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Review

# Return to sport (RTS) tests and criteria following an anterior cruciate ligament (ACL) reconstruction (ACLR): a scoping review

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ABSTRACT

*Objective:* Anterior cruciate ligament reconstruction (ACLR) surgery is a common procedure to restore knee stability and enable athletes to return to sport (RTS). This scoping review aimed to explore RTS tests and criteria used in decision-making following ACLR surgery.

*Methods:* A scoping review methodology was undertaken. A comprehensive search of MEDLINE, CINAHL, and SPORTDiscus was conducted to identify studies reporting RTS tests and criteria for athletes post-ACLR. Studies involving level I and II sports were included. Data was extracted and study characteristics, RTS criteria, and results were summarised.

*Results:* Of 1703 studies screened, 33 met the inclusion criteria, involving over 6000 participants. RTS criteria showed significant variability across studies, with protocols emphasising limb symmetry indexes (LSI) for strength and jump and hop performance, often set at ≥90 %. RTS timing ranged from a minimum of six to nine months post-surgery. While psychological readiness was frequently reported, assessments of change of direction, agility, and biomechanics were less common.

*Conclusions:* This review highlights the lack of standardisation in RTS protocols, leading to inconsistencies in clinical practice. Developing consistent, evidence-based guidelines is essential to enhance RTS outcomes, minimise re-injury risk, and optimise performance for athletes post-ACLR.



**Contents**



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## 1. Introduction

Anterior cruciate ligament (ACL) injuries are common in sport and have deleterious effects for athletes [1–3]. ACL injury rates are increasing, particularly in females and younger athletes [4], with an annual incidence ranging from 30 to 78 per 100,000 person-years in the United States [5]. Most ACL injuries occur during non-contact pivoting and cutting manoeuvres in sports like football, netball, basketball, and rugby [4,6]. While non-operative management is an option, the prevailing

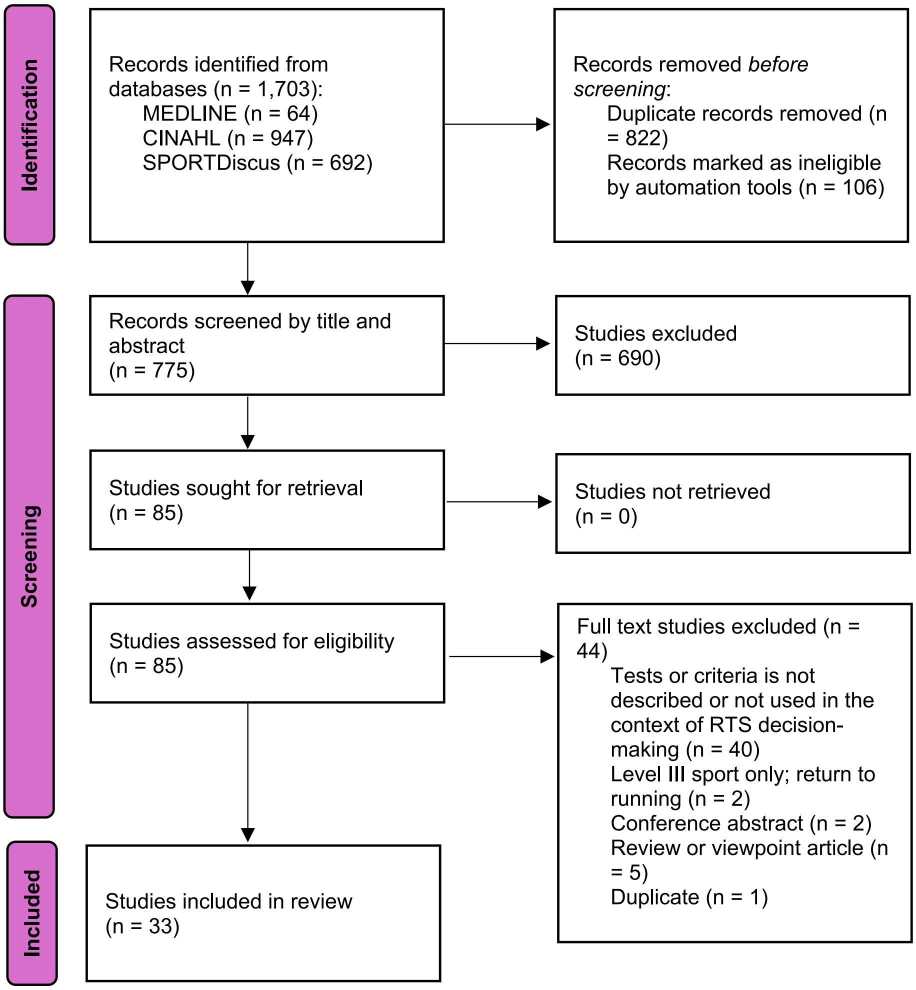


**Figure 1.** PRISMA diagram.

choice for those aiming to resume sport is undergoing an ACL reconstruction (ACLR), considered by many as the gold standard treatment [7,8].

While nearly 80 % of individuals are reported to return to sport (RTS) following an ACLR [9], many do not reach pre-injury performance levels [2,10,11]. Return to pre-injury performance rates range from 50 % to 90 %, with elite athletes representing the higher percentages [12]. RTS following an ACLR also carries a significant risk of graft or contralateral ACL rupture [13,14], often leading to poorer outcomes [15]. Global rates of ACL graft rupture can reach up to 24 % [16]. Rehabilitation must focus on identifying those at greater risk of a second injury and restoring pre-injury performance levels.

While passing RTS criteria has shown promise in reducing ACL re-injury rates [1,17,18], the lack of standardised criteria for RTS assessment remains a challenge [19]. Despite the growing popularity of criterion based RTS decision-making, a consensus on tests and pass thresholds remains elusive, leading to high variability in definitions, evaluations, and reporting [20]. Correspondingly, published literature reflects significant heterogeneity in RTS pass rates, ranging from 18.8 % to 88.1 % [21]. This scoping review aims to assess the tests and criteria currently used to support RTS decision-making following ACLR.

## 2. Methods

A scoping review was selected due to the broad scope of the research question and the wider inclusion criteria compared to a traditional systematic review. Scoping reviews offer the advantage of summarising and disseminating research findings while also identifying gaps in the existing literature. This review follows the five-stage methodological framework outlined by Arksey and O'Malley [22], with additional guidance from the Joanna Briggs Institute (JBI) Reviewer Manual [23,24]. To ensure transparency and rigor, the review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews (PRISMA) and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) which is detailed in Figure 1.

The initial step was to identify the research question, centred on how specific tests or criteria influence RTS decision-making following ACLR surgery. The JBI recommends using the PCC (Population, Concept, and Context) framework for scoping reviews as it provides a structured approach for formulating clear and meaningful objectives and eligibility criteria [25]. The primary aim was to ascertain which tests or criteria (concept) are reported and utilised in RTS decision-making (context) for athletes post-ACLR (population).

In the second step, relevant studies were identified through a structured search strategy outlined in Table 1. This search utilised Medical Subject Headings (MeSH) terms in the title and abstract across three key databases: MEDLINE, CINAHL, and SPORTDiscus. Automation techniques were employed to filter results to peer-reviewed academic journals, and duplicates were removed, yielding 775 studies for screening. This comprehensive search strategy ensured a thorough identification of relevant literature on the topic.

The third step involved the selection of studies based on the inclusion and exclusion criteria detailed in Table 2. Only peer-reviewed interventional or observational studies with more than 10 participants were included. These focused only on ACLR surgery in athletes participating in level I (frequent cutting, pivoting, and abrupt changes in direction) or II sport (occasional quick changes in direction), defined by the Cincinnati Sports Activity Scale (CSAS) [26]. For studies that did not report the athletes' sport level, participation at a minimum of level II was assumed if RTS occurred six months post-ACLR, and RTS testing included strength or jump performance with a limb symmetry index (LSI) pass threshold of 80 % or higher. Studies relating to surgical techniques, graft choices, or those that did not specify RTS criteria were excluded. This screening process resulted in a subset of studies directly relevant to RTS decision-making post-ACLR (n = 33).

In the fourth step, key details from the selected studies were extracted and summarised in Table 3. This data extraction included information on study design, participant characteristics, and the specific tests or criteria used for RTS decision-making. The standardised format for data extraction ensured consistency and comparability across the included studies, aligning with the review's objectives. The key themes derived from this synthesis are presented in Table 4, offering valuable insights into the current landscape of RTS decision-making which will be discussed in the sections to follow.

**Table 1**
Scoping review search 22/07/2024.

| Search terms | Records identified |
|---|---|
| **XB** "Anterior cruciate ligament reconstruction" **OR** "ACL reconstruction" **OR** ACLR | MEDLINE (n = 14,858)<br>CINAHL (n = 9,375)<br>SPORTDiscus (n = 6,725) |
| **AND**<br>"Return to play" **OR** "return to sport" **OR** "return to competition" | MEDLINE (n = 1,497)<br>CINAHL (n = 971)<br>SPORTDiscus (n = 763) |
| **AND**<br>test* or criteria | MEDLINE (n = 839)<br>CINAHL (n = 641)<br>SPORTDiscus (n = 499) |

**Table 2**
Inclusion/exclusion criteria.

| Inclusion | Exclusion |
|---|---|
| Study design: peer-reviewed interventional or observational study with >10 participants and clinical practice guidelines or recommendations | Study design: systematic reviews, conference abstracts, surveys, case reports, case series, translations, non-peer reviewed interventional or observational studies, study protocols |
| Participants: human, participating in level I or II sport, primary ACLR, revision ACLR | Participants: non-human (animal or cadaver), non-op ACL, ACL repair, not ACL-related, not participating in sport or participating in level III sport |
| Outcome: describes specific test or criterion used for RTS decision-making (e.g. reported scales, strength, jump performance) | Outcome: surgical techniques or graft choice, no description of specific test or criterion used to inform RTS decision-making following an ACLR, or testing or criteria is not described in the context of RTS decision-making |

## 3. Results

The initial search identified 1703 studies, of which 33 met the inclusion criteria. Of these, 11 were cross-sectional studies, 14 were prospective cohort studies, four were observational cohort studies, one was a retrospective cohort study, two were controlled laboratory studies, and one was a case-control study. The studies provided broad geographical representation, including North and South America, Europe, Asia, and Oceania.

A total of 6010 participants were included across the studies, with 64 % being male (n = 3871) and 36 % female (n = 2139). The mean age (SD) of participants was 24.8 (3.7) years. Among the studies, 16 focused on athletes from level I sports [1,17,27,28,32,35,36,39,41,44–46,50,52–54], seven focused on level I and II sports [29,31,34,37,44,47,48], and two on level I, II, and III sports [14,30]. Eight studies did not specify the type of sport participation but met the inclusion criteria and were included in the review [16,33,38,40,42,43,49,55].

The most frequently used graft type in this review is the hamstring tendon autograft, representing approximately 70 % of participants from studies reporting graft type. Patellar tendon autografts are the second most used, accounting for approximately 8 % of participants. Iliotibial band (ITB) and quadriceps tendon autografts each make up 1 % of participants. Five studies did not report the graft type [31,32,43,47,53], accounting for approximately 20 % of participants.

Four studies involved professional athletes [17,27,39,54], one study included both professional and amateur athletes [42], while the remaining studies involved amateur and recreational athletes, or did not report the level of sport participation [1,14,16,28–41,43–53,55].

## 4. Return to sport criteria

### 4.1. Time

Time is a key factor for RTS decision-making, however only three studies explicitly report using time as an RTS criterion [27,28,42]. Two of these studies describe an accelerated rehabilitation programme aimed at RTS within six months [27,28]. The third study sets specific timeframes for RTS based on the level of sport: level III at a minimum of four months, level II at six months, and level I at nine months [42].

### 4.2. Strength

Strength assessments were reported in nearly 80 % of the studies in this review [1,14,27–35,37,38,40,41,43–51,53,54]. Most studies included knee extension strength: 35 % assessed a maximal voluntary isometric contraction (MVIC) [27,29,30,32,33,46,47,50,53], while 65 % assessed torque using isokinetic dynamometry (IKD) [1,14,17,27,31,33–35,37,38,41,43–45,49,54,56]. Over half of these studies also measure knee flexion strength (61 %): three used MVIC [30,40,50], one assessed eccentric strength [50], and nine used IKD [31,34,35,37,41,43,49,54,56]. There is some variation in MVIC and in IKD testing protocols (90- or 60-degrees flexion angles, and 60, 90, 180, or 300 degrees per second speeds, respectively).

Among studies assessing strength, 70 % used an LSI of ≥90 % as the RTS cut-off [1,14,17,29,31,32,34,35,37,40,41,45,46,49,50,53,56], while 12 % used an LSI of ≥85 % [30,38,43], and one study applied an LSI of ≥80 % [33]. Six studies utilised alternatives to LSI: one used pre-injury strength levels as a threshold [27], another used body weight percentages (260 ± 40 %) [35], and the remaining three used force per kilogram of body mass (e.g., >3.0 Nm/kg for knee extension) [31,37,41]. The final study used knee flexor and extensor strength to form part of a composite score of strength, power, and reactive strength (Total Score of Athleticism, TSA) [54].

Four studies incorporated the hamstring-to-quadriceps (H:Q) ratio for RTS decision-making [30,31,37,41]. Three of these studies assessed the H:Q ratio at 300 degrees per second, recommending thresholds of >62.5 % for males and >55 % for females [31,37,41], while the other study used an MVIC pass threshold of ≥85 % LSI [30].

**Table 3**
PCC Framework Data Extraction.

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| Angelozzi, Madama [27] Descriptive, prospective, longitudinal single cohort study | To investigate the RFD of MVIC as an outcome measure for determining readiness for RTS | 45 male professional footballers Mean age (SD): 23.4 (4.7) Graft type: HT autograft | IKDC, laxity, isometric leg press MVIC and RFD | I | Tegner score | - Average MVIC at 6 m post-op was 97 % - Average RFD at 6 m post-op was 80 % ($RFD_{30}$), 77 % ($RFD_{50}$), and 63 % ($RFD_{90}$) - Mean RFD >90 % was achieved at 12 m post-op |
| Di Stasi, Logerstedt [28] Controlled laboratory study | To compare gait characteristics of athletes who pass and do not pass RTS criteria 6 m post-ACLR | 42 athletes 30 male, 12 female Mean age (SD): 29.3 (10.8) Graft type: soft tissue allograft or HT autograft (n=NR) | Isometric knee extension strength, SHD, THD, CHD, 6MTH, KOS-ADLS, GRS | I | KFAIC, KFAPKF, KEMPKF | - Athletes who do not pass RTS criteria demonstrate significant differences between limbs in all kinematic and kinetic variables at the knee ($p \leq 0.27$) |
| Gardinier, Di Stasi [29] Descriptive laboratory study | To determine whether knee joint contact force asymmetries during gait exist 6 m post-ACLR and whether these are associated with performance on RTS tests | 29 patients 17 male, 12 female Mean age (SD): 29.15 (10.75) Graft type: HT autograft (12) or allograft (17) | KOS-ADLS, GRS, isometric knee extension strength, SHD, THD, CHD, 6MTH | I, II | MCpk, TCpk | - No significant or meaningful differences in joint or muscle contact forces among all patients - Those who failed RTS testing exhibited meaningful contact force asymmetries with tibiofemoral contact force being significantly lower in the involved limb |
| Müller, Krüger-Franke [30] Prospective cohort study | To find predictive parameters for successful RTS post-ACLR | 40 patients 21 male, 19 female Mean age (SD): 32.2 (10.4) Graft type: HT autograft | Isometric knee extension and flexion strength, SHD, THD, CHD, square hop test, IKDC, TSK-11, ACL-RSI, | I, II (38), III (8) | | - No difference between RTS and non-RTS patients with strength, square hop and TSK-11. - LSI for single hop for distance, cross-over, and triple hop, and ACL-RSI and IKDC were significantly lower in non-RTS patients |
| Grindem, Snyder-Mackler [1] Observational cohort study | To assess the relationship between reinjury post-ACLR and return to level I sport, timing for RTS and knee function before RTS | 100 patients 46 male, 54 female Mean age (SD): 24.3 (7.3) Graft type: HT or PT autograft (n=NR) | Isokinetic knee extension strength, SHD, CHD, THD, 6MTH, GRS | I | | - Patients who returned to level I sport had a 4.32x ($p = 0.048$) higher rate of injury - Reinjury rates reduced by 51 % for each month RTS was delayed until 9 months post-ACLR - 38.2 % who failed RTS testing reinjured vs 5.6 % who passed - More symmetrical knee extension strength significantly reduced reinjury rates |
| Kyritsis, Bahr [17] Observational cohort study | To evaluate whether objective discharge criteria are associated with risk of ACL graft rupture after RTS post-ACLR | 158 male professional athletes Mean age (SD): 21.5 (4.5) Graft type: HT or PT autograft (n=NR) | Isokinetic knee extension and flexion strength, running *t*-test, SHD, THD, CHD | I | | - 16.5 % sustained an ACL graft rupture (average = 105 days post-RTS) - Not meeting all discharge criteria (RTS tests) and decreased H:Q ratio (at 60d/s) were associated with increased risk of ACL graft rupture |
| Gokeler, Welling [31] Observational cohort study | To develop a test battery to ensure safe RTS post- | 28 patients 22 male, 6 female Mean age (SD): | Isokinetic knee extension and flexion strength, | I, II | | At 6 m post-ACLR: - 2 patients passed RTS test battery - 67.9 % passed LESS - 78.5 % passed SHD |

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**Table 3** (*continued*)

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| | ACLR | 25.5 (8.3)<br>Graft type: NR | H:Q ratio, jump-landing task assessed with LESS, SHD, THD, SH, ACL-RSI, IKDC | | | - 85.7 % passed THD<br>- 50 % passed SH<br>- 39.3 %, 46.4 % and 42.9 % passed knee extension peak torque at 60, 180 and 300°/s respectively<br>- 85.7 % passed IKDC<br>- 75 % passed ACL-RSI |
| Wellsandt, Failla [32]<br>Prospective cohort study | To evaluate the use of the unaffected limb as a reference standard for LSI in RTS testing and its relationship with second injury | 70 athletes<br>47 male, 23 female<br>Mean age (SD): 26.6 (10)<br>Graft type: NR | Isometric knee extension strength, SHD, CHD, THD, 6MTH, IKDC, GRS | I | EPIC levels | - 57.1 % passed RTS tests but only 28.6 % met 90 % EPIC levels<br>- EPIC levels were more sensitive than LSIs in predicting second ACL injury (LSI, 0.273; 95 % CI: 0.010, 0.566; EPIC, 0.818; 95 % CI: 0.523, 0.949) |
| Burland, Kostyun [33]<br>Cross-sectional study | To investigate the relationship between self-reported and functional outcome measures on RTS timing in adolescent athletes identify a cut-off value for knee extension strength | 50 athletes<br>27 male, 23 female<br>Mean age (SD): 15.9 (1.82)<br>Graft type: HT autograft | Isometric and isokinetic knee extension and flexion strength, pedi-IKDC, ACL-RSI | NR | | - ↑ strength was associated with ↑ ACL-RSI and pedi-IKDC scores<br>- Differences were found in isometric extension strength ($p = 0.001$) and isokinetic extension strength at 180°/s ($p = 0.03$) and 300°/s ($p = 0.002$) between those who RTS and those who did not<br>- A 6-month isometric extension deficit (mean LSI = 85.48 ± 23.15) accurately identified patients who RTS after ACLR (AUC = 0.82, 95 % CI = 0.68, 0.95) |
| Ebert, Edwards [34]<br>Prospective cohort study | To compare the 'Back in Action' (BIA) test battery to standard RTS criteria (hop and strength test) | 40 participants<br>25 male, 15 female<br>Mean age: 23.8<br>Graft type: HT autograft | Isokinetic knee extension and flexion strength, 6MTH, SHD, THD, CHD, | I, II | BIA test battery | - Significantly less participants passed the BIA compared with the standard RTS test batteries ($p < 0.001$)<br>- LSIs for the standard hop test battery were significantly ↑ than the BIA single leg tests ($p < 0.001$) |
| O'Malley, Richter [35]<br>Cross-sectional study | To examine CMJ and isokinetic strength to identify which measures can distinguish between ACLR and control participants and provide normative values for young male field athletes | 118 male athletes<br>Age: 24–26<br>Graft type: PT autograft | isokinetic knee extension and flexion strength, SL CMJ, | I | | - The CG differed strongly from ALCR group in isokinetic extension peak torque ($d = -1.33$), SL CMJ performance ($d > 0.4$) and LSI in isokinetic strength and jump outcomes ($d > 1.1$) |
| Webster and Feller [36]<br>Observational cohort study | To determine the proportion of athletes who return to level I sport within 12 m, compare return rates by age and sex and examine whether RTS is associated with some commonly used | 1440 athletes<br>992 male, 448 female<br>Mean age (SD) = 26<br>Graft type: HT autograft (1414), PT autograft (8), LARS (18) | SHD, knee laxity (arthrometer), IKDC | I | Number of athletes who RTS within 12 m | - RTS was ↑ in athletes aged ≤25 (48 %) than those aged 26–35 ($p < 0.0001$) or 36+ ($p < 0.001$)<br>- Males had ↑ return rates than females in the ≤25 (52 % vs 39 %) and 26–35 (37 % vs 18 %) groups, with no sex differences >36<br>- Younger athletes were more likely to meet RTS criteria |

**Table 3** (*continued*)

| Author (year)<br>Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| | outcome criteria | | | | | - Athletes with an LSI ≥ 90 were 2x as likely to RTS ($p < 0.0001$), and those with IKDC scores ≥ 95 were 3x as likely to RTS ($p < 0.0001$) |
| Welling, Benjaminse [37]<br>Prospective, longitudinal, cohort study | To assess changes over time in patients tested at 6 and 9 months post-ACLR using a RTS test battery | 64 patients<br>45 male, 17 female<br>Mean age = 24.2<br>Graft type: HT autograft (45), PT autograft (19) | Isokinetic knee extension and flexion strength, jump-landing task assessed with LESS, SHD, THD, SH, IKDC, ACL–RSI | I, II | | - At 6 m, 3.2 % passed all criteria, increasing to 11.3 % at 9 m<br>- Patients improved in all RTS criteria over time, except for IKDC<br>- At 9 m, 46.8 % failed the strength criterion at 60°/s |
| Barfod, Feller [38]<br>Prospective cohort study | To examine the association between knee extensor strength and hop distance and evaluated strength deficits at 6 m and 12 m post-ACLR | 69 patients<br>47 male, 22 female<br>Mean age (SD) = 27.1 (8.1)<br>Graft type: HT autograft | Isokinetic knee extension strength, SHD | NR | | - At 6 m, 27.5 % of patients had satisfactory knee extensor strength, increasing to 46.4 % at 12 m<br>- 66.7 % achieved hop symmetry at 6 m and 89.9 % at 12 m<br>- Hop distance recovery was not linked to knee extensor strength |
| Lloyd, Oliver [39]<br>Cross-sectional study | To examine the discriminative ability of LSI threshold 90 % using total hop distance vs reactive strength ratios of individual hops during a triple hop test | 20 male footballers<br>Mean age (SD) = 24.6 (4.2)<br>Graft type: HT autograft (16), PT autograft (4) | THD | I | Contact time, flight time, RSR | - Significant, small to moderate between-limb differences ($p < 0.05$) for triple hop distance, flight time and RSR for each hop, with lower performance consistently displayed in the operated limb<br>- Large, significant differences in RSR between hops one and two on the operated limb ($p < 0.05$)<br>- 80 % of participants achieving 90 % LSI for total hop distance<br>- <50 % of participants reached the 90 % LSI threshold for RSR |
| Sugimoto, Heyworth [40]<br>Cross-sectional study | To examine the proportion of skeletally immature, paediatric ACLR patients who achieve ≥ 90 % on RTS tests | 105 young patients<br>62 male, 43 female<br>Mean age (SD) = 13.4 (1.4)<br>Graft type: HT autograft (54), ITB autograft (51) | Isometric knee extension, knee flexion, hip abduction and hip extension strength, YBT, SHD, THD, CHD, 6MTH | NR | | - Only 4.2 % patients demonstrated ≥ 90 % LSI in all RTS tests<br>- % of patients who passed all 4 strength, 3 balance, and 4 hop tests were 20, 65.4, and 27.8 % respectively |
| Webster and Feller [14]<br>Prospective, logitudinal, cohort study | To determine the proportion of patients who pass RTS tests 6 m post-ACLR; age, sex, and activity level differences between those who pass and do not pass; and specific tests are associated with return to competitive sport at 12 m | 450 patients<br>274 male, 176 female<br>Mean age (SD) = 24 (7)<br>Graft type: HT autograft (391), QT autograft (47), PT autograft (12) | Isokinetic knee extension strength, IKDC, ACL-RSI, SHD, CHD | I (381), II/III (69) | | - 3.8 % met all 5 test criteria at 6 m and 21 % did not pass any test<br>- More of the younger patients (<21 years) passed all functional tests ($p < 0.01$)<br>- More male patients met the IKDC threshold (P = 0.03)<br>- Patients who played level I sports had the same pass rates as those who played level II/III sports<br>- Patients who passed the thresholds for the ACL-RSI and IKDC had 4x and 3x the odds of RTS at 12 months, respectively ($p < 0.0001$) |

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**Table 3** (*continued*)

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| | | | | | | - ≥90 % LSI for quadriceps strength or either hop test at 6 m was not associated with RTS |
| Welling, Benjaminse [41] Prospective cohort study | To compare the results of a RTS test battery between patients who RTS (pre-injury level) and patients who did not RTS | 64 patients 44 male, 20 female Mean age (SD) = 27.8 (8.8) Graft type: HT autograft (45), PT autograft (19) | Isokinetic knee extension and flexion strength, jump-landing task assessed with LESS, SHD, THD, SH | I | | - Significantly ↓ LESS score in RTS group ($p = 0.01$)<br>- Significantly ↑ absolute scores on hop tests with both legs in RTS group<br>- Significantly ↑ hamstring strength in the injured leg in RTS group ($p = 0.009$ at 60°/s; 0.012 at 180°/s; 0.013 at 300°/s)<br>- No differences in test results were identified between patients who sustained a second ACL injury and patients who did not |
| Franck, Saithna [42] Case control study | To determine the key factors that influence RTS test scores, when using K-STARTS (a composite score) | 676 patients Casual to professional sport participation 476 male, 200 female Mean age (SD) = 27.6 (10.4) Graft type: HT autograft (624) or PT autograft (52) | ACL-RSI, QASLS, SHD, THD, CHD, SH, MICODT | NR | | - Significantly ↑ K-STARTS score in males ($p < 0.001$), younger patients ($p < 0.001$) patients with hamstring graft vs patella tendon graft ($p = 0.003$) and in patients who completed specific RTS programme ($p < 0.001$)<br>- Completion of specific RTS programme only factor that influenced K-STARTS score beyond minimal detectable change |
| Higbie, Kleihege [43] Retrospective cohort study | To compare self-reported and functional test performance, and re-injury rates in patients with high (≥33 %) versus low (<33 %) isometric hip abduction strength to body weight (BW) ratios on RTS testing post-ACLR | 528 participants 292 males, 236 females Mean age (SD) = 24.75 (11.74) Graft type: NR | Isokinetic knee extension and flexion strength, IKDC, ACL-RSI, flexion and extension ROM deficit, SL balance deficit, SHD, THD, CHD, 6MTH | NR | Isometric hip abduction strength | - 68.9 % had a low strength:BW ratio<br>- More females and ↑ BMIs were seen in the < 33 % group ($p < 0.05$)<br>- At RTS, the < 33 % group had ↓ IKDC ($p < 0.01$), ACL-RSI ($p < 0.01$), and isokinetic hamstring peak torque ($p = 0.04$)<br>- At 2 years, the < 33 % group reported ↓ SANE scores ($p = 0.05$), with no significant differences in re-injuries |
| Tallard, Hedt [44] Cross-sectional study | To assess the effect of fatigue on performance of various hop tests used in clinical rehabilitation settings | 21 participants 15 male, 6 female Mean age (SD) = 24.6 (9.3) Graft type: HT autograft, PT autograft, allograft (n=NR) | Isometric knee extension and flexion strength, SHD, THD, CHD, 6MTH, MRH, LRH, VJ | I | RTS test in fatigued state (FS) | - Differences between limbs were seen in all hop tests in NFS, with the ACLR limb showing reduced performance (↓5.4–9.1 %, $p < 0.05$)<br>- In FS, significant differences remained for the CHD (↓4.9 %), MRH (↓7.1 %), LRH (↓5.5 %), and VJ (↓10.0 %) ($p < 0.05$)<br>- Comparing NFS to FS, only the control limb showed decreased performance in the THD (↓7.4 %), CHD (↓8.7 %), and LRH (↓5.2 %) ($p < 0.05$) |

**Table 3** (*continued*)

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| [45] Prospective cohort study | To assess differences in strength, jump, CoD performance, and 3D biomechanics between athletes who reinjured their ACL (RI) and those without reinjury (NRI) after 2 years, and to evaluate if these differences predict reinjury | 88 male athletes Age = 18–35 Graft type: HT autograft (68), PT autograft (20) | isokinetic knee extension and flexion strength, SLCMJ, SHD, DLDJ, planned CoD, unplanned CoD, IKDC, Marx activity scale, ACL-RSI | I | Number of athletes who reinjured (RI) | - No differences were found in strength or performance on the ACLR side or in symmetry<br>- Biomechanical differences in the RI group were noted in the sagittal plane during the double-leg drop jump (ES = 0.59–0.64) and in frontal plane asymmetry during unplanned CoD (ES = 0.61–0.69)<br>- Multivariate regression showed limited ability to predict ACL reinjury (AUC 0.67–0.75). |
| Losciale, Ithurburn [46] Prospective cohort study | To evaluate the sagittal plane + knee joint loading patterns during a DL landing task in young athletes who passed or failed RTS tests post-ACLR and in uninjured athletes | 205 participants (57 control) 64 male, 141 female Mean age (SD) = 16.7 (2.77) Graft type: HT autograft (82), PT autograft (55), allograft (11) | Isometric knee extension strength, SHD, THD, CHD, 6MTH, IKDC, | I | vGRF, KFA, KEM | - 26.4 % passed all RTS tests<br>- 73.6 % failed at least one<br>- LSI cut off was not met by 41.9 % on quadriceps strength, 24.3 % on the SHD, 17.6 % on the THD LSI, 23 % on the CHD, 18.9 % on the 6MTH, and 47.3 % scored <90 on the IKDC<br>- The involved limb showed greater KFA at landing ($p < 0.001$), while the RTS-FAIL group had lower peak knee flexion during weight acceptance than control ($p < 0.001$)<br>- RTS-FAIL group had lower peak vGRF and internal KEM compared to RTS-PASS and CTRL ($p < 0.05$), with significant interactions for both measures ($p < 0.001$) |
| Hadley, Rao [16] Prospective cohort study | To assess how a 'Safer Return to Play Checklist' combining subjective and objective functional tests affects injury rates post-ACLR | 184 patients analysed 88 male patients, 96 female Mean age (SD); 19.2 (2.1)Graft typr: HT autograft (67), PT autograft (99), PT allograft (5), HT allograft (3), tibialis anterior allograft (1), HT autograft with allograft augmentation (9) | Effusion, ROM, laxity, thigh circumference, IKDC, FMS, SHD, THD, CHD, 6MTH, pro agility, movement assessment | NR | Number of pt who RTS, reinjury rate | - 146 patients passed the checklist, and 38 did not<br>- Among those who passed, 16.4 % sustained an injury to either knee, compared to 26.3 % from the group that did not pass ($p = 0.162$)<br>- In the group that passed, 5.5 % had an ipsilateral knee injury, compared to 18.4 % in the group that did not pass ($p = 0.017$) |
| Paterno, Thomas [47] Prospective, longitudinal, observational cohort study | To identify associations between knee-related confidence, meeting RTS criteria, and future second ACL injury risk | 159 participants 47 male, 112 female Mean age (SD); 17.2 (2.6) Graft type: NR | Isometric knee extension strength, SHD, THD, CHD, 6MTH, KOS-QOL, IKDC | I, II | Reinjury rate | - High knee-related confidence at RTS: 37.7 %<br>- 26.4 % met RTS criteria<br>- 22 % sustained second ACL injury post-RTS<br>- Higher proportion of confident participants met RTS criteria ($p = 0.001$)<br>- Confident participants meeting all RTS criteria had a 10x higher risk of second ACL injury ($p = 0.02$) |
| Ronden, Koc [48] Prospective cohort study | To determine the percentage of patients passing the BIA RTS test post-ACLR, and evaluate the association between passing | 103 patients 78 male, 25 female Mean age (SD); 19.75 (11) Graft type: PT autograft | DL and SL stability test, SL CMJ, CMJ, TL-PJ, OL-SY, TL-QF | I, II, "other" | | - 17.5 % passed RTS at 9 months after ACLR reconstruction<br>- PROMs were not statistically significant different between the pass and fail groups |

(*continued on next page*)

**Table 3** (*continued*)

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| | the RTS test and PROMS | | | | | |
| Ueda, Matsushita [49] Cross-sectional study | To examine whether patients who met 1 RTS criterion had higher psychological readiness than those who did not meet any of the criteria and if those who met more had higher psychological readiness | 144 patients 82 males, 62 females Mean age (SD); 25.9 (8.1) Graft type: HT autograft, PT autograft (n=NR) | Isokinetic knee extension and flexion strength, SHD, IKDC, ACL-RSI | NR | Knee laxity, heel-height difference | - 16.0 % met none, 18.7 % met 1, 23.6 % met 2, 24.3 % met 3, and 17.4 % met all 4 criteria<br>- Higher ACL-RSI scores associated with meeting hamstring strength LSI ($p = 0.002$), single-leg hop LSI ($p = 0.004$), and IKDC score ($p < 0.001$)<br>- Significant ACL-RSI score differences in none vs. 2, 3, or 4 criteria, and 1 vs 4 criteria ($p < 0.001$) |
| van Melick, Pronk [50] Prospective cohort study | To assess if second ACL injury rate 2 years after ACLR in those who RTS was associated with meeting RTS criteria, and to determine why athletes do not return to their preinjury level of sport | 175 athletes 123 male, 52 female Mean age (SD); 24 (6) Graft type: HT autograft | Isometric knee extension, flexion and hip abduction strength, eccentric hamstring strength, SLVJ, SHD, SH, SLHAH, CMJ (assessed with LESS), KOOS, K-SES | I | Level of sport resumed, reason for not resuming the same level of sport, reinjury rate | - 82 % completed the questionnaire, 97 athletes returned to pivoting sports, and 7 sustained a second ACL injury<br>- Meeting the hop test battery RTS criterion ($p = 0.047$) and SLHAH test ($p = 0.031$) significantly reduced the second ACL injury rate<br>- Combined RTS criteria did not show a significant association with the injury rate |
| Broman, Piussi [51] Cross-sectional study | To determine pass rates for clinician friendly RTS test batteries (CF) and the relationship between passing CF test batteries and passing gold standard RTS test batteries (GS) post-ACLR | 588 patients 285 male, 303 female Mean age (SD); 29.3 (9.8) Graft type: HT autograft (479), PT autograft (98) | Isokinetic knee extension and flexion strength, SLVJ, SHD, SH, K-SES, ACL-RSI | I, II | Tegner score | - The pass rate for the GS test battery was 28 %, and the CF test battery was 27 %<br>- Among the CF test batteries most closely related to the GS test, 49 % to 51 % of patients who passed each CF test battery also passed the GS test battery |
| Correa, Verhagen [52] Cross-sectional study | To compare the performance in RTS tests between athletes who were psychologically ready and not ready to return to unrestricted training or competitions post-ACLR | 35 male footballers Mean age (SD); 22 (7) Graft type: HT autograft | SL squat, CHD, MICODT, RAT, ACL-RSI | I | FPKPA, TSK-11, IKDC | - Those not ready to RTS had lower performance on the MICODT ($p < 0.001$) and RAT ($p = 0.004$) tests and higher FPKPA ($p < 0.001$)<br>- The not ready to RTS group had lower IKDC ($p < 0.001$) and higher TSK- 11 ($p < 0.001$) scores |
| Kiani Haft Lang, Mofateh [53] Cross-sectional study | To compare the neurocognitive functions between healthy controls and ACLR athletes who passed or failed RTS tests | 45 male footballers Mean age (SD); 23.6 (2.73) Graft type: NR | Isometric knee extension strength, SHD, THD, CHD, 6MTH, KOS-ADLS, GRS | I | CANTAB | - Neurocognitive deficits were seen in both groups when comparing CANTAB scores<br>- The RTS fail group had higher 5-choice movement time than both the RTS pass ($p = 0.02$) and healthy groups ($p = 0.01$) but had lower stop signal reaction time ($p = 0.03$ vs. healthy; $p = 0.001$ vs. pass) and successful stops ($p = 0.02$) |

**Table 3** (*continued*)

| Author (year) Study type | Objective | Population | Concept (RTS test/criteria) | Context (Sport type) | Other outcomes | Results |
|---|---|---|---|---|---|---|
| | | | | | | - Both ACLR groups showed greater between errors ($p < 0.001$, $p = 0.008$) and reaction latency ($p = 0.002$, $p = 0.01$) than the healthy group |
| Maestroni, Turner [54] Cross-sectional study | To examine the utility of the TSA in aiding RTS decision-making post-ACLR | 95 male footballers Mean age (SD); 24.45 (7.7) Graft type: HT autograft (19), PT autograft (76) | Isokinetic knee extension and flexion strength, DL CMJ, SL CMJ | I | TSA | - large difference in TSA score between the ACLR and uninjured groups ($d = 0.84$; $p < 0.0001$)<br>- For each increase of 1 unit in the TSA, the odds of belonging to the ACLR group decreased by 74 % (95 % CI, 0.19–0.56)<br>- The frequency of reinjured players was higher in the low (4/7) TSA tertile compared with the medium (2/7) and high (1/7) |
| Weber, Müller [55] Cross-sectional study | To investigate the relationship between LSI of hop tests as an indication of performance and the total score of a movement quality assessment | 34 participants 18 males, 16 females Mean age (SD); 24.2 (8.2) Graft type: HT autograft (29), QT autograft (5) | VJ, SHD, SH | NR | "Quality First" score | - The correlation test between the LSI and the "Quality First" score showed no correlation for all three jumps ($r = -0.1$–$0.02$, $p = 0.65$–$0.93$) |

Note: ACL-RSI = Anterior Cruciate Ligament Return to Sport after Injury Scale, AUC = Area Under the Curve, BW = Body Weight, CHD = Cross-Over Hop for Distance, CoD = Change of Direction, CMJ = Countermovement Jump, DL = Double Leg, DJ = Drop Jump, EPIC = Estimated Pre-Injury Capacity, FMS = Functional Movement Screen, GRS = Global Rating of Symptoms, H:Q ratio = Hamstring-to-Quadriceps Ratio, IKDC = International Knee Documentation Committee, LSI = Limb Symmetry Index, MVIC = Maximum Isometric Volitional Contraction, MRH = Medial Rotation Hop, NR = Not Reported, RFD = Rate of Force Development, RSR = Reactive Strength Ratio, SL = Single Leg, THD = Triple Hop for Distance, TCpk = Total Concentric Peak, vGRF = Vertical Ground Reaction Force, YBT = Y-Balance Test, KOS-ADLS = Knee Outcome Survey-Activities of Daily Living Scale, 6MTH = 6-Month Follow-up, MICODT = Modified Illinois Change of Direction Test, RAT = Return to Activity Test, K-SES = Knee-Specific Evaluation Scale, LESS = Landing Error Scoring System, SLHAH = Single Leg Hop and Hold, OL-SY = One Leg Speedy Jump, TL-QF = Two Leg Quick Feet, TL-PJ = Two Leg Plyometric Jump, PROMS = Patient-Reported Outcome Measures, PT = Patella tendon, QT = Quadriceps tendon, HT = Hamstring tendon, SHD = Single Hop Distance, ROM = Range of Motion, KFA = Knee Flexion Angle, VJ = Vertical Jump, LRH = Lateral Rotation Hop, QASLS = Qualitative Assessment of Single-Leg Landing, pedi-IKDC = Pediatric-IKDC, TSK-11 = Tampa Scale of Kinesiophobia (11-item version).

Finally, three studies assessed hip strength [40,43,50]. Two studies measured hip abduction MVIC with an LSI of ≥90 % as the RTS cut-off [40,50], while one study used a percentage of body weight (33 %) [43]. One study also used hip adduction MVIC, setting an LSI cut-off of ≥90 % [40].

### 4.3. Jump and hop performance

Over three quarters of the studies (79 %) used a hop test battery with one or more horizontal hop tests, including 6 m timed, single, triple, and triple crossover hops [1,14,16,17,28,29,31–34,36–46,49–53]. One study also assessed horizontal hop performance under fatigued conditions [44]. Nearly all the studies assessing horizontal hop tests set a pass threshold of ≥ 90 % LSI (96 %) [1,14,16,17,28,29,31,32,34,36,37,39–43,45,46,49–53]. In addition to hop-for-distance tests, four studies included the side-hop test with a ≥ 90 % LSI cut-off [37,41,50,51].

Several studies also included vertical jump tests. Seven studies described using either a double leg countermovement jump (CMJ) or a single-leg vertical jump (VJ) in RTS decision-making [34,35,45,48,50,54,56]. There is variability in pass criteria, with cut-off thresholds ranging from 80 % to 90 % for jump height or LSI. One study used a double and single leg CMJ as part of a composite score (TSA), as previously described [54]. Additionally, one study used a single leg drop jump (DJ) to assess reactive strength indexes (RSI), using ≥90 % LSI as an RTS cut-off [45]. RSI is a measure of an individual's reactive strength capabilities derived from ground reaction time and flight time [57].

Finally, four studies assessed a jump and landing task using the qualitative Landing Error Scoring System (LESS) [31,37,41,50]. Three of these studies had an RTS cut-off score of less than five [31,37,41,50], and the remaining study used a score of less than six [50].

### 4.4. Biomechanical assessment

Two studies assessed gait using three-dimensional (3D) motion capture technology [28,45]. Jump and landing kinematics were examined in three studies, with one utilising 3D motion capture [45], and two employing the LESS [16,42,55].

Four studies assessed balance and stability [34, 48), with two using double and single leg stability tests, setting different LSI thresholds for the non-dominant (≥80 %) and dominant legs (≥90 %) [34,48]. The other two studies utilised the Y-Balance Test (YBT) [40,43]. A final study used the Functional Movement Screen (FMS), a standardised screening tool designed to assess movement patterns and identify potential weaknesses, imbalances, or mobility issues [16].

### 4.5. Change of direction and agility

Four studies evaluated CoD in the context of RTS [16,42,45,52]. Two studies used the Modified Illinois Change of Direction Test (MICODT) [42,52], one employed the Pro-Agility Test [16], one incorporated a 90 degree planned and unplanned direction change test [45], and one used a running T-Test [17]. A cut-off criterion for RTS was described in the study using the T-Test, which reported a threshold of ≥90 % LSI for time completion.

Agility was assessed in three studies [34,48,52]. Two studies employed the Two-Leg Quick Feet Test (TL-QF), the One- and Two-Leg Plyometric Jump Test (O(T)L-PJ), and the One-Leg Speedy Test (OL-SY), using LSI thresholds of ≥80 % for the non-dominant leg and ≥90 % for the dominant leg [34,48]. The third study utilised the Reactive Agility Test (RAT) [52].

### 4.6. Patient-reported measures

Patient-reported outcome measures (PROMs) were described in 62 % of the included studies [16,30,31,34,36,37,41,43,45–49,52,53,58]. The International Knee Documentation Committee (IKDC) questionnaire was the most frequently used PROM, featuring in 15 studies [16,30,31,34,36,37,41,43,45–49,52,53], followed by the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale, which was reported in 10 studies [30,31,36,37,41,42,45,48,52,56]. RTS cut-off thresholds ranged from ≥85 to ≥95 for the IKDC, and >55 to >75 for the ACL-RSI.

Other PROMs used in the studies included in this review are the Tampa Scale of Kinesiophobia (TSK) [30,51], the Knee Outcome Survey-Activities of Daily Living Scale (KOS-ADLS) [1,28,29,32], the Global Rating Scale (GRS) [1,28,29,32,59], the Global Knee Rating Scale (GKRS) [53], and the Marx Activity Scale [45]. Only two studies described specific cut-off values for RTS: a TSK (−11) score of < 7.5 [51] and GRS or KOS-ADLS scores of >90 % [32].

## 5. Discussion

### 5.1. Time

The remodelling of the ACL graft may take from six to 36 months [60], though exact timelines are debated [61]. This may explain why few studies incorporate time as an RTS criterion. Although earlier studies used accelerated rehabilitation approaches to target RTS at six months [27,28], more recent evidence has reshaped practices, establishing nine months as the recommended minimum RTS timeframe [45,61,62].

Substantial evidence emphasises the importance of delaying RTS to reduce reinjury risk. Beischer, Gustavsson [63] found that young athletes who RTS before nine months face a sevenfold higher risk of a second injury, even after achieving 90 % knee strength LSI. Grindem, Snyder-Mackler [1] reinforce this, demonstrating that each additional month of RTS delay between six and nine months decreases reinjury risk by 51 %.

Nevertheless, some experts advocate for more conservative timelines for high-risk populations. Nagelli and Hewett [3] recommend delaying RTS for up to two years in certain groups, such as females, highlighting the importance of tailoring RTS protocols to individual risk profiles.

### 5.2. Strength

Strength measurement is commonly used for RTS decision-making. IKD is considered the gold standard for strength assessment and is the most frequently used method in this review [64]. However, handheld dynamometry (HHD) and portable fixed dynamometry (PFD) are more commonly used in clinical practice to assess MVIC due to their affordability and convenience [65,66]. PFD has demonstrated high test–retest reliability, however HHD is considered poor in this respect [67]. However, both methods are specific to the joint angle tested, therefore the results should be interpreted with caution.

The most common strength cut-off for RTS found in this review (≥90 % LSI at 60 degrees per second) is supported by the wider literature [1,17,68]. However, several researchers recommend higher LSI cut-offs for athletes returning to level I sports [69,70], a stance supported by recent clinical guidelines suggesting 100 % symmetry for elite athletes returning to pivoting sports [61]. As uninjured athletes demonstrate an LSI of 96 % [69], the widely adopted ≥90 % LSI cut-off may prove insufficient for informing RTS decisions.

Moreover, there is growing criticism of LSI in RTS decision-making due to reduced contralateral limb strength following ACLR surgery, affecting its accuracy as an RTS measure [71–73]. Wellsandt, Failla [32] found that only 28.6 % of athletes who achieved ≥90 % strength LSI post-ACLR reached their estimated pre-injury capacity (EPIC). To improve the validity of LSI, baseline measurements pre-surgery, and setting EPIC-based thresholds are recommended. Alternatively, Buckthorpe, Tamisari [74] support using body weight percentages, suggesting that those returning to pivoting sports require ≥90 % LSI and a one-repetition maximum (1RM) of at least twice body weight on a unilateral leg press.

Finally, H:Q ratio is rarely used to inform RTS decision-making, likely due to conflicting evidence for its utility. Although research suggests that H:Q ratio is not an independent risk factor for primary ACL injuries [75], it is associated with an increased risk of graft rupture [17]. As the hamstring counteracts anterior tibial translation caused by quadriceps contraction, a lower H:Q ratio could indicate a higher risk of re-injury [76]. Supporting this, Kyritsis, Bahr [17] found a 10.6-fold increase in graft rupture risk for every 10 % decrease in H:Q ratio among male athletes, suggesting it is an important assessment measure during RTS testing.

### 5.3. Jump and hop performance

The literature links hop test batteries to a reduced risk of graft or contralateral ACL rupture [1,18,77]. Whilst there is agreement across these studies for the inclusion of a horizontal hop test battery, inconsistencies exist in how these tests are used to assess knee function, identify injury risk, and predict rehabilitation outcomes or performance. Various factors contribute to these inconsistencies, including testing errors which impact reliability [73], and as they primarily reflect hip and ankle function [78,79].

Although the ≥90 % LSI threshold for horizontal hop tests is widely accepted for RTS clearance, some researchers suggest this is insufficient given the decline in contralateral limb performance post-ACLR [32]. Davies, Myer [73] argue four horizontal hop tests may not be more effective at detecting abnormalities than two and recommend focusing on single and triple hop tests. Kotsifaki, Van Rossom [80] demonstrate that the landing phase of these tests are sensitive for evaluating knee energy absorption efficiency.

Furthermore, traditional hop tests fail to consider motor coordination and neurocognitive demands inherent in sports [81]. To address this, Simon, Millikan [82] augmented these hop tests with visually mediated response time using a light-timing system to introduce neurocognitive, reactive, and anticipatory components under dual-task conditions. By performing hops under both standard and neurocognitive conditions, a dual-task cost can be calculated, quantifying the degree of neurocognitive reliance. Grooms, Chaput [81] propose that a dual-task cost exceeding 10 % may indicate heightened neurocognitive reliance, and therefore an increased risk of re-injury. This enhances the ecological validity of hop testing by simulating sport-specific scenarios, targeting cross-modal neural processing, and supporting more informed RTS decisions.

Finally, advanced technology such as force platforms, wireless sensors, and 3D motion capture has facilitated the use of tests such as the CMJ and single-leg VJ. These are more sensitive to detecting asymmetries compared to horizontal hop tests, partly due to the higher knee forces generated [80,83]. They are becoming the gold standard for identifying kinematic and kinetic deviations [84,85]. A recent study by Pontillo, Hines [85] found that individuals post-ACLR showed significant deficits in the explode and drive phases of the force–time curve during vertical jump tests, as well as load-to-explode ratios. This highlights a reduced ability to generate, sustain, and transfer force efficiently during explosive movements. Importantly, these deficits were predictive of injury in this study. Nevertheless, their limited adoption in this review may reflect the expense and training required for the use of specialised equipment.

**Table 4**
RTS criteria themes.

| Criteria | Detail | References |
|---|---|---|
| Time | ≥4 months | |
| | Level III | [42] |
| | ≥6 months | [27,28] |
| | Level II | [42] |
| | ≥9 months | |
| | Level I | [42] |
| Strength | **Knee extension MVIC** | |
| | 90° flexion | |
| | Pre-injury level | [27] |
| | ≥80 % LSI | [33] |
| | ≥85 % LSI | [30] |
| | ≥90 % LSI | [29,32,46,53] |
| | 60° flexion | |
| | ≥90 % LSI | [47,50] |
| | **Knee extension IKD** | |
| | 60°/s | |
| | ≥85 % LSI | [38,43] |
| | ≥90 % LSI | [1,14,17,31,35,37,41,45,49] |
| | 260 % (±40 %) BM | [35] |
| | >3.0 Nm/kg | [37,41] |
| | Composite score (TSA) | [54] |
| | 90°/s | |
| | ≥90 % LSI | [31,51] |
| | >3.0 Nm/kg | [31] |
| | 180°/s | |
| | ≥80 % LSI | [33] |
| | ≥85 % LSI | [43] |
| | ≥90 % LSI | [31,37,41] |
| | 300°/s | |
| | ≥85 % LSI | [43] |
| | ≥90 % LSI | [37,41] |
| | Pre-injury level | [27] |
| | Not reported | [44] |
| | **Knee flexion MVIC** | |
| | ≥85 % LSI | [30] |
| | ≥90 % LSI | [40,50] |
| | **Knee flexion eccentric** | |
| | ≥90 % LSI (HHD) | [50] |
| | **Knee flexion IKD** | |
| | 60°/second | |
| | ≥90 % LSI | [31,35,37,41,49] |
| | Composite score (TSA) | [54] |
| | 90°/second | |
| | ≥90 % LSI | [31,34,51] |
| | 180°/second | |
| | ≥90 % LSI | [31,37,41,43] |
| | 300°/second | |
| | ≥90 % LSI | [37,41,43] |
| | **H:Q ratio (%)** | |
| | IKD 300°/s | |
| | >55 for females, >62.5 % for males | [31,37,41] |
| | MVIC | |
| | ≥85 % LSI | [30] |
| | **Hip abduction MVIC** | |
| | >33 % BW | [43] |
| | ≥90 % LSI | [40,50] |
| | **Hip adduction MVIC** | |
| | ≥90 % LSI | [40] |
| Jump and hop performance | **Distance hop tests (≥1 of SHD, THD, CHD, 6MTHT); non-fatigued state** | |
| | ≥100 % LSI | [44] |
| | ≥90 % LSI | [1,14,16,17,28,29,31,32,34,36,37,39,40,41,42,43,45,46,49,50,51,52,53] |
| | ≥90 % EPIC | [32] |
| | ≥85 % LSI | [30,38,42] |
| | ≥80 % LSI | [42] |
| | "Satisfactory" | [33] |

**Table 4** (*continued*)

| Criteria | Detail | References |
|---|---|---|
| | **THD** | |
| | CT, FT, RSR ≥ 90 % LSI | [39] |
| | **Distance hop tests (≥1 of SHD, THD, CHD, 6MTHT); fatigued state** | |
| | ≥100 % LSI | [44] |
| | **Side hop test** | |
| | ≥90 % LSI | [37,41,50,51] |
| | **DLCMJ** | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [48] |
| | Composite score (TSA) | [54] |
| | **SLCMJ/SLVJ/SLJ** | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [48] |
| | ≥90 % LSI | [34,35,45,50] |
| | >17 cm (±4 cm) | [35] |
| | Cut-off not reported | [51] |
| | Composite score (TSA) | [54] |
| | **SLDJ** | |
| | ≥90 % LSI | [45] |
| | **SLHAH** | |
| | ≥90 % of SLHD test | [50] |
| | **LESS** | |
| | <5 | [31,37,41] |
| | <6 | [50] |
| Biomechanical assessment | **Running/gait/CoD kinematics** | |
| | 3D motion capture | [28,45] |
| | **Jump/landing** | |
| | 3D motion capture | [45] |
| | Qualitative score | [42,55] |
| | ≥80 % LSI | [16] |
| | **Balance/stability** | |
| | DLST, SLST | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [34,48] |
| | YBT(−LQ) | |
| | ≥90 % LSI | [40] |
| | Cut-off not reported | [43] |
| | **FMS** | |
| | >14 | [16] |
| CoD and Agility | **CoD** | |
| | MICODT | [42,52] |
| | Pro-agility | [16] |
| | 90° planned and unplanned | [45] |
| | Running *t*-test | |
| | ≥90 % LSI | [17] |
| | **Agility** | |
| | TL-QF (s) | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [34,48] |
| | OL-PJ (s) | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [34,48] |
| | OL-SY (s) | |
| | ≥80 % LSI (non-dominant leg), ≥90 % LSI (dominant leg) | [34,48] |
| | RAT | [52] |
| Patient reported measures | **ACL RSI** | |
| | >55 | [31,42,48] |
| | >56 | [37,41] |
| | >60 | [52] |
| | >65 | [14,42] |
| | >75 | [42,51] |
| | Cut-off not reported | [30,45] |
| | **IKDC** | |
| | ≥85 | [14,48] |
| | ≥90 | [46,47,49] |
| | ≥95 | [36] |
| | within 15 % of healthy, gender- and age-matched controls | [37,41] |
| | Cut off not reported | [16,30,31,34,43,45,52,53] |
| | **TSK(−11)** | |
| | >7.5 | [51] |
| | Cut-off not reported | [30] |
| | **KOS-ADLS** | |
| | >90 % | [32] |
| | Cut-off not reported | [1,28,29] |

(*continued on next page*)

**Table 4** (*continued*)

| Criteria | Detail | References |
|---|---|---|
| | **KOS-QOL** | |
| | **GRS** | [1,28,29] |
| | >90 % | [32] |
| | Cut-off not reported | [47] |
| | **GKRS** | |
| | Cut-off not reported | [53] |
| | **Marx Activity Scale** | |
| | Cut-off not reported | [45] |

Note: ACL RSI = Anterior Cruciate Ligament Return to Sport Index, BW = Body Weight, CHD = Crossover Hop for Distance, CoD = Change of Direction, CT = Contact Time, DLCMJ = Double-Leg Countermovement Jump, DLST = Double-Leg Stance Test, EPIC = Estimated Pre-injury Capacity, FMS = Functional Movement Screen, FT = Flight Time, GKRS = Global Knee Rating Scale, GRS = Global Rating Scale, H:Q = Hamstring to Quadriceps ratio, HHD = Hand-Held Dynamometer, IKDC = International Knee Documentation Committee, IKD = Isokinetic Dynamometer, KOS-ADLS = Knee Outcome Survey-Activities of Daily Living Scale, KOS-QOL = Knee Outcome Survey-Quality of Life, LESS = Landing Error Scoring System, LSI = Limb Symmetry Index, MICODT = Modified Illinois Change of Direction Test, MVIC = Maximal Isometric Voluntary Contraction, MVIC = Maximal Voluntary Isometric Contraction, OL-PJ = One-Legged Plyometric Jump Test, OL-SY = One-Legged Speedy Jump Test, RAT = Reactive Agility Test, RSR = Reactive Strength Ratio, SHD = Single Hop for Distance, SLCMJ = Single-Leg Countermovement Jump, SLDJ = Single-Leg Drop Jump, SLHAH = Single-Leg Hop and Hold, SLHD = Single-Leg Hop for Distance, TL-PJ = Two Leg Plyometric Jump, SLST = Single-Leg Stability Test, SLCMJ = Single-Leg Countermovement Jump, TSK = Tampa Scale for Kinesiophobia, TSA = -Total Score of Athleticism, 6MTHT = Six-Meter Timed Hop Test, THD = Triple Hop for Distance, TL-QF = Two Leg-Quick Feet, YBT(–LQ) = Y-Balance Test (Lower Extremity).

### *5.4. Biomechanical assessment*

Reliance on high-tech tools is similarly evident in studies assessing biomechanics using 3D motion capture. King, Richter [45] found interlimb differences in sagittal plane mechanics during drop jump tests, even in athletes who passed traditional RTS assessments. By contrast, Di Stasi, Logerstedt [28] found only athletes who failed a similar RTS assessment at six months post-ACLR demonstrated significant asymmetries in sagittal plane kinematic and kinetic variables at the knee.

While biomechanical assessments provide valuable insights for RTS decision-making, the practical limitations of the technology required make them less feasible for widespread application. Consequently, researchers have explored alternatives to bridge this gap. Franck, Saithna [42] introduced the Qualitative Assessment of Single-Leg Landing (QASLS), which evaluates movement strategies during SL jump and landing tasks as part of a composite score. Hadley, Rao [16] proposed an assessment focusing on hip stability, shock absorption, and pelvic and trunk control. Weber, Müller [55] developed a qualitative tool to assess kinematics during three single leg hop and jump tasks. While these tools demonstrated reliability, the inherent subjectivity of qualitative measures presents accuracy concerns [86].

Balance assessments are suggested to help RTS decision-making due to evidence that athletes post-ACLR exhibit reduced postural stability in SL stance compared to uninjured controls, even when meeting other RTS criteria [87]. However, this evidence derives from assessments using devices that objectively measure postural control under dynamic stress. Reliance on such equipment to assess balance may explain the infrequent inclusion of these assessments in this review.

Other examples of balance assessment that require minimal equipment include one- and two-leg balance tests and the YBT. These tests may reveal neuromuscular deficits not always detectable through strength or hop tests. Oleksy, Mika [88] demonstrated that footballers post-ACLR scored significantly lower on the YBT compared to uninjured players. However, others highlight that athletes often employ varied movement strategies during the YBT, limiting its ability to provide meaningful insights into joint kinematics or ACL reinjury risk [89]. Moreover, balance tests fail to replicate the high-velocity, multidirectional demands of sports, reducing their specificity and applicability, therefore limiting their relevance to RTS decision-making.

### *5.5. Change of direction and agility*

Most ACL injuries occur during non-contact CoD movements [90–92], suggesting that RTS assessments may be inadequate if these movements are not addressed. Welling and Frik [93] emphasise the importance of RTS assessments that better reflect pivoting sports. They argue that without on-field assessments, clinicians have "incomplete information about a patient's physical capacity" (p. 6). This is supported by Kyritsis, Bahr [17], who included a timed running T-test in their RTS criteria, failure of which showed a fourfold increase in the risk of graft rupture. This test, together with the Pro-Agility and MICODT, are examples of planned CoD tests. While they clearly have merit, they may not capture the reactive and neurocognitive demands of sport, where athletes adapt their movements based on unpredictable situations [94]. As mentioned, RTS carries environmental, cognitive and physical demands, which researchers suggest RTS criteria should better reflect [81].

Correspondingly, unplanned CoD movements have been shown to mimic knee mechanics associated with ACL injury risk [95]. Knee loads during unplanned movements can be twice those of planned CoD movements [93]. King, Richter [45] and Correa, Verhagen [52] both include unplanned CoD tests in their studies; the unplanned 90-degree CoD test and the RAT. The former necessitates the athlete to react to a timing light, while the latter requires the athlete to respond to the assessor's cue during a sprint. Another example is demonstrated by Wilk, Thomas [96] in their theoretical model of reactive agility assessment, including variations of the running T-test and the L-test, where the direction of movement is instructed during a sprint. Incorporating on-field reactive tests in RTS assessments may better reflect the neurocognitive demands of sport, particularly for level I athletes, marking a more comprehensive approach, reflecting the specific demands of sport.

Nevertheless, reactive agility and CoD assessments have limitations, reflected in the low proportion of studies including these for RTS decision-making. These tests primarily evaluate performance based on interlimb timing, which may not detect underlying biomechanical asymmetries [17,96].

As discussed, the widespread use of 3D motion capture is not feasible. Alternatives for CoD assessment are qualitative tools like the Cutting Movement Assessment Score (CMAS) [97], which has been validated for assessing knee abduction moments and whole-body kinetics. The CMAS requires video analysis of an agility test and has demonstrated excellent intra-rater reliability. Notwithstanding the issues associated with subjective measures, when used alongside interlimb timing assessments, tools like this could provide a more robust evaluation of reactive agility to help guide RTS.

### *5.6. Patient-reported measures*

PROMs are included in most of the studies, reflecting the recommendations of clinical guidance [61,62]. The ACL-RSI and IKDC are often used to assess subjective readiness to RTS [61,98,99], a trend seen in this review. Other PROMS, such as TSK and GRS, are occasionally used, however due to their low validity in patients with an ACL injury, ACL-RSI and IKDC are considered better measures of psychological readiness [100].

Webster and Feller [14] identified strong associations between self-reported measures of psychological readiness (IKDC and ACL-RSI) and RTS at 12 months post-ACLR, and individuals with higher scores demonstrate increased chances of returning to pre-injury performance [66]. Furthermore, Müller, Krüger-Franke [30] found that athletes who did not RTS had significantly lower ACL-RSI scores at six and 12 months. This finding matches other studies, highlighting fear of injury as a common reason for unsuccessful RTS [99,101,102]. Current research supports the continued use of these measures to identify low scores at critical milestones for clinicians to intervene and address concerns.

## 6. Recommendations

Drawing on the findings of this review, RTS following an ACLR should be based on a comprehensive, criteria-based approach that extends beyond arbitrary timelines. While a minimum delay of nine months is supported by robust evidence, this should be a consideration rather than a universal standard. High-risk groups, such as young or female athletes, may benefit from even more conservative timelines, potentially up to 18–24 months, particularly where psychological readiness or neuromuscular deficits persist.

Strength testing should remain a cornerstone of RTS decision-making. IKD provides ideal standardisation, but where unavailable, PFD is an acceptable alternative. However, $\geq$90 % LSI alone is not sufficient. The author recommends including 1RM measures adjusted to body weight (e.g., $\geq 2\times$ body weight unilateral leg press) and, where possible, referencing pre-injury baselines.

Functional testing should not rely solely on traditional horizontal hop tests. Incorporating vertical jump testing using force platforms, where available, adds sensitivity to detect asymmetries. If unavailable, single- and triple-hop tests remain useful, ideally performed under dual-task or reactive conditions to simulate sport-specific cognitive demands.

Agility and CoD assessments are essential, especially for athletes in level I sports. While planned CoD tests (e.g., T-test, MICODT) provide a performance baseline, incorporating reactive CoD tests such as the RAT or reactive 90-degree CoD test better replicate sport-specific demands. In the absence of advanced technology, clinicians can use dual task hop tests or reactive CoD drills to introduce neurocognitive load. Tools like the CMAS offer valuable insight into movement quality using only video footage, making them practical for wider clinical application.

Psychological readiness is critical. The ACL-RSI and IKDC should be included at six, nine, and 12 months post-op, with a low score triggering psychological intervention. Structured RTS counselling or gradual exposure to sport-specific tasks can be implemented in those with low confidence or elevated fear of reinjury. A minimum ACL-RSI score of $\geq$65 to 70 may serve as a clinical threshold for RTS.

Finally, RTS protocols must be individualised and multidisciplinary, involving collaboration between the patient, surgeons, physiotherapists, sports physicians, and where appropriate, psychologists. Decisions should never be based on a single metric or time-based cutoff but rather a composite profile of physical, functional, biomechanical, and psychological readiness.

## 7. Strengths and limitations

This scoping review has several limitations to consider when applying the findings in clinical or research settings. By design, scoping reviews do not require a formal assessment of bias or methodological quality, limiting the ability to critically evaluate the strength and reliability of the evidence. While the review offers an overview of published RTS research, it omits innovative or practice-based approaches.

Furthermore, limitations in the search strategy, including variations in RTS terminology and database coverage, could have resulted in missed studies. The exclusion of clinical commentaries and reviews, whilst intended to minimise interpretive and selection bias, may have inadvertently omitted valuable studies. Additionally, excluding non-English language publications likely overlooked relevant research.

Nonetheless, this scoping review offers a broad synthesis of evidence on RTS decision-making, providing valuable insights into current practices and highlighting key themes. It follows a rigorous methodology, ensuring consistency and reliability, and the identification of literature gaps provides clear direction for future research.

## 8. Conclusion

This scoping review underscores the multifaceted nature of RTS decision-making following ACLR surgery. Evidence supports delaying RTS to at least nine months to minimise reinjury risk, though recommendations vary for high-risk populations. Strength assessments, particularly those using isokinetic dynamometry, remain central to RTS protocols, but the limitations of LSI highlight the need for more robust metrics. Clinicians should interpret LSI with caution and consider supplementing it with bodyweight-relative strength and pre-injury data, where available. In resource-limited settings, PFD can be a viable alternative to IKD.

Functional tests, including hop and balance, offer valuable insights but often lack specificity for sport demands. Emerging technologies, such as force platforms and 3D motion capture, improve sensitivity to biomechanical deficits, but contain accessibility restrictions, while innovations in agility, CoD and neurocognitive assessments bring greater relevance to sport-specific RTS evaluation.

Finally, psychological readiness plays a critical role in successful RTS, emphasising the need for interventions to address psychological barriers. Routine use of ACL-RSI and IKDC can help clinicians identify athletes needing psychological support.

Collectively, these findings highlight the importance of individualised, multidisciplinary approaches that integrate physical, functional, and psychological considerations. Clinicians should adopt a layered RTS framework incorporating strength benchmarks, sport-specific functional assessments, and psychological screening to optimise outcomes and reduce reinjury risk following ACLR surgery.

## CRediT authorship contribution statement

**Alexander J. Wright:** Writing – original draft. **Duncan Reid:** Writing – review & editing. **Geoff Potts:** Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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