



Rehabilitation after Anterior Cruciate Ligament (ACL) Reconstruction: A Review of Criterion-Based vs Time-Based Progression

Manasa Ranjan Pattanaik (PT)¹, Pritam Sahoo (PT)², Priyabrata Dash (PT)³, Mujahidur Raheman Khan (PT)⁴

¹Senior Physiotherapist, KIMS school of physiotherapy, KIMS, KIIT DU, Bhubaneswar

²Senior Physiotherapist, KIMS school of physiotherapy, KIMS, KIIT DU, Bhubaneswar

³Vice Principal cum Associate Professor, KIMS School of Physiotherapy, KIMS, KIIT DU, Bhubaneswar

⁴Physiotherapist, KIMS School of Physiotherapy, KIMS, KIIT DU, Bhubaneswar

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Corresponding author: Dr. Manasa Ranjan Pattanaik (PT)

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Abstract

Anterior Cruciate Ligament (ACL) injuries are common among athletes and active individuals, often requiring surgical reconstruction followed by structured rehabilitation. Traditionally, rehabilitation protocols have followed a time-based progression, advancing patients through recovery phases based on predetermined weeks post-surgery. However, emerging evidence supports the use of criterion-based rehabilitation, which emphasizes individualized progression based on specific functional and clinical milestones.

This review explores and compares the two approaches, highlighting the strengths and limitations of each. Time-based models offer structure and simplicity but may overlook variations in patient healing and readiness, increasing the risk of reinjury. In contrast, criterion-based protocols focus on objective measures such as strength symmetry, neuromuscular control, range of motion, and psychological readiness to guide rehabilitation. Studies suggest that this individualized approach leads to better functional outcomes, lower reinjury rates, and safer return-to-sport decisions. Despite implementation challenges such as equipment needs and therapist expertise, criterion-based rehabilitation is increasingly recognized as a more effective and evidence-based strategy in modern ACL care.

Keywords: ACL reconstruction, rehabilitation, criterion-based progression, time-based protocol, return to sport, functional milestones, knee injury, physiotherapy, re-injury prevention, individualized rehabilitation.

Introduction

The anterior cruciate ligament (ACL) is one of the most vital stabilizing ligaments in the knee joint, playing a crucial role in maintaining anterior tibial translation and rotational control of the knee. Injuries to the ACL are among the most common musculoskeletal injuries, particularly in athletes participating in sports involving sudden stops, pivoting, jumping, or change of direction such as football,

basketball, skiing, and gymnastics. The incidence of ACL injuries continues to rise globally, not only among professional athletes but also in the general physically active population.

When the ACL is ruptured, conservative management may suffice in a sedentary individual; however, surgical reconstruction is

often the treatment of choice for those aiming to return to high-level activities. While surgical techniques have evolved significantly, it is well-established that the success of ACL reconstruction (ACLR) depends largely on a structured and effective post-operative rehabilitation program.

Traditionally, rehabilitation protocols after ACL reconstruction have been governed by time-based progression models. These protocols divide recovery into fixed stages based on the number of weeks post-surgery. For instance, weight-bearing, range of motion exercises, and strength training are initiated and progressed at specific time intervals—regardless of the patient's actual healing response or functional recovery. This approach, although convenient and easy to follow, often ignores individual variations in healing, graft integration, neuromuscular recovery, and psychological readiness.

In recent years, growing awareness of the limitations of time-driven protocols has led to the development and implementation of criterion-based rehabilitation models. These models emphasize the need to progress rehabilitation based on achievement of specific physical, biomechanical, and psychological milestones, rather than on predetermined timelines. This approach encourages therapists to assess each patient as a unique case and to tailor interventions based on objective clinical markers—such as strength symmetry, limb control, range of motion, functional tests, and confidence levels.

The debate between criterion-based versus time-based progression is central to modern physiotherapy and sports medicine. A poorly timed return to sport, especially without meeting functional benchmarks, is associated with a significantly increased risk of reinjury, graft failure, and long-term joint degeneration. On the other hand, unnecessarily delayed progression due to rigid timeframes can

impede athletic performance, prolong absence from sport, and reduce patient motivation.

Therefore, this review aims to explore and compare both rehabilitation paradigms. It highlights the strengths and weaknesses of each approach, supported by current evidence and clinical guidelines. The goal is to provide clinicians, rehabilitation specialists, and students with a comprehensive understanding of which strategy fosters safer, more efficient, and more individualized recovery following ACL reconstruction.

Time-Based Rehabilitation: Overview and Limitations

Time-based rehabilitation has long been the standard protocol following ACL reconstruction. It typically divides the recovery journey into predefined phases based on the number of weeks or months since surgery. Each phase outlines specific goals, exercises, and functional activities expected to be achieved within that set time frame, often without considering individual variability in healing or performance.

Structure of Time-Based Rehabilitation

Most time-based protocols follow a five-phase model:

Phase 1: Immediate Post-operative Phase (0–2 weeks)

Focuses on reducing inflammation, achieving full passive knee extension, and initiating quadriceps activation.

Phase 2: Early Rehabilitation Phase (2–6 weeks)

Emphasizes regaining range of motion (ROM), partial to full weight-bearing, and beginning gentle strengthening.

Phase 3: Strengthening Phase (6–12 weeks)

Prioritizes muscle strengthening, improved balance, and controlled functional movement.

Phase 4: Advanced Strength and Proprioception (12–24 weeks)

- Involves plyometrics, agility training, and complex movements.

Phase 5: Return to Sport (after 6 months)

- Includes sport-specific drills, endurance, and eventual return to competition.

Advantages of Time-Based Protocols

- **Simplicity:** Easy to implement in clinics with minimal assessment tools.
- **Predictability:** Provides patients and therapists a structured timeline.
- **Standardization:** Useful for large rehabilitation setups or community programs.

Limitations of Time-Based Progression

Despite its simplicity, time-based progression poses several risks and limitations:

- **Neglect of Individual Recovery Rates:** Healing timelines differ due to age, graft type, surgical technique, and tissue response. A fixed schedule cannot reflect these differences.
- **Risk of Overloading or Undertraining:** Advancing therapy based on time alone may overload healing structures or, conversely, delay progression unnecessarily if the patient is ready earlier.
- **Lack of Objective Decision-Making:** Decisions like return to sport or beginning advanced exercises are often made without functional testing, increasing the risk of reinjury.
- **Psychological Readiness Overlooked:** Time-based models rarely include the assessment of fear, confidence, or emotional readiness—key factors for successful reintegration into sports.

Criterion-Based Progression: An Individualized Approach

As the limitations of time-based rehabilitation became increasingly apparent, clinicians and

researchers began advocating for a more individualized approach criterion-based progression. Unlike traditional protocols that depend solely on the passage of time, this model emphasizes the attainment of specific functional, biomechanical, and clinical milestones before moving from one rehabilitation phase to the next.

This approach acknowledges that recovery is not linear and varies significantly between individuals, depending on factors such as age, surgical technique, graft type, muscle strength, neuromuscular control, motivation, and overall health status.

Core Principles of Criterion-Based Rehabilitation

Criterion-based protocols are founded on these essential ideas:

- Progression is performance-driven, not time-dependent.
- Each phase has measurable, objective exit criteria.
- Quality of movement and function takes precedence over the speed of progression.
- Return to sport is permitted only after meeting comprehensive physical and psychological benchmarks.

Criteria used in Clinical Practice

Criterion-based rehabilitation includes a range of assessments to ensure safe progression. The most frequently used markers include:

1. Range of Motion (ROM)

- Full passive and active extension and at least 90°–120° flexion before advanced loading.
- Symmetrical ROM with the contralateral limb by mid-rehabilitation.

2. Muscle Strength

- Quadriceps and hamstring strength should achieve at least 70–90% Limb

Symmetry Index (LSI) compared to the uninjured side.

- Isokinetic testing or manual muscle testing may be used for evaluation.

3. Neuromuscular Control and Balance

- Successful completion of single-leg balance, Y-Balance Test, or Star Excursion Balance Test.
- Focus on controlled dynamic movement without compensation.

4. Hop Tests

- Four commonly used hop tests: single hop for distance, triple hop, crossover hop, and 6-meter timed hop.
- Performance must reach $\geq 90\%$ of the uninvolved limb.

5. Psychological Readiness

- Evaluated using tools like the ACL-Return to Sport after Injury (ACL-RSI) scale.
- Confidence, fear of reinjury, and readiness to perform sport-specific tasks are considered.

6. Pain, Effusion, and Inflammation

- No joint effusion or pain during or after exercises.
- Normal patellar mobility and absence of joint tenderness.

Advantages of Criterion-Based Rehabilitation

- Personalized progression based on patient capacity and healing.
- Objective benchmarks for decision-making in clinical practice.
- Lower risk of reinjury, particularly in young athletes.
- Promotes functional symmetry, not just strength or ROM.
- Addresses psychological components, often neglected in time-based models.

Practical Considerations

Criterion-based models do demand more from clinicians:

- Frequent assessments to monitor readiness for progression.
- Access to functional testing tools, such as force plates or hop test equipment.
- Skilled clinical reasoning to interpret test results.
- Patient adherence and education are essential to understand why criteria matter.

However, studies show that when implemented properly, criterion-based rehabilitation leads to better long-term outcomes, improved return-to-sport rates, and enhanced patient safety.

Comparative Evidence: Criterion-Based vs Time-Based Approaches

Over the past decade, numerous studies and clinical trials have examined the outcomes of criterion-based and time-based rehabilitation following ACL reconstruction. A growing body of evidence suggests that criterion-based progression yields superior results, especially in terms of functional performance, patient safety, and return-to-sport success.

Return to Sport (RTS): A Critical Outcome

One of the most important goals after ACL reconstruction is achieving a safe and sustainable return to sport. Traditional time-based protocols often recommend RTS at a fixed timeline, commonly around 6 months post-operation. However, research has shown that:

- Athletes who return only based on time have 2 to 4 times greater risk of re-injury.
- Delaying RTS until functional criteria are met such as achieving $\geq 90\%$ LSI in strength and hop tests significantly reduces the re-injury rate.

Functional Performance

Criterion-based rehab emphasizes movement quality, strength balance, coordination, and neuromuscular control elements often ignored

in time-based progression. Research supports that:

- Criterion-based groups perform better in hop tests, balance assessments, and movement symmetry.
- They demonstrate higher quadriceps strength, particularly important for knee joint protection.

Patient-Centered Benefits

Patients managed with criterion-based rehabilitation tend to have:

- Greater satisfaction and motivation, as they are actively involved in meeting goals.
- Reduced fear of reinjury, due to objective reassessment before progression.

- Better psychological readiness, measured by tools like ACL-RSI scores.

Scientific Consensus

Major clinical practice guidelines, including those by the American Orthopaedic Society for Sports Medicine (AOSSM) and National Athletic Trainers' Association (NATA), now advocate for function- and criteria-based progression models over fixed timeframes.

Systematic reviews and meta-analyses further confirm that the rate of second ACL injury is lowest in patients who:

- Undergo minimum 9 months of rehabilitation
- Pass all return-to-sport criteria
- Demonstrate psychological preparedness

Table 1: Comparison Between Time-Based and Criterion-Based Progression

Aspect	Time-Based Progression	Criterion-Based Progression
Progression Driver	Calendar weeks/months post-surgery	Functional and clinical milestones
Customization	Low – One-size-fits-all	High – Tailored to individual response
Assessment Requirement	Minimal	Requires objective testing
Return to Sport Timeline	Fixed (usually 6–9 months)	Variable – Based on meeting all functional criteria
Re-injury Risk	Higher	Lower
Functional Symmetry	Often ignored	Emphasized
Psychological Readiness	Rarely addressed	Actively considered
Evidence Support	Limited	Strong and growing

Overall, criterion-based progression is now considered a best-practice approach in post-ACLR rehabilitation. It fosters a more individualized, safer, and functionally superior recovery pathway. Although it demands more clinical skill and resources, the benefits in terms of reduced re-injury rates and improved performance far outweigh the challenges.

Rehabilitation Phases using Criterion-Based Milestones

Unlike time-bound protocols that prescribe exercises and progressions based on postoperative weeks, criterion-based rehabilitation uses functional achievements and clinical readiness markers to determine when a patient should move forward. This model respects biological healing, graft maturation, and patient-specific progress.

Below is a phase-wise structure of ACL rehabilitation, guided by clinical milestones, not by time:

Phase 1: Protection & Mobility Phase

Goal: Control pain and inflammation, restore passive extension, activate quadriceps

Criteria to progress:

- Pain under control without medications
- Minimal joint effusion
- Full passive knee extension
- Voluntary quadriceps contraction

Interventions:

- Cryotherapy and elevation
- Patellar mobilizations
- Ankle pumps and heel slides
- Isometric quadriceps exercises
- Gait training with appropriate assistive device

Phase 2: Range of Motion & Early Strengthening Phase

Goal: Regain knee flexion, normalize gait, initiate controlled loading

Criteria to progress:

- ROM: 0–120 degrees
- Independent walking without limping
- Normal patellar mobility
- Straight leg raises without lag

Interventions:

- Closed-chain kinetic exercises (mini-squats, leg press)
- Balance board and single-leg stance
- Stationary cycling
- Step-ups and hip-strengthening drills

Phase 3: Intermediate Strengthening & Neuromuscular Control Phase

Goal: Build strength, enhance joint control, introduce dynamic movement

Criteria to progress:

- Quadriceps and hamstring strength $\geq 70\%$ of uninvolved leg (LSI)
- No effusion after exercise

- Single-leg balance ≥ 30 seconds with good form

Interventions:

- Resistance band drills
- Lunges, wall sits, hamstring curls
- Proprioceptive drills (BOSU, unstable surfaces)
- Light agility tasks (ladder drills, low-speed shuttle runs)

Phase 4: Advanced Strengthening & Plyometric Phase

Goal: Improve power, agility, and prepare for sports-specific training

Criteria to progress:

- Hop test scores $\geq 85\%$ LSI
- Pain-free performance of dynamic tasks
- Normalized movement pattern during jumps and landings

Interventions:

- Plyometrics (jump squats, lateral hops)
- Agility ladders, change of direction drills
- Interval jogging programs
- Advanced resistance training with external load

Phase 5: Return to Sport Phase

Goal: Restore sport-specific skills, ensure psychological readiness

Criteria for Return to Sport:

- LSI ≥ 90 –95% in strength and functional hop tests
- Completion of a sport-specific training circuit without discomfort or compensation
- High confidence scores on ACL-RSI or similar scales
- Surgeon and physiotherapist clearance

Interventions:

- High-level plyometric and cutting drills
- Contact and non-contact sport simulation

- Fatigue-based testing (to mimic game conditions)
- Gradual reintroduction to competitive situations

This approach reduces premature return to sport, decreases reinjury rates, and ensures physical and psychological preparedness—factors that are vital in long-term athletic success and joint protection.

Challenges in Implementation of Criterion-Based Rehabilitation

While the criterion-based model offers a more individualized, safe, and evidence-based framework for post-ACL reconstruction rehabilitation, it is not without its challenges. Successful implementation demands more than just clinical knowledge—it requires structured systems, patient commitment, and sometimes, resources that may not be readily available in all settings.

1. Requirement for Skilled Assessment

Criterion-based rehabilitation relies on objective measures such as hop tests, strength symmetry (LSI), ROM, balance tests, and psychological scales. This demands that therapists are:

- Trained in test administration and interpretation
- Capable of identifying compensatory patterns
- Proficient in recognizing subtle deficits that may not be obvious
- Inexperienced or undertrained professionals may misjudge readiness and compromise safety.

2. Access to Testing Equipment

Many advanced assessments, like isokinetic testing or force plate analysis, require specialized equipment often found only in high-performance clinics or research settings. Limited-resource environments may lack:

- Dynamometers for accurate strength testing
- Balance measurement platforms
- Space and tools for reliable hop test execution
- Without these, clinicians may have to rely on subjective judgment or simpler field tests.

3. Patient Adherence and Understanding

Unlike time-based plans where patients "wait out" the weeks, a criterion-based plan requires active engagement and consistent effort from the patient. Challenges include:

- Lack of motivation to meet milestones
- Impatience to return to sport prematurely
- Frustration if progress plateaus
- Education and continuous feedback are essential to keep patients committed to goals rather than dates.

4. Integration into Clinical Systems

In large hospitals or community rehabilitation setups, there may be:

- Inconsistent therapist continuity, making progression tracking difficult
- Limited time for comprehensive assessments
- Pressure from coaches, parents, or athletes to speed up RTS timelines
- Collaboration between surgeon, physiotherapist, coach, and patient is essential to create a unified rehab plan.

5. Psychological Readiness Often Overlooked

Even in criterion-based models, psychological components are sometimes neglected due to:

- Lack of training in mental health screening
- Unavailability of sports psychologists
- Focus being more on physical parameters
- Tools like the ACL-RSI scale should be a routine part of discharge criteria for return to sport.

Addressing These Challenges: Practical Solutions

- **Therapist Training:** Regular workshops and certifications on functional testing and evidence-based rehab.
- **Use of Simplified Tools:** In absence of machines, clinicians can use hand-held dynamometers, stopwatch-based hop tests, and video analysis for movement quality.
- **Patient Education:** Early counseling on goals, progression, and expectations from Day 1 post-surgery.
- **Structured Protocols:** Clinics can adopt hybrid protocols that combine time awareness with strict milestone-based advancement.
- **Team-Based Approach:** Encourage communication among orthopedic surgeons, rehab specialists, coaches, and patients.

Conclusion

Rehabilitation following Anterior Cruciate Ligament (ACL) reconstruction is a critical phase that determines the long-term success of the surgical outcome, functional recovery, and most importantly, the safe return to physical activity or sport. While traditional time-based rehabilitation protocols have served as foundational frameworks for decades, they often fail to accommodate the unique healing capacities, functional performance, and psychological readiness of individual patients.

In contrast, criterion-based progression offers a more personalized, dynamic, and evidence-driven approach to post-ACLR rehabilitation. By focusing on objective milestones such as strength symmetry, neuromuscular control, hop test outcomes, and psychological preparedness it ensures that progression through each phase of recovery is based on readiness rather than routine. This reduces the likelihood of reinjury, improves functional outcomes, and enhances patient confidence.

However, criterion-based models do require greater clinical skill, access to testing resources, and strong patient engagement. Overcoming implementation challenges through clinician training, interdisciplinary teamwork, and patient education can enable broader adoption of this superior approach.

In summary, the future of ACL rehabilitation lies not in rigid calendars, but in flexible, patient-centered models that adapt to real-time recovery. A hybrid approach, where clinicians are aware of general timelines but prioritize functional milestones, could serve as the gold standard merging structure with individualized care.

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