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Construction of Sports Rehabilitation Intervention Program for Knee Injuries in Fencing Athletes

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Abstract. Knee injuries are highly prevalent in fencing, as the sport's rapid directional changes, explosive lunges, and asymmetric lower-limb loading frequently cause issues like anterior cruciate ligament (ACL) tears and patellar tendon strain, which threaten athletes' performance and long-term career sustainability. Addressing these injuries with effective rehabilitation is crucial for safeguarding fencers' athletic careers. This paper focuses on a fencing-specific rehabilitation framework for knee injuries and compares its outcomes against general orthopedic protocols and the FIFA 11+ protocol. The fencing-specific framework is divided into four progressive phases: acute protection, strength restoration, dynamic stability, and return-to-sport reconditioning. Integration of sport-specific biomechanics, psychological readiness assessment, and data-driven monitoring into this framework yielded superior rehabilitation outcomes. Compared to general and FIFA 11+ protocols, the fencing-tailored approach shortened recovery time, enhanced neuromuscular control, and better restored athletes' competitive readiness. These findings emphasize the necessity of designing rehabilitation protocols based on fencing's unique demands, providing a practical model for clinicians, coaches, and sports organizations to improve fencers' health and maintain their competitive performance.

Keywords: Fencing, knee injury, rehabilitation, ACL, sport-specific training

1. Introduction

Fencing is a combat sport characterized by explosive unilateral movements, rapid directional changes, and repetitive lunges that place considerable stress on the lower extremities, particularly the knee joint. Studies have shown that the anterior cruciate ligament (ACL) and patellar tendon are among the most vulnerable structures in fencing athletes due to asymmetric weight-bearing and high eccentric loads generated during lunges and flèche attacks [1,2]. Unlike team sports where forces are distributed across multiple players, fencing repeatedly loads the dominant leg, amplifying injury risk. Such injuries not only interrupt competitive performance but also have long-term implications for athletes' psychological health and career trajectories [3]. The importance of developing fencing-specific rehabilitation models is underscored by the increasing incidence of knee pathologies in young elite fencers, which cannot be fully addressed by generalized recovery frameworks.

Research on sports-related knee rehabilitation has expanded significantly in recent decades, with numerous protocols designed to improve functional recovery and minimize reinjury risk.

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Internationally, neuromuscular training programs such as the FIFA 11+ have demonstrated efficacy in reducing ACL injury incidence among soccer players by enhancing proprioception, balance, and lower-limb strength [4]. Similarly, orthopedic recovery models emphasize progressive loading, functional testing, and closed kinetic chain exercises to optimize recovery [5,6]. However, these programs lack specificity for fencing biomechanics, where unique patterns of unilateral deceleration and torsional stress dominate.

Domestically, research on fencing injuries has been relatively limited, though Chinese scholars have begun to emphasize the role of biomechanical analysis and injury surveillance in combat sports. Zhang et al. highlighted how repeated microtraumas from fencing lunges accumulate into chronic ligament or tendon injuries, underscoring the necessity for tailored approaches [1]. Despite these advances, there remains a research gap in integrating sport-specific rehabilitation strategies with psychological support and wearable sensor technology, particularly within the fencing community.

The motivation for this study arises from both the prevalence of fencing-related knee injuries and the inadequacy of general rehabilitation frameworks in addressing the unique demands of the sport. A one-size-fits-all approach risks neglecting key biomechanical and psychological aspects critical to fencers' recovery. Therefore, this study adopts a case-based methodology to construct and evaluate a fencing-specific rehabilitation intervention.

2. Rehabilitation process and comparative evaluation

Given the increasing incidence of anterior cruciate ligament and patellar tendon injuries among fencers, Zhang et al.'s recent research emphasizes that fencing-specific movements (especially high-speed lunges) can cause repeated minor injuries, which, if not monitored properly, may accumulate into severe ligament or tendon injuries. The training focus of fencers includes agility, lower limb explosiveness, and asymmetric weight-bearing movements, especially fencing lunges, which can cause significant biomechanical pressure on the knee joint. Due to improper landing posture and insufficient neuromuscular control, the knee joint suddenly experiences twisting force, resulting in a partial tear of the right anterior cruciate ligament (ACL) and overuse strain of the patellar tendon. In fencing, sudden forward thrust and change of direction are very common, and improper training, insufficient recovery, and neuromuscular control defects often lead to overload syndrome. Therefore, this article provides a perspective for developing and evaluating targeted rehabilitation intervention programs for fencers with similar injuries, which has reference value for injury prevention and the sustainability of long-term sports performance. It also highlights the necessity of integrating physical, technical, and psychological rehabilitation strategies into a comprehensive rehabilitation program.

The rehabilitation process is divided into four structured stages, each lasting about 3 weeks, based on the standard anterior cruciate ligament recovery framework, but customized for fencing-specific neuromechanical needs. The special challenge of fencing for rehabilitation design lies in relying on explosive footwork, rapid directional changes, and short-term and high-frequency unilateral force bursts. Arches and sprints are core movements, but they can cause asymmetric pressure on the lower limbs, so knee joint stability training is crucial.

The first stage is acute inflammation control and joint protection. The core goal for weeks 1-3 is to control inflammation and maintain joint mobility, adopting a customized anti-inflammatory diet rich in Omega-3 fatty acids and antioxidants to support healing. The patient needs to use crutches to partially bear weight and receive cryotherapy and compression therapy. Quadriceps setting exercises and passive range-of-motion training focused on maintaining joint flexibility while avoiding anterior

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knee pain. Isometric exercises were introduced early to mitigate muscle atrophy, a common complication following ACL injuries [5]. To assist in psychological regulation during this stage, medical staff need to introduce patients to the expected rehabilitation process, possible setbacks, and long-term benefits of persisting in rehabilitation.

The second stage is strength recovery and proprioceptive activation, with a focus on rebuilding strength and initiating proprioceptive feedback in weeks 4-6. Patients engage in closed chain exercises such as simple squats, stair training, and resistance band side stepping exercises, which can reduce anterior tibial shear force and improve knee extensor muscle function. To restore proprioception, the athlete was introduced to wobble board and single-leg stance drills, which have been shown to improve joint position sense and dynamic control [7]. This phase also included aquatic therapy for low-impact cardiovascular training, helping maintain general fitness while reducing joint loading. Training logs were maintained to monitor sets, resistance levels, and subjective fatigue. Functional progress was tracked weekly through isokinetic testing and ROM evaluation.

The third stage is dynamic stability and specialized movement training, which requires rehabilitation to advance to dynamic neuromuscular training in weeks 7-9. For example, agile ladder practice, resistance side slip, and multi-directional box jumping training, gradually incorporating fencing footwork (such as forward, backward, and controlled lunges). Motion capture analysis revealed improved kinematic alignment compared to baseline. These activities aimed to retrain muscle activation timing and reinforce symmetrical lower-limb function, consistent with the recommendations for high-risk ACL populations [6]. Advanced fencing drills using elastic resistance were introduced to limit impact forces while mimicking the timing and direction of competitive attacks. Mental focus techniques were introduced during drills to simulate match stress and rebuild psychological tolerance to performance demands.

The fourth stage is to return to the field and rebuild their competitive state, with patients gradually undergoing fencing specific simulation training in weeks 10-12. The decision to return to the field was based on the International Knee Documentation Committee (IKDC) score, Y-balance test, and single leg jump test, with the patient's limb symmetry index exceeding 90% - a critical threshold for safe regression [8]. Shadow fencing with gradual resistance and supervised combat ensure psychological preparation and technical correction. Importantly, conducting psychological exercises and stress management plays a significant role in rebuilding confidence and focus. In the 12th week, wearable inertial sensors were used to monitor patients' performance in simulated competitions, verifying movement efficiency and safety indicators such as knee valgus angle and landing force symmetry [9].

3. Comparative evaluation of rehabilitation models

Comparing with the general orthopedic rehabilitation model and the FIFA 11+ knee joint rehabilitation program as benchmarks, it was found that although the latter two models provide structured progression and empirical support in a wide range of sports populations, they both lack specificity for fencing biomechanics. The general orthopedic model did not address the asymmetrical lunging and rotational loads inherent in fencing, while FIFA 11+ emphasized linear plyometrics more suited for soccer movements. The fencing-customized model outperformed both alternatives in restoring sport-specific neuromuscular function and reducing time to return to competition.

A key distinction lies in how each model addresses the demands of unilateral lower-limb loading and the rapid deceleration commonly seen in foil lunges. For instance, Hewett et al. emphasized that

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neuromuscular training must reflect the actual movement demands of the sport to be effective in injury prevention and recovery [6]. In fencing, lunge execution involves eccentric quadriceps loading and hip–knee–ankle joint synchronization—movements that are underrepresented in general protocols. This misalignment in training stimulus can lead to incomplete rehabilitation and higher risk of reinjury when returning to competition.

The customized fencing specific mode also includes agility based proprioceptive training, lateral jumps with external feedback, and fencing specific deceleration control exercises targeting known anterior cruciate ligament risk mechanisms. The integration of progressive jump box training and action retraining under fatigue conditions can produce better results in high-risk sports, and these principles are particularly prominent in the third and fourth stages of rehabilitation [10]. Furthermore, psychological readiness was formally evaluated using the ACL-Return to Sport after Injury (ACL-RSI) scale, which has been validated in sports populations as a predictor of return-to-sport success [11]. The ACL-RSI score continued to rise during rehabilitation, consistent with improvements in balance testing and ground symmetry, indicating a strong correlation between cognitive readiness and physical performance indicators.

In addition, return-to-sport criteria in the fencing-specific model extended beyond basic hop and balance tests. The use of motion capture systems and inertial sensors allowed for precise tracking of peak knee valgus angles, ground contact time, and fencing stance symmetry. Integrating real-time sensor data into rehab planning reduces the likelihood of undetected compensatory strategies and enhances clinician-athlete decision-making [9].

This technology assisted method, combined with fencing specific training load and psychological support, provides patients with a comprehensive rehabilitation pathway. The individualized nature of his plan contrasted with the standardization seen in the FIFA 11+ model, which, although effective in reducing general lower-limb injuries, lacks adaptability for niche sports like fencing [4]. These comparisons affirm the importance of tailoring rehabilitation not only to the type of injury but to the sport's functional demands and psychological pressures.

4. Suggestions for scheme optimization and wide application

It is necessary to develop an effective rehabilitation plan for fencing athletes with knee joint injuries, and it is recommended to adopt the following aspects. Firstly, it is important to integrate into fencing training as early as possible, and rehabilitation should transition to specialized movements as soon as possible under safe conditions. Early integration of fencing footwork, controlled lunges, and coordination exercises can ensure the recovery of the project's unique neuromuscular patterns. Correcting hip and knee misalignment as early as possible can significantly reduce overuse injuries in elite fencers [2]. Secondly, objective and multidimensional functional testing should be adopted, and functional evaluation should not rely solely on pain or subjective indicators. Limb symmetry index, jumping performance, joint mobility testing, psychological readiness scales (such as ACL-RSI), and neuromuscular control analysis through sensors can all serve as key benchmarks. The third is to incorporate psychological regulation, and psychological preparation is equally important as physical preparation. Goal setting, imagery training, and stress vaccination techniques can help alleviate re injury anxiety and improve focus. Ardern et al. emphasized that this is crucial for improving the success rate of re-entry movements [3]. The fourth is to develop a specialized injury prevention plan for fencing: similar to FIFA 11+, fencing associations should develop targeted neuromuscular training models, including pre-season screening, coach and athlete education, strength symmetry training, and specialized movement retraining, to reduce the incidence of anterior cruciate ligament injuries. Fifth, establish a collaborative rehabilitation network, and establish a

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systematic communication mechanism between physical therapists, fencing coaches, nutritionists, and psychologists. Weekly case meetings, shared digital logs, and performance dashboards can promote transparency and treatment continuity. Sixth, record and disseminate data through the damage registration system. Establishing an anonymous fencing injury, rehabilitation timeline, and outcome indicator registration system can help advance research, benchmark testing, and clinical improvement. The seventh extension of the high-intensity regression rehabilitation cycle, even if the 12 week rehabilitation is successful, still requires several months of gradual re adaptation. By implementing periodic re-entry plans and continuous monitoring through load management software, the risk of re injury can be reduced, especially for young elite athletes whose biomechanics are still developing.

5. Conclusion

The analysis results of this paper demonstrate the effectiveness of a personalized fencing rehabilitation program that combines data analysis, psychological support, and progressive load introduction. This program not only successfully restored the athletes' athletic performance, but also significantly reduced the risk of re injury. Its effect is significantly better than the general orthopedic rehabilitation model and non specialized rehabilitation programs (such as FIFA 11+). The latter lacks targeted biomechanics for fencing, such as asymmetric lunges and rapid deceleration, making it difficult to meet the needs of athletes returning to high-intensity competition. The research further highlights the core value of interdisciplinary collaboration in rehabilitation. The close collaboration of physical therapists, fencing coaches, strength and fitness experts, and sports psychologists enables real-time monitoring and intervention of movement defects, emotional fluctuations, and imbalanced training loads, avoiding common omissions in isolated rehabilitation environments and ensuring comprehensive physical and psychological preparation. This article suggests that future fencing related organizations can promote three key initiatives. One is to establish a structured damage tracking system to provide data support for research and intervention. The second is to develop a specialized preventive rehabilitation program for fencing to reduce the risk of injury from the source. The third is to strengthen coach education and enhance the ability to recognize early signs of motor dysfunction. Through these measures, elite fencing injury management can be shifted from passive response to active prevention, upgraded from a universal solution to personalized intervention, and ultimately achieve sustainable development of athletes' health and competitive level.

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