re-education in time and in the correct order which is directed to the restoration of the effective scapular stability and coordination of the contraction of the rotator cuff muscles in the whole kinetic chain.

2.2. Rehabilitation assessment

Planned and gradual development and customized treatment planning is a pillar of a standardized and evidence-based evaluation procedure. In contrast to a single initial assessment, a detailed analysis must be introduced in the whole rehabilitation process that will inform the transition to the

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next stage, the training parameters changes, and the results. Pré-rehabilitation assessment should be to give a general account of the scenario of the injury and functional debilitations [8,9]. It is divided into four basic modules, which include pain assessment, which is assessed mainly by the means of validated quantitative scales, including Visual Analogue Scale (VAS); range of motion (ROM) assessment, which is assessed in accordance with the use of goniometer to measure the active and passive range of motion in each direction in the shoulders; muscle strength assessment, which is assessed on the basis of the use of a manual muscle testing or handheld muscle dynamometer; and functional assessment, which is assessed on the basis of using the reliable and validated standardized scales including the American Shoulder and In-process assessment is based on providing an opportunity to have correct transition of stages, as well as specific training parameters change.

During the protection and early recovery stage, the objective measures of the level of pain and the pain-free active/passive ROM can be used to explain whether the patient is going to the next stage or not. During the muscle strength reinforcement phase, the assessment indicators change to isotonic strength progression curve of rotator cuff muscles and scapular postural stability during the dynamic low-load activity. During the late functional restoration stage, the evaluations focus on sport and daily living functional ability and use simulated functional testing to imitate the actual movement requirements in the real world. Outcome measurement refers to analysis of the whole protocol of rehabilitation in a comprehensive and objective manner, which is done by the comparison between the baseline data and the post-intervention data. The results will be measured based on overall pain scores reduction, muscle strength, and joint ROM, as well as functional scale scores that reveal all the results of the rehabilitation strategy.

3. Rehabilitation training solution systematic optimization and design

This protocol optimization spirit lies by following the modern spirit of rehabilitation ideologies on gradual progression and adaption as an individual factor; high emphasis on the timely nature of neuromuscular control training intervention; and developing a close relationship between the evaluation outcomes and the stages of rehabilitation, to make the clinical practice less subjective and arbitrary.

3.1. Stages and process principles of rehabilitation

According to the biological phases of the soft tissue recovery and the principles of functional recovery, the overall process of rehabilitation is subdivided into four sequential and, to some extent, overlapping periods with specific goals and evidence-based developmental standards. The Protection Phase is 0-4 weeks after acute trauma or surgical reconstruction and the main goals of that stage are pain and inflammation management, healing soft tissues protection and the preservation of adjacent joints range of motions in case of effective pain management (VAS score $\leq$3) and the possibility to execute prescribed passive or assisted active movements within a rigid pain-free range.

The Recovery Phase is estimated to take between 4 and 12 weeks with its objective core being the attainment of full pain-free range of motion of the shoulder and the re-engagement of the typical neuromuscular control patterns of the rotator cuff and scapular stabilizers muscles and the criteria by which 1 can identify that the stage had reached is by: active and passive range of motion approximating closely those of the opposite healthy shoulder and by: stable maintenance of scapular neutral position during low load dynamic and static activities. The Reinforcement Phase is between 12-20 weeks and is aimed at enhancing rotator cuff and periscapular muscle strength, endurance and

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dynamic stability to withstand progressive functional loads, the corresponding progression criteria is muscle strength of key muscle groups is 75% of higher of contralateral limb (when measured using handheld dynamometry) and ability to perform low-to-moderate intensity activities of daily living activities without pain. The Functional Phase begins at about 20 weeks and more, the main task here being to recover high-grade functional capacity, power, and repetitive fatigue related to everyday activities, occupation, or sport-specific exercises with an approximate specification, and the progression level and criteria of returning to activity encompasses the achievement of normal-level sequential functional tests, optimal biomechanical performance, and the accomplishment of simulated sport-specific activities without pain or fear of movement.

3.1.1. Protection and recovery phase

All such training during this stage should be carried out in a pain-free or at an insignificant pain scope to prevent second-degree damage to the healing tissues. Ice therapy and physical agent modalities are auxiliary interventions that can be used to provide pain and inflammation control [9]. In ROM training, the first type of recommended exercises is pendulum exercises, then followed by progressive passive and active-assisted ROM training in all directions of the shoulder, when assisted by the other opposite limb or assistive devices. The main elements of protocol optimization during this stage are neuromuscular activation and stability training; proprioceptive neuromuscular facilitation (PNF) training is suggested to develop usual muscle recruitment sensations and increase scapular stability during the initial rehabilitation phase [4].

3.1.2. Reinforcement phase

The training at this step shifts to progressive isotonic training and resistance training. Typically, resistance bands, light dumbbells and other devices are applied to engage rotator cuff and periscapular muscles in various planes of the shoulder in which the scapular-plane external rotation movement, internal rotation movement, and scapular plane abduction movement are emphasized. The particular focus should be made on the training of eccentric contraction, which has been reported to stimulate tendon remodeling and functional recovery. In the case of neuromuscular integration training, close-chain exercises and the open-chain exercises with dynamic control are introduced to improve the stability of the dynamic joints. PF Rhythmic stabilization and dynamic reversal methods could be applied as well to enhance work capacity of the 2 or more muscle groups during dynamic shoulder movements with synergistic effects.

3.1.3. Functional phase

Design training at this stage needs high individualization, which closely matches the objectives of patient rehabilitation. It requires stimulating certain activities of daily living or sport-specific technical movements in order to design segmented and integrated training [10]. As an example, in the case of overhead athletes, full throwing or swinging action training should be made functional, which includes acceleration and deceleration of the sports activity. During the construction of the power and endurance training, practice methods of adding muscular power (addition of medicine ball throws and resistance band rows). Lastly, there is gradual, standardized sport-related pre-return-to-sport test, which is an objective procedure that is used to ascertain the physical fitness/movement pattern demanded in the patient to enable her to resume athletic activity safely.

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3.2. Protocol individualization changes

An effective rehabilitation program should be designed with respect to the differences between the populations and tailor the strategies on the basis of the population and the severity of injuries with consideration of safety and effectiveness. In patients with full-thickness massive rotator cuff tears or those who have undergone surgical repair, each of the phases ought to be appropriately increased in duration and reduction of load ought to be more cautious particularly during the protection and initial recovery phases to safeguard the repaired tissue. In the case of non-surgical intervention on patients who have a partial-thickness tear, the recovery period can be fairly shortened after they develop effective pain management. In older patients, one should also pay more attention to the impairment in the field of the daily lives activities and the influence of underlying chronic illness. Training protocols prioritize safety, with interventions focused on maintaining full joint ROM, balance training and fall prevention education. Manual therapies such as therapeutic massage can be used to relieve local pain and improve circulation, followed by low-intensity exercise therapy. For high-demand athletes, thorough biomechanical and movement pattern analysis is essential. In the functional phase, training content is highly sport-specific, with early introduction of competition-simulated functional training and psychological adaptation training to restore both physical function and competitive confidence.

4. Conclusion

This study takes the theoretical and assessment system for rotator cuff injury rehabilitation as the core foundation and has systematically accomplished the optimized design of rehabilitation training regimens and the development of a personalized framework, thereby providing a holistic solution characterized by standardization and clinical practicability for the clinical sports rehabilitation of rotator cuff injuries. Firstly, the study clarifies three core theoretical underpinnings for rotator cuff injury rehabilitation, namely epidemiological characteristics, the biomechanical mechanism of the shoulder joint, and the neuromuscular control theory. Second, based on the biological laws of the soft tissue healing and nature of functional recovery, the process of rehabilitation of rotator cuff injury is subdivided into four sequential and to some extent overlapping phases of Protection Phase, Recovery Phase, Reinforcement Phase and Functional Phase.

The work specifies the main goals and the objective development plan of each step and elaborates the specific training programs according to the stage. At the same time, it highlights the essence that neuromuscular control training needs to be done at an early age, and it should be given throughout the whole process of rehabilitation and develops specific tailored adaptations to various levels of injuries, types of treatment, and special populations such as the elderly and athletes. The framework of rehabilitation regimen developed in the research provides a direct relationship between the outcome of the rehabilitation assessment and stage, which proves to be effective in reducing subjectivity and arbitrariness in clinical practices of rehabilitation. It can offer a structured reference template on rehabilitation therapists to develop rehabilitation plans and increases the standardization and accuracy on rehabilitation training to rotator cuff injuries.

The research has been segmented to have some limitations: first of all, the theoretical integration and framework construction has not been worked out yet; secondly, there is the specific rehabilitation of athletes pertaining to distinct sports specializations, which is yet to be thoroughly refined. For future research, large-sample clinical studies can be carried out to verify the efficacy and practicability of the regimen; the rehabilitation training parameters for different populations can be refined by integrating sports biomechanical detection technologies; and intelligent rehabilitation

DOI: 10.54254/2753-7048/2026.32750

equipment can be incorporated to achieve precise monitoring and intelligent management of rehabilitation training. These efforts will further advance the in-depth integration of theoretical research and clinical practice in the field of sports rehabilitation for rotator cuff injuries.

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