

Review Article

From Injury to Return to Play: Criterion-Based Rehabilitation and Return-to-Sport Decision-Making after Anterior Cruciate Ligament Reconstruction

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Submitted: 28 July 2026

Accepted: 08 September 2026

Published: 10 September 2026

ISSN: 2475-9112

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OPEN ACCESS**Keywords**

- Anterior Cruciate Ligament
- Rehabilitation
- Return to Sport
- Proprioception
- Criterion-Based Progression

Abstract

Anterior cruciate ligament (ACL) rupture remains one of the most severe and extensively studied injuries in sport, particularly in disciplines involving cutting, deceleration, and pivoting. The pathway that follows surgical reconstruction is long and multifactorial, and its success cannot be measured by anatomical healing alone but by the athlete's ability to safely return to prior levels of sport participation. This clinical commentary synthesizes recent evidence on ACL injury epidemiology, the principles of criterion-based rehabilitation, the role of neuromuscular and proprioceptive training, and the criteria used to guide return-to-sport (RTS) decisions. Despite widespread adoption of structured, phase-based protocols, only a minority of patients fully satisfy recommended RTS criteria at the time of clearance, and second ACL injury rates remain clinically meaningful, particularly among younger athletes and within the first year after return to sport. Practical implications for rehabilitation programming and interdisciplinary decision-making are discussed.

INTRODUCTION

The anterior cruciate ligament (ACL) plays a central role in knee stability, limiting anterior tibial translation relative to the femur and contributing to rotational control during sport-specific movements. ACL injury is among the most feared in competitive and recreational sport, not only because of its clinical severity but because of its consequences for an athlete's career: months away from competition, surgical reconstruction in most active individuals, and a long, demanding rehabilitation course that carries a non-trivial risk of reinjury.

Over the past fifteen years, clinical understanding of ACL management has shifted from a narrow focus on graft healing toward a broader, function-based model of recovery in which strength, neuromuscular control, proprioception, and psychological readiness are recognized as essential components of a successful rehabilitation pathway. The purpose of this clinical commentary is to synthesize recent evidence on the epidemiology of ACL injury, the principles underlying criterion-based rehabilitation, and current return-to-sport (RTS) decision-making frameworks, with attention to the practical implications for clinicians managing athletes through this process.

Injury Mechanism and Epidemiology

A recent epidemiological analysis of the top five European football (soccer) leagues (England, Spain, Italy, Germany, and France) over six consecutive seasons reported an incidence of approximately 0.40 ACL ruptures per 1,000 match hours, with noncontact mechanisms predominating, typically occurring during pressing actions in the defensive phase and within the early minutes of play [1].

An overview of systematic reviews encompassing 51 meta-analyses confirmed a high incidence of ACL injury in sports such as American football, basketball, soccer, and volleyball, with a higher risk observed in female athletes relative to male athletes in several disciplines [2]. This sex-related pattern is corroborated by a longitudinal study of male and female soccer players followed over six seasons, which described incidence differences related to both sex and age category [3].

These epidemiological patterns underscore the continued importance of primary prevention and neuromuscular preparation, while also highlighting that,

once injury has occurred, the rehabilitation pathway must account for risk factors specific to sex, age, and sport type.

Surgical Management: Brief Overview

Because the ACL is poorly vascularized, spontaneous healing after complete rupture is generally not achievable, and surgical reconstruction remains the treatment of choice for athletes and other individuals with high functional demands. Reconstruction is typically performed arthroscopically using an autologous tendon graft (patellar tendon, hamstring tendons, or quadriceps tendon). The immediate surgical goals are restoration of full range of motion and static and dynamic knee stability — necessary, but not sufficient, conditions for a safe return to sport, which depends heavily on the quality of the subsequent rehabilitation process.

Criterion-Based Rehabilitation Following ACL Reconstruction

Current evidence-based practice guidelines recommend a rehabilitation pathway comprising a prehabilitation phase followed by three criterion-based postoperative phases — an impairment-based phase, a sport-specific training phase, and a return-to-play phase — with progression from one phase to the next contingent on objective strength, hop, movement-quality, and psychological readiness testing rather than fixed timelines. Postoperative rehabilitation is generally recommended to continue for 9 to 12 months [4].

A criterion-based protocol developed by the Royal Dutch Society for Physical Therapy (KNGF) similarly structures rehabilitation into three phases with progression conditional on achievement of specific, measurable goals confirmed by objective and subjective testing. A randomized controlled trial comparing this approach with conventional physical therapy reported superior functional outcomes at six months, while noting that program duration should likely be extended beyond this point to allow patients to achieve return-to-play goals [4,5].

In clinical practice, early postoperative milestones (approximately two weeks after surgery) typically include knee flexion greater than 110°, ambulation without crutches, comfortable use of a stationary bike or stair climber, full-extension gait, and reciprocal stair negotiation [6]. A more recent description of the recovery timeline characterizes the early phase (weeks 0-6) as centered on pain and swelling reduction, restoration of range of motion, and a quadriceps limb symmetry index (LSI) of at least 60%, supported by neuromuscular electrical

stimulation and progressive introduction of open kinetic chain exercise once cleared by the surgical team [7].

A recent narrative review has challenged the rigidity of fixed-phase models, proposing a framework of overlapping progression blocks that better accommodates individual variability in tissue healing, motor control, and psychological readiness. In this model, quadriceps arthrogenic muscle inhibition — a persistent reduction in voluntary muscle activation induced by injury and surgery — is treated as a variable to be monitored throughout the entire rehabilitation course rather than addressed only in the early phase, allowing more accurate calibration of load and movement complexity as rehabilitation progresses [8-15].

Neuromuscular and Proprioceptive Considerations

ACL injury disrupts the mechanoreceptors embedded within the ligament, altering afferent signaling and prompting reorganization within the central nervous system. These neurophysiological changes can persist even after completion of standard rehabilitation and have been associated with impaired postural stability, altered lower-limb movement patterns, and increased reinjury risk [16].

A meta-analysis examining the effects of proprioceptive training after ACL reconstruction found improvements in subjective knee function, single-leg hop performance, and proprioceptive acuity, without significant effects on range of motion or knee flexion strength [16]. Consistent with this, a randomized controlled trial demonstrated that neuromuscular training programs incorporating plyometric, strengthening, and balance exercises improved knee proprioception even in athletes with a history of ACL reconstruction who had already completed standard rehabilitation, underscoring the persistence of proprioceptive deficits not fully resolved by conventional protocols [17].

More recent work has emphasized the neurocognitive dimension of rehabilitation, noting that altered proprioception, impaired motor control, and increased reliance on visual feedback may persist into late-stage rehabilitation and contribute to reinjury risk. Comprehensive prevention programs incorporating plyometric, strengthening, and neuromuscular training components have been associated with reduced overall ACL injury risk and, specifically, reduced noncontact injury risk among female athletes [18].

The preoperative period also appears relevant: a systematic review of ACL prehabilitation found moderate-

quality evidence that quadriceps strengthening, restoration of range of motion, and balance/proprioceptive training conducted prior to reconstruction improve postoperative functional outcomes and RTS rates [19].

Return-to-Sport Criteria and Reinjury Risk

Current guidelines identify minimum RTS criteria as at least 9 months postoperatively, quadriceps strength symmetry of at least 90% relative to the uninjured limb, performance of at least 90% on all hop tests, a score of at least 90% on the Knee Outcome Survey-Activities of Daily Living Scale, and a score of at least 80% on the ACL-Return to Sport after Injury scale (ACL-RSI); return to competition should proceed in a stepwise, progressive manner [9].

Despite the existence of these criteria, their application in clinical practice remains inconsistent. A systematic review with meta-analysis found that only 42.7% of patients formally tested for RTS clearance actually passed the recommended criteria; among those who passed, 14.4% nonetheless sustained a second ACL injury, either graft rupture or contralateral injury [10]. This finding suggests that meeting RTS criteria reduces, but does not eliminate, reinjury risk, and that RTS readiness is better conceptualized as a probabilistic continuum than a binary threshold.

Timing itself appears to carry an independent protective effect: a meta-analysis estimated a pooled second ACL injury incidence of 16.9%, with athletes who sustained a second injury having returned to sport, on average, approximately 25 days earlier than those who did not [11]. This finding reinforces the recommendation against accelerating RTS even when physical performance metrics appear satisfactory.

The psychological dimension of RTS readiness is receiving increasing attention. A systematic review of ACL-RSI scores found that psychological confidence improves rapidly in the early period after injury before plateauing, with limited further improvement up to at least two years after reconstruction; a longer interval between injury and surgery, female sex, and older age were associated with lower ACL-RSI scores at 12-24 months postoperatively [12].

It should be noted that overall evidence regarding prognostic factors for RTS remains of very low certainty: a recent systematic review identified associations between physical, psychological, and demographic factors and RTS outcomes but emphasized the need for methodologically stronger research [13]. Similarly, evidence guiding RTS testing in individuals under 16 years of age remains

limited, with most available studies conducted in the 16-18 year age range [14].

A further point of ongoing debate concerns whether surgical reconstruction itself is necessary to achieve RTS: a meta-analysis found that ACL reconstruction was not associated with higher RTS rates compared with structured rehabilitation without surgery, although most included studies carried a high risk of bias favoring the surgical group [15]. This remains preliminary evidence that does not alter current clinical indications for competitive athletes, but it highlights an area warranting further investigation and more individualized treatment decision-making.

Finally, sport-specific reintegration deserves explicit attention within the RTS continuum. A narrative review focused on elite athletes emphasized that RTS should be conceived as a continuum encompassing return to participation, return to sport, and return to performance, and highlighted the value of an interdisciplinary team — surgeon, physical therapist, athletic trainer, strength and conditioning coach, and sports scientist — in guiding progression through sport-specific training [20].

Clinical Implications and Future Directions

The current literature reveals substantial heterogeneity in the RTS criteria applied in clinical practice, inconsistent implementation of testing batteries, and variable methodological quality across studies. Evidence in specific populations, such as adolescent athletes, remains particularly limited. Promising directions for future research and clinical practice include the systematic integration of psychological readiness alongside physical criteria, the development of individualized, criterion-based progression models rather than rigid fixed-phase protocols, and further investigation of the neurocognitive contributors to reinjury risk.

CONCLUSION

Recovery following ACL reconstruction is a complex process that extends well beyond graft healing. Current evidence converges on the need for a criterion-based, multidimensional approach that integrates strength, neuromuscular control, proprioception, and psychological readiness, rather than relying on fixed timelines alone. The observation that only a minority of patients fully meet recommended RTS criteria — and that a meaningful proportion of those who do still experience a second injury — indicates that the path toward truly predictive and effective RTS protocols remains open, and that close collaboration among surgeons, physical therapists,

strength and conditioning professionals, and sport psychologists remains essential to athlete safety.

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