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POSTOPERATIVE REHABILITATION FOLLOWING ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION: STAGES, PROTOCOLS AND THEIR ROLE IN PREVENTING REINJURY

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ABSTRACT

Introduction and purpose: An anterior cruciate ligament (ACL) injury is one of the most common knee joint injuries, particularly among athletes. Its reconstruction is one of the most frequently performed orthopedic procedures, enabling a return to full physical function. However, a crucial component of recovery is a well-planned and consistently implemented postoperative rehabilitation program, which helps reduce the risk of reinjury. This review discusses the individual stages of rehabilitation, the methods used, and their role in minimizing the aforementioned risk.
Material and methods: A comprehensive review and analysis of the literature from 2000 to 2025 was conducted using the PubMed, Google Scholar, Scopus, and Web of Science databases (including randomized controlled trials, meta-analyses, and guidelines). The focus was on various rehabilitation methods following ACL reconstruction and their impact on reducing the risk of reinjury.
Brief description of the state of knowledge: Current guidelines and studies identify four phases of rehabilitation: early, intermediate, late, and return to sport. Modern rehabilitation protocols vary in terms of progression rate, techniques used, and tools for assessing therapy outcomes. The psychological aspect is also emphasized, as fear of reinjury can have a significant impact on recovery.
Conclusions: Rehabilitation programs based on functional criteria and individualization allow for precise adaptation of therapeutic interventions to the patient's needs at different stages of the recovery process, thereby significantly reducing the risk of reinjury. Moreover, modern technologies such as biofeedback, virtual reality, and biomechanical analysis can enhance the effectiveness of therapy by improving exercise precision and enabling better monitoring of the patient's progress.

KEYWORDS

Anterior Cruciate Ligament (ACL), Reconstruction, Postoperative Rehabilitation, Reinjury, Return to Sport

CITATION

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Introduction:

An anterior cruciate ligament (ACL) injury is one of the most common knee joint injuries, particularly among athletes involved in sports such as football, handball, volleyball, and skiing. It is estimated that approximately 3% of amateur athletes sustain an ACL injury each year, while the rate can reach up to 15% among professional athletes [1].

ACL injuries affect women more frequently than men (2 to 10 times more often), and half of all ACL injuries occur in individuals aged 15–25. Reconstruction is a standard and integral part of ACL injury treatment; however, surgical intervention alone does not guarantee full recovery. While 65–95% of patients return to sport at their pre-injury level, in practice, around 60% resume full athletic activity [2,3,4].

Rehabilitation plays a key role in restoring knee stability, muscle strength, reducing the risk of subsequent injuries, and enabling return to activity. Following ACL reconstruction surgery, the risk of re-rupture is estimated at 5–10%. Despite advancements in surgical techniques, the optimal rehabilitation program remains a topic of debate and depends on the surgical course, additional procedures, the individual's previous activity level, and physical condition. Appropriate rehabilitation programs are fundamental to returning to sport and minimizing the risk of re-injury.

The aim of this paper is to present current guidelines for postoperative rehabilitation and its importance in preventing ACL re-injuries.

Materials and methods:

A comprehensive review and analysis of literature from 2000 to 2025 was conducted using databases such as PubMed, Google Scholar, Scopus, and Web of Science. The focus was on various rehabilitation methods after ACL reconstruction and their impact on reducing the risk of reinjury. Search terms included "rehabilitation after ACL reconstruction," "rehabilitation protocols," and "return to sport." The review included primarily meta-analyses, systematic reviews, clinical trials, and other literature reviews.

Phases of rehabilitation:

Early phase

This phase includes the first 6 weeks after ACL reconstruction surgery. It is critical for setting the foundation for successful rehabilitation and influences the subsequent course of functional recovery.

The main goals of this phase are:

- reducing swelling and pain through cryotherapy [5], compression, and limb elevation above heart level
- restoring range of motion (ROM), with emphasis on achieving full knee extension
- initiating mobility and gait training
- preventing muscle atrophy
- protecting the operated joint with braces and crutches

Both passive and active exercises are used to mobilize the knee joint. Passive exercises include the use of a Continuous Passive Motion (CPM) device to support gentle flexion and extension of the knee. Active exercises may include heel slides or seated knee flexion. However, no superiority of passive over active exercises has been demonstrated [6].

To maintain muscle strength without overloading the joint, isometric exercises such as quadriceps contractions ("quad sets") are recommended. The patient should lie on their back with a roll or towel under the operated knee, then press the heel into the ground and the knee into the roll simultaneously, holding for 6 to 8 seconds. If conscious quadriceps activation is difficult, muscle electrostimulation is advised.

Proprioception (joint position sense) exercises are also initiated during this phase. Initially, they are performed lying down or seated, with progressive knee flexion angles. Standing proprioceptive exercises are usually introduced after week 3.

Neuromuscular training and proprioception can support functional recovery but should not replace exercises aimed at increasing ROM and strength [6].

Intermediate phase

This phase typically spans from week 6 to week 12 post-surgery. The goal is to continue building muscle strength, improve motor control, and prepare the patient for more demanding physical activities while further developing ROM.

By the end of this phase, walking without crutches, exercising without a brace, and achieving full knee extension and flexion should be possible. Around week 6, water exercises and light jogging may begin.

To strengthen the muscles, progressive resistance exercises (both isometric and isotonic) are introduced, along with resistance bands and weight machines. Recommended movements include squats, lunges, and closed kinetic chain (CKC) exercises [7], which help limit shear forces on the ACL graft and simulate functional, everyday movements.

Proprioceptive training may be enhanced with stabilometric platforms or balance balls.

In addition to strength training, cardiovascular fitness is important. Stationary cycling, anti-gravity treadmill use, and swimming (excluding breaststroke kicks) are recommended [8].

This phase lays the foundation for more advanced functional training and sport preparation. Regular progress assessments by a physical therapist are essential. To move to the next (late) phase of rehabilitation, the following criteria should be met [9]:

- full ROM in the knee joint
- no swelling or pain during exercises
- operated limb strength at least 70% of the healthy limb
- sufficient stability and motor control

Late phase

This phase spans 3 to 6 months after ACL reconstruction and focuses on:

- achieving muscle strength symmetry between the operated and healthy lower limb (flexors and extensors ≥90% of healthy limb)
- improving proprioception and neuromuscular control under dynamic conditions
- preparing the body for intense loads, especially in contact sports or sports involving sudden direction changes

This phase includes both isolated and multi-joint open kinetic chain (OKC) exercises, gradually progressing to bodyweight-loaded CKC exercises such as squats and lunges. OKC exercises increase joint loading as resistance increases, while CKC exercises do not increase ACL graft strain in the same way [10].

Scientific literature shows no significant differences in outcomes between patients using CKC and OKC exercises [11].

Other rehabilitation methods in this phase include plyometric training (e.g., multidirectional jumping) and dynamic stability drills [3]. Sport-specific drills such as sprinting, pivoting, and deceleration are essential for competitive athletes.

To advance to the final rehabilitation phase, the following criteria should be met:

- ≥90% performance in functional tests (e.g., single-leg hop tests, agility tests) compared to the healthy leg
- no pain or swelling after high-intensity training
- clinically and biomechanically confirmed knee stability

Progression should be halted if signs of overuse (pain, swelling, instability) occur.

Return to sport phase

This final phase of postoperative rehabilitation, when properly planned and based on objective criteria and individualized goals, minimizes reinjury risk and allows for a safe return to full activity. Strong cooperation among the patient, physiotherapist, and coach is essential.

The duration varies depending on the patient's progress and sport-specific demands, averaging between 6 months and a year.

Goals of this phase include:

- restoring muscle strength so that the operated limb is within 10% of the healthy leg [12]
- improving stabilization and neuromuscular control through enhanced proprioception and coordination [13]
- restoring movement patterns specific to the patient's sport [14]
- addressing psychological readiness and reducing fear of reinjury [15]

To assess readiness, functional tests such as the Single-Leg Hop Test and postural control landing assessments are conducted. Motion biomechanics, ROM, and quadriceps/hamstring strength are evaluated, with acceptable side-to-side differences below 10–15%. Dynamic stability is assessed with tests like the Y-Balance Test, where the patient balances on one leg while reaching in three directions (anterior, posterolateral, and posteromedial).

This stage may also include plyometric drills (jumping, sprinting, change of direction). The intensity is gradually increased by manipulating jump height, duration, direction, and complexity. Multiplanar exercises help simulate sport-specific movements.

Injury prevention during this stage is crucial. Patient education and appropriate training programs strengthen the previously injured ligament and significantly reduce the risk of re-rupture. One such program is FIFA 11+, recommended as a warm-up before training and games. It focuses on injury prevention, improving movement patterns, and enhancing body stability.

Wearing a functional brace has been found to reduce the risk of subsequent knee injuries in high-demand sports post-ACL reconstruction [16], although its use remains controversial.

Rehabilitation is considered complete when the following criteria are met [17]:

- the operated limb achieves ≥90% of the strength of the healthy limb
- knee stability, absence of pain and swelling, and full ROM
- equal performance in dynamic tests (e.g., Single-Leg Hop Test)
- patient confidence and lack of fear of reinjury

The role of rehabilitation in preventing ACL reinjury

At every stage of rehabilitation, specific criteria must be met (**Figure 1**) to reduce the risk of ACL reinjury and ensure a safe return to activity. In patients who fail to meet functional criteria (e.g., <90% strength in the operated limb), the risk of reinjury is as high as 33–40% [18]. Premature return to sport increases reinjury risk. A return after 9 months with full functional readiness reduces the risk to 3–5%, compared to 14–18% with earlier return [19]. Rehabilitation protocols based on functional criteria are more effective than time-based ones in reducing reinjury rates [7].

Early control of knee motion and extension is critical. Regaining full extension within the first 2 weeks prevents long-term limitations (arthrofibrosis), contractures, and reduces the risk of ACL graft failure [18]. Lack of extension leads to biomechanical overload and increases reinjury risk.

Neuromuscular control, proprioception, and balance training effectively address asymmetries and abnormal movement mechanics, which contribute to reinjury and functional deficits. Strengthening the quadriceps and gradual progression of strength training have a significant protective effect. Quadriceps symmetry (>90% of the healthy limb) reduces reinjury risk by around 50% [17]. A 10–15% strength asymmetry in hop tests increases the risk of reinjury by 30–50% within the first year post-return [20].

Movement mechanics, alongside muscle strength, are crucial for secondary injury prevention. Patients participating in neuromuscular and proprioceptive training programs have a 25–30% lower risk of secondary injuries than those using only traditional strength training [21].

Effective rehabilitation must address both biomechanical and psychosocial aspects. Reducing fear and improving self-confidence are essential in preventing reinjury [6].

Conclusions

A comparison of rehabilitation protocols indicates that those based on functional criteria, rather than solely on time elapsed since surgery, are the most effective. A multi-phase rehabilitation approach grounded in these criteria contributes to a more successful return to activity and greater reduction in reinjury risk compared to traditional rehabilitation models. Functional testing, muscle balance, and proprioception are essential for ensuring patient safety, as they allow for a reliable assessment of the injured joint from both motor and anatomical perspectives. The psychological aspect (mental readiness) is also highly significant. Reducing fear of reinjury facilitates a smoother and more effective return to pre-injury activity levels.

Disclosure

Author's contributions:

The authors confirm contribution to the paper as follows:
Conceptualization: Marcelina Broda, Kamil Marzec
Methodology: Kinga Dyndał, Adam Żuczek
Software: Aleksandra Mokrzycka, Olga Żuczek
Validation: Adam Żuczek, Izabela Szczap
Formal analysis: Kamil Marzec, Anna Hawryluk
Investigation: Olga Żuczek, Katarzyna Urbańska
Resources: Katarzyna Urbańska, Kamil Marzec
Data curation: Kinga Dyndał, Patrycja Jędrzejewska-Rzezak
Writing-original draft preparation: Izabela Szczap, Olga Żuczek
Writing-review and editing: Marcelina Broda, Izabela Szczap
Visualization: Anna Hawryluk, Katarzyna Urbańska
Supervision: Kinga Dyndał, Anna Hawryluk
Project administration: Patrycja Jędrzejewska-Rzezak, Aleksandra Mokrzycka

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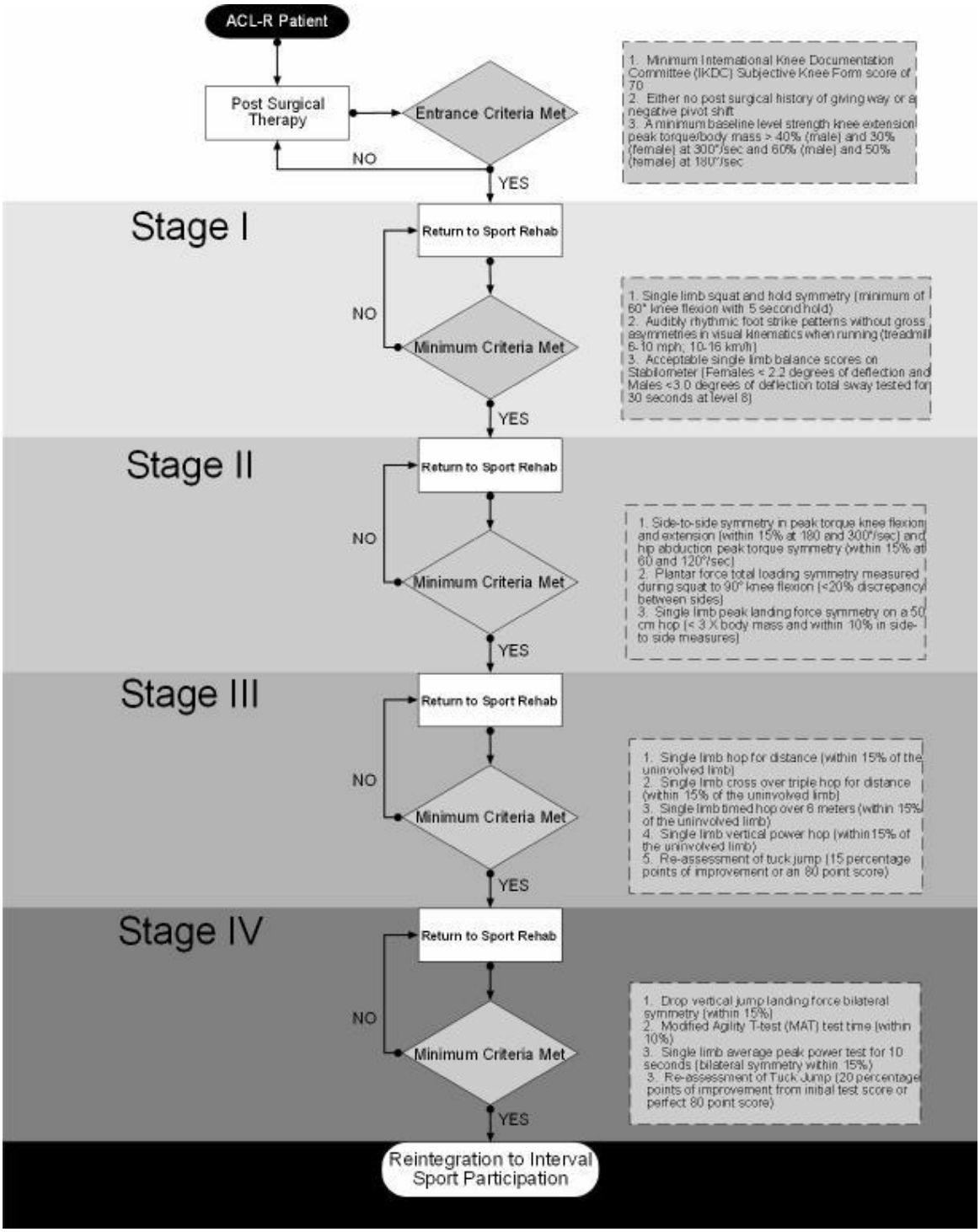

Fig. 1. *Return-to-sports activities post ACL reconstruction. Before progressing to the next rehabilitative stage in the program, the patientmust meet the minimum progression criteria*
Source: Rehabilitation After Anterior CruciateLigament Reconstruction: Criteria-BasedProgression Through the Return-to-SportPhase https://doi.org/10.2519/jospt.2006.2222

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