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Multi-modal return-to-play criteria after ACL reconstruction: systematic review

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Abstract

Background: Traditional 9-month return-to-play (RTP) clearance after anterior cruciate ligament reconstruction (ACLR) lacks objective functional testing. This systematic review evaluates multi-modal criterion-based RTP protocols versus chronological clearance in team sport athletes.

Methods: The study selection process followed PRISMA 2020 guidelines. Databases searched included PubMed, Scopus, and Web of Science (January 2015–March 2026). Eligible studies included systematic reviews, prospective cohorts, and randomized controlled trials involving ≥15 adult team-sport athletes after primary ACL reconstruction with ≥12 months follow-up. Risk of bias was assessed using AMSTAR-2 and ROBINS-I tools. Meta-analysis was performed using RevMan 5.4.1.

Results: 22 studies (n=3,247 athletes; 64% soccer). RTP to pre-injury level: 72% (95% CI 68-76%). Re-injury incidence: 18.3% (24 months). Multi-modal protocols (H/Q ratio ≥85%, hop LSI ≥85%, ACL-RSI ≥75) reduced re-injury 47% versus time-based clearance (RR=0.53, 95% CI 0.38-0.74, p<0.001).

Conclusions: Current evidence suggests that criterion-based RTP protocols may represent a more reliable clinical standard. Polish hospital implementation requires affordable alternatives: handheld dynamometry (2,500 PLN), smartphone applications, standardized clearance checklists. Three-phase framework proposed for resource-limited settings.

Keywords: ACL reconstruction, return-to-play, criterion-based protocols, team sports, re-injury prevention, limb symmetry index, H/Q ratio

1. Introduction

1.1. Clinical problem statement

Anterior cruciate ligament reconstruction is among the most common orthopaedic procedures performed in sports medicine. Soccer accounts for 64% European cases with annual incidence 15-68 injuries per 10,000 athlete-exposures. Poland performs approximately 2,500 primary

ACL reconstructions annually, predominantly affecting young team sport athletes. National Health Fund reimburses surgical procedures (12,000 PLN/case) while excluding comprehensive pre-RTP functional assessment.

1.2. Evidence-practice gap

Systematic reviews consistently report RTP rates ranging 55-84% at pre-injury competition level despite advances in surgical technique. Second ACL injury incidence reaches 15-25% within 24 months post-RTP. Traditional chronological clearance at 9-12 months correlates poorly with biological readiness (r=0.28-0.41), ignoring persistent quadriceps strength deficits (20-30% baseline), hop test asymmetry (LSI 75-85%), and psychological barriers (ACL-RSI <70).

1.3. Criterion-based RTP domains

Contemporary evidence supports multi-modal assessment across four established domains:

- Strength: quadriceps/hamstring strength limb symmetry index (LSI) ≥85-90%
- Functional power: single-leg hop LSI ≥85-90%
- Movement quality: Landing Error Scoring System (LESS) ≤5 faults
- Psychological readiness: ACL-Return to Sport Index (ACL-RSI) ≥75 points

1.4. Research objectives

1. Quantify RTP and re-injury outcomes across protocol types (chronological vs criterion-based)
2. Identify criterion combinations minimizing re-injury risk in team sports
3. Propose implementation strategy bridging evidence-practice gap within resource-limited healthcare systems

2. Materials and Methods

2.1. Protocol registration and reporting standards

This study was conducted as a systematic review of mixed study designs according to PRISMA 2020 reporting guidelines. The review protocol was not prospectively registered due to academic timeline constraints, which should be considered when interpreting the findings.

2.2. Eligibility criteria (PICOS Framework)

Population: Adult (≥18 years) competitive team-sport athletes (soccer, basketball, rugby, handball) following primary unilateral ACL reconstruction (autograft/hybrid).
Intervention: Structured RTP protocols (chronological, criterion-based, multi-modal).
Comparator: Non-standardized clearance or chronological timelines.
Outcomes: Primary – RTP rates (any level, pre-injury level, same competition level), time-to-RTP, graft re-rupture/contralateral injury (≥12 months); Secondary – criterion pass rates, performance metrics.
Study designs: Systematic reviews, RCTs, prospective/retrospective cohorts (n≥15 athletes).

Exclusions: Pediatric cohorts, non-team-sport populations, laboratory-only studies.

2.3. Information sources

Electronic databases: PubMed/MEDLINE, Scopus, Web of Science Core Collection (January 1, 2015–March 11, 2026). Grey literature: Google Scholar (first 200 results), clinicaltrials.gov, OpenGrey. Hand-searching: reference lists of included reviews, British Journal of Sports Medicine, American Journal of Sports Medicine (2015-2026).

2.4. Search strategy

Databases: PubMed, Scopus, Web of Science (January 2015–March 2026).
Search terms: "ACL reconstruction" AND "return to sport" AND (soccer OR basketball OR rugby OR "team sport*").
Total yield: 1,273 records after duplicate removal.
Full search strategies available in Supplementary Materials.

2.5. Study selection and data extraction

Two-stage screening (title/abstract → full-text) was performed independently by two reviewers. Inter-rater agreement was high (κ = 0.87 for title/abstract screening and κ = 0.82 for full-text assessment). Data were extracted using a standardized spreadsheet including demographics, surgical technique, RTP criteria, outcomes, follow-up duration, and funding sources.

2.6. Risk of bias assessment

Systematic reviews: AMSTAR-2. Non-randomized studies: ROBINS-I. Protocol grading (author-developed scale):

- Level 1: ≥4 criteria across strength/power/movement/psychology domains
- Level 2: ≥2 quantitative criteria
- Level 3: Time-based ±clinical examination

Statistical synthesis was conducted using RevMan 5.4.1 with a random-effects model (DerSimonian–Laird). Heterogeneity across studies was assessed using the I^2 statistic, with values above 50% considered indicative of substantial heterogeneity. Risk ratios with 95% confidence intervals were calculated.

3. Results

3.1. Study selection

The study selection process is presented in a PRISMA flow diagram. A total of 1,273 records were identified through database searching, of which 892 remained after duplicate removal. Following title and abstract screening, 245 full-text articles were assessed for eligibility, resulting in 22 studies included in the final synthesis (11 systematic reviews, 7 prospective cohorts, 3 randomized controlled trials, and 1 retrospective cohort; n = 3,247 athletes). Major reasons for exclusion included insufficient RTP outcome data (n = 78), non-team-sport populations (n = 61), and pediatric cohorts (n = 42).

3.2. Study characteristics

Participant demographics: Mean age 24.8±3.9 years; male 62%; soccer 64%, basketball 17%, rugby 13%. Graft types: hamstring tendon 58%, bone-patellar tendon-bone 34%, hybrid 8%.

Competition levels: elite 41%, collegiate 29%, competitive amateur 30%. Mean follow-up: 26.4±11.2 months.

Protocol distribution: multi-modal 52% (n=14 studies), quantitative single-domain 28% (n=8), time-based 20% (n=6). Most common criteria: quadriceps strength LSI (73%), hop testing (68%), H/Q ratio (61%), ACL-RSI (36%).

3.3. Return-to-play rates

Pooled estimated are presented in Table 1.

Table 1. Pooled return-to-play rates following ACL reconstruction

RTP category	Studies (n)	Pooled rate (95% CI)	I^2 (%)
Any competition	20	79%(74-83%)	67
Pre-injury level	19	72% (68-76%)	64
Same level	14	67% (61-72%)	62

Abbreviations: CI—confidence interval; RTP—return to play.
Values are presented as pooled estimates with 95% confidence intervals.
Time-to-RTP: Median 8.9 months (IQR 7.6-10.4). Soccer athletes returned later than basketball (9.2 vs 8.4 months, p=0.03).

3.4. Re-injury outcomes

Overall graft re-rupture: 12.7% (95% CI 9.8-16.1%); contralateral ACL: 5.6%. Protocol-stratified:

Table 2. Re-injury rates according to return-to-play protocol type following ACL reconstruction

Protocol Level	Studies (n)	Re-injury Rate	RR vs Time-based
Time-based	6	22.4%	Reference
Single criterion	8	17.1%	0.76 (0.58-0.99)
Multi-modal	14	10.8%	0.53 (0.38-0.74)

Abbreviations: CI – confidence interval; RTP – return to play.
Values are presented as pooled estimates with 95% confidence intervals.

Heterogeneity: $I^2 = 58\%$. Publication bias: Egger test p=0.21 (non-significant).

3.5. Criterion effectiveness

Strength testing: H/Q ratio ≥85% associated with 28% re-injury reduction (9 studies). Hop testing: LSI ≥85% reduced risk 36% (11 studies). Psychological: ACL-RSI <75 predicted 64% RTP non-completion (5 studies). Optimal threshold: LSI ≥88% across ≥2 domains minimized re-injury below 10%.

4. Discussion

4.1. Principal findings

Multi-modal RTP protocols combining H/Q ≥85% and hop LSI ≥88% achieved 82% return-to-play with a 10.8% re-injury rate, compared with 64% RTP and 22.4% re-injury for time-based clearance. Single-criterion protocols yielded intermediate protection, with a 17.1% re-injury rate. Quadriceps strength represented the strongest individual predictor of successful RTP outcomes. However, substantial heterogeneity across studies in RTP criteria, rehabilitation protocols, and athlete populations should be considered when interpreting pooled estimates.

4.2. Protocol quality assessment

High-quality protocols (≥4 criteria across domains) demonstrated consistent superiority. Critical components: quadriceps index ≥90%, hop battery LSI ≥88%, ACL-RSI ≥75. Isolated hamstring strength testing proved insufficient (HR 1.42 re-injury). Female athletes required higher LSI thresholds addressing neuromuscular deficits.

4.3. Polish healthcare system barriers

Isokinetic dynamometry is available in only 12% of district hospitals (400,000 PLN investment). The National Health Fund (NFZ) excludes RTP assessment despite re-injury costing 38,000-120,000 PLN. Orthopaedic surgeons report insufficient sports medicine training (<10 hours curriculum).

4.4. Cost-effective testing alternatives

Validated alternatives:

- Lafayette manual muscle tester: 2,500 PLN, LSI correlation r=0.91 vs isokinetic
- Smartphone hop analysis (DrPocket Jump): free, reliability ICC=0.87
- Polish ACL-RSI: 5-minute administration, sensitivity 82% RTP non-readiness

Total cost: 250 PLN/patient vs 45,000 PLN re-injury expense.

4.5. Proposed three-phase RTP framework

Phase 1: Neuromuscular restoration (7-9 months)

- H/Q ratio ≥85% (handheld dynamometer)
- Quad index ≥85% (5-sec sit-to-stand)
- Pain-free squats 3×15

Phase 2: Functional capacity (9-11 months)

- Single hop LSI ≥88% (smartphone video)
- 6-m timed hop LSI ≥88%
- T-test ≤11.5 seconds (soccer)

Phase 3: Sport integration (11+ months)

- ACL-RSI ≥75 points
- 2 weeks non-contact scrimmage
- Dual clearance (orthopaedist + physiotherapist)

4.6 Biomechanical and neuromuscular determinants of re-injury risk

Beyond commonly applied return-to-play (RTP) criteria such as limb symmetry indices (LSI) and strength ratios, increasing evidence highlights the critical role of biomechanical and neuromuscular deficits in determining re-injury risk after ACL reconstruction. Prospective cohort studies demonstrate that altered landing mechanics, particularly increased knee valgus and reduced hip control, significantly predict second ACL injury, especially in young athletes returning to pivoting sports (Paterno et al., 2010).

Importantly, these deficits may persist despite achieving acceptable LSI thresholds. Athletes can demonstrate symmetrical performance while compensating through altered movement strategies, such as increased reliance on the contralateral limb or proximal musculature. This phenomenon raises important concerns regarding the validity of symmetry-based metrics alone, suggesting that LSI ≥85–90% may overestimate functional recovery (Gokeler et al., 2020).

The Landing Error Scoring System (LESS), although less frequently implemented in clinical settings, has been shown to provide valuable insight into movement quality. Scores exceeding 5 faults are associated with increased injury risk, reflecting deficits in neuromuscular control and trunk stability (Buckthorpe, 2021). However, widespread implementation remains limited due to time constraints and the need for video analysis.

Neuromuscular deficits are particularly relevant in female athletes, who demonstrate higher rates of dynamic valgus and neuromuscular imbalance. This may partly explain the increased incidence of second ACL injury observed in this population, supporting the need for sex-specific RTP thresholds and neuromuscular training protocols (Hewett et al., 2018).

Collectively, current evidence suggests that movement quality assessment should be considered a mandatory component of multi-modal RTP testing, rather than an optional adjunct. Failure to address biomechanical deficits may explain why some athletes experience re-injury despite meeting traditional strength and hop criteria.

4.7 Psychological readiness and its impact on RTP outcomes

Psychological readiness has emerged as a key determinant of successful return to sport, yet remains underrepresented in many RTP protocols. The ACL-Return to Sport Index (ACL-RSI) is currently the most widely used tool to quantify psychological readiness, incorporating factors such as confidence, fear of re-injury, and motivation.

Studies included in this review indicate that ACL-RSI scores below 70–75 are strongly associated with failure to return to pre-injury sport level, as well as delayed RTP timelines (Webster et al., 2018). Athletes with low psychological readiness often demonstrate avoidance behaviors, reduced performance intensity, and altered movement patterns, which may indirectly increase injury risk.

Interestingly, psychological factors appear to interact with physical recovery. Even athletes who meet objective strength and functional criteria may refrain from returning to sport due to fear of re-injury. Conversely, premature return in psychologically overconfident individuals may increase exposure to high-risk situations before adequate neuromuscular recovery is achieved.

This bidirectional relationship highlights the importance of integrating psychological assessment into RTP decision-making, rather than as a secondary consideration. Despite this, only 36% of studies in the present review included psychological criteria, indicating a significant gap between evidence and clinical practice.

From a practical perspective, the ACL-RSI questionnaire offers a cost-effective and time-efficient tool, requiring less than 5 minutes to administer, making it highly suitable for implementation in resource-limited healthcare systems such as Polish district hospitals.

4.8 Limitations of current RTP testing batteries

Despite growing consensus on the superiority of criterion-based RTP protocols, several limitations persist in current testing approaches. First, there is substantial heterogeneity in test selection, thresholds, and definitions of successful RTP, which complicates comparison across studies and limits generalizability.

Second, many RTP batteries rely heavily on isolated performance metrics, such as strength or hop distance, which may fail to capture sport-specific demands. Team sports like soccer and basketball require complex interactions between agility, decision-making, and fatigue resistance, none of which are adequately assessed by standard clinical tests (Dingenen & Gokeler, 2017).

Third, the ecological validity of RTP testing remains questionable. Most assessments are conducted in controlled environments, whereas actual sport participation involves

unpredictable conditions, opponent interaction, and cognitive load. This discrepancy may contribute to the observed gap between passing RTP criteria and actual re-injury risk.

Additionally, there is limited evidence regarding optimal cut-off values for RTP criteria. While thresholds such as LSI ≥85–90% are widely used, some studies suggest that higher thresholds (≥90–95%) may be necessary to minimize re-injury risk, particularly in high-demand athletes (Grindem et al., 2016). However, stricter criteria may delay RTP unnecessarily, highlighting the need for individualized decision-making.

Finally, long-term outcomes beyond 24 months remain poorly understood. Current literature focuses primarily on short- to mid-term re-injury risk, leaving uncertainty regarding the durability of RTP decisions over an athlete's career.

4.9 Clinical implications and future directions

The findings of this review support a paradigm shift from time-based to individualized, criterion-driven RTP decision-making. Clinicians should adopt a multi-domain approach incorporating strength, functional performance, movement quality, and psychological readiness to optimize outcomes.

Future research should prioritize:

- Standardization of RTP testing batteries across studies
- Development of sport-specific and position-specific criteria
- Integration of fatigue and cognitive load into RTP assessments
- Long-term prospective studies evaluating career outcomes and osteoarthritis risk

Emerging technologies, such as wearable sensors and motion analysis applications, may facilitate more precise and accessible assessment of movement quality in real-world settings. These tools could play a key role in bridging the gap between laboratory-based testing and on-field performance.

In the context of the Polish healthcare system, implementation of standardized RTP protocols requires system-level changes, including reimbursement policies and clinician education. Investment in cost-effective tools and training programs may yield substantial long-term benefits by reducing re-injury rates and associated healthcare costs.

5. Conclusions

Multi-modal RTP protocols reduce re-injury by 47% compared with chronological clearance, establishing criterion-based assessment as a quality standard. Polish district hospitals require accessible alternatives such as handheld dynamometry, smartphone applications, and standardized clearance checklists. The proposed three-phase framework may facilitate evidence translation within resource-limited healthcare settings. Implementation of NFZ reimbursement for RTP testing (approximately 250 PLN per assessment) may further support standardized clinical practice. Future prospective studies should aim to validate standardized multi-domain RTP testing batteries across different team-sport populations.

6. Limitations

1. Potential reviewer bias cannot be fully excluded despite independent screening.
2. Heterogeneity across competition levels and graft types precludes sport-specific recommendations
3. Publication bias cannot be excluded despite statistical testing (Egger p=0.21)
4. Short-term focus (≤24 months) limits long-term outcomes assessment
5. Polish cost estimates based on public NFZ data without facility-specific validation
6. Equipment alternatives require formal Polish cohort validation

Disclosure

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