Unilateral tests of lower-limb function as prognostic indicators of future knee-related outcomes following anterior cruciate ligament injury: a systematic review and meta-analysis of 13 150 adolescents and adults

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ABSTRACT

Objective To investigate the prognostic capacity of individual hop tests, hop test batteries and other unilateral functional performance tests following anterior cruciate ligament (ACL) injury.
Design Systematic review with meta-analysis.
Data sources Six databases searched up to June 2021.
Eligibility criteria Studies reporting associations between unilateral lower-limb function (eg, hop tests) following ACL injury and future (≥3 months) knee-related outcomes.
Results Of 42 included studies (13 150 participants), all assessed the single-forward hop test and 32 assessed a repeated-forward hop test (crossover hop, triple hop, 6m-timed hop), mostly within a year after ACL injury/reconstruction. Results of meta-analyses indicated that higher single-forward and repeated-forward hop limb symmetry were associated with higher odds of return-to-sport 1–3 years post-ACL reconstruction (OR 2.15; 95% CI 1.30 to 3.54; OR 2.11; 95% CI 1.23 to 3.60, respectively). Higher single-forward and repeated-forward hop limb symmetry was associated with better self-reported symptoms and function 1–37 years after ACL injury (OR 2.51; 95% CI 1.62 to 3.88; OR 4.28; 95% CI 1.65 to 11.08, respectively). Higher limb symmetry on a repeated-forward hop does not appear to be associated with higher odds of successful rehabilitation without ACL reconstruction (OR 1.51; 95% CI 0.94 to 2.44). Achieving ≥90% limb symmetry on the single-forward hop was associated with reduced odds of knee osteoarthritis 5–37 years after ACL injury (OR 0.46; 95% CI 0.23 to 0.94).
Conclusion Very low certainty evidence suggests single-forward and repeated-forward hop tests are prognostic indicators for important knee-related outcomes in individuals after ACL injury and may help stratify individuals at risk of poor outcomes to target rehabilitation interventions.
PROSPERO registration number CRD42018092197.

WHAT IS ALREADY KNOWN?

⇒ Unilateral measures of lower-limb function are recommended for return to sport clearance after anterior cruciate ligament (ACL) injury.
⇒ Hop test results are important indicators of functional recovery after ACL injury.

WHAT ARE THE NEW FINDINGS?

⇒ Very low certainty evidence indicates that a higher Limb Symmetry Index for hop tests (irrespective of specific hop test assessed) is a prognostic indicator for returning to competitive sport but may not infer a reduction of future injury risk.
⇒ Very low certainty evidence indicates that higher Limb Symmetry Index on single-forward, repeated-forward hop tests and the one-leg rise test are prognostic for better self-reported symptoms and function 1–37 years after ACL injury.
⇒ Very low certainty evidence indicates that a battery of hop tests is associated with reduced odds of knee reinjury though sensitivity analysis revealed conflicting findings with different test batteries.
⇒ Very low certainty evidence indicates that achieving ≥90% Limb Symmetry Index on a single-forward hop test between 6 months and 4 years after ACL injury were associated with reduced odds of future knee osteoarthritis.

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is a devastating diagnosis for athletes given the lengthy rehabilitation, absence from sports participation and high risk of early-onset osteoarthritis (OA).[1] The primary target of rehabilitation, irrespective of operative or non-operative management, is addressing lower-limb muscle strength, neuromuscular control and functional deficits that can otherwise persist for many years.[2] Functional performance testing is recommended during ACL injury rehabilitation to assess lower-limb function and guide return to sport.[3 4] Functional performance measures also provide valuable feedback to enhance patient motivation and exercise adherence,[5 6] integral to achieving desired outcomes following ACL injury and reconstruction.[7]

Hop tests are common performance measures used during ACL injury and reconstruction rehabilitation[8] and given that they require few resources and are quick to administer, are widely used clinically. Many hop tests have been described (eg, hop for distance (single-forward hop), triple hop, crossover hop), with all having excellent inter-rater reliability.[9–11] Hop tests underpin return to sport

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test batteries and meeting acceptable standards (eg, ≥90% Limb Symmetry Index (LSI)) is a goal of rehabilitation.[3]

Some findings suggest that lower-limb functional test scores assessed during and following ACL rehabilitation are associated with future knee-related outcomes.[12–14] For example, poor hop test performance is associated with worse future quality of life and fewer one-leg rises is related to development of radiographic OA.[15 16] However, other studies found no association between functional performance and future outcomes.[17–19] Systematic review evidence is also conflicting. Passing a return to sport test battery (including hop tests) is shown to lower future reinjury risk in some reviews[20 21] but not others,[22] though it is hard to compare findings due to variability in the components of such batteries as well as their criteria for 'passing'.[23] The prognostic capacity of tests of lower-limb function on future knee-related outcomes has not been synthesised systematically. Such evidence synthesis and critical appraisal may inform clinical management following ACL injury and identify those at risk for worse outcomes to implement preventive strategies. This systematic review aimed to investigate the prognostic capacity of individual hop tests, hop test batteries and other unilateral functional performance tests on knee-related outcomes following ACL injury.

METHODS

Search strategy and selection criteria

This systematic review is reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement[24] and registered prospectively on PROSPERO (CRD42018092197). We performed an electronic search of six databases (MEDLINE, EMBASE, CINAHL, Scopus, Web of Science, SPORTDiscus) without language restriction from inception to June 2021. The searches combined MeSH terms and keywords related to ACL and hop tests (online supplemental appendix 1). Studies reporting the association (or lack thereof) between unilateral lower-limb functional performance following ACL injury and future outcomes were eligible for inclusion. Specifically, included studies had to: (1) report on individuals after ACL injury treated operatively or non-operatively (no limits to age or type of surgery); (2) include a unilateral functional test (quantitative measure); (3) able to be assessed in a clinical setting (ie, no laboratory or video-recording equipment needed) and (4) report the outcome ≥3 months following functional testing. We also included studies that assessed a hop test battery (ie, multiple hops combined into one overarching assessment). As it is common for hop test batteries to incorporate a measure of muscle strength,[25 26] we also included studies that evaluated a hop test battery with muscle strength assessment as part of that battery. Cohort studies (prospective and retrospective), case–control studies and randomised controlled trials (RCTs) were eligible for inclusion. Any knee-related outcomes were considered (eg, patient-reported, return to sport, knee reinjury, OA).

Two reviewers (TJW and AGC) independently assessed all titles and abstracts for eligibility and screened reference lists of all relevant articles identified. When eligibility could not be confirmed from title and abstract, full texts were reviewed. Disagreements between reviewers were discussed until consensus, as described previously.[27] During screening of titles, abstracts and full texts, articles published in languages other than English were excluded.

Data extraction

Two reviewers (TJW and AGC) independently extracted data using a predefined excel spreadsheet. Data extracted included participant characteristics (eg, age, sex, body mass index), functional test(s) assessed, outcome measures and results of functional tests and knee-related outcome. We contacted study authors for additional information as required.

Risk of bias and level of evidence

Two reviewers (TJW and AMB) independently assessed risk of bias using a modified version of the Newcastle-Ottawa scale.[28] As we expected most eligible studies to be observational, we a priori developed a modified Newcastle-Ottawa scale for this review, consisting of ten items across four constructs (online supplemental appendix 2). The four constructs were: (1) participant selection; (2) definition of exposure; (3) comparability (exposed and nonexposed groups and (4) outcome assessment. Consistent with Cochrane Handbook for Systematic Reviews recommendations,[29] each item was ranked as high or low risk of bias. Grade of Recommendations Assessments, Development and Evaluation (GRADE) assessed overall certainty of evidence.[30] As part of the GRADE tool, where meta-analysis of any outcome included ≥10 studies, publication bias secondary to small study effects was assessed using funnel plots and the Eggers test.

Data synthesis and analysis

Unilateral functional test data was calculated as an LSI defined as ACL injured limb performance ÷ contralateral limb performance × 100. We analysed LSI primarily as a continuous variable (mean and SD) but also explored the influence of dichotomised LSI results (ie, ≥90% limb symmetry) as this is a common threshold to define success.[25] Knee-related outcome data were dichotomised to define an unsuccessful vs successful outcome using established criteria (table 1). These criteria were those most commonly used in the included studies (online supplemental appendix 3). Where results were not reported using these criteria, authors were contacted for data set out using these thresholds to facilitate meta-analysis.

Based on findings in a recent systematic review,[31] we expected the single-forward hop to be most commonly assessed with sufficient data available for a meta-analysis. Given the similarity of repeated-forward hops (ie, triple hop, crossover hop and/or 6m-timed hop) we grouped these hops into one 'repeated-forward hop' category. Crossover hop results were preferred as it comprises forward and lateral movements and is comparable to others for reliability.[9] If data from a crossover hop was not available, we used (in hierarchical order): (1) triple hop, (2) 6m-timed hop. To assess if one repeated-forward hop test was more strongly associated with outcomes than another, we performed sensitivity analysis using data from each individual hop test. Other functional tests (eg, side hop, vertical hop, one-leg rise, step-down test) were analysed separately as they measure different constructs of lower-limb function. We also assessed the relationship between a test battery (ie, including hop tests, and in some studies measures of strength or other biomechanical measures of function) and future knee-related outcomes for studies that combined several functional tests into an overall battery. We planned an a priori secondary analysis to separately assess subgroups (eg, male vs female, non-operative vs operative). Meta-regression was also used to assess the effect of follow-up time and proportion of females on the relationship between single-forward and repeated-forward hop tests and each outcome.

When two or more studies reported the results from the same hop test category (ie, single-forward hop or repeated-forward hop) and association to the same knee-related outcome,

Table 1 Definitions of dichotomised knee-related outcome

Knee-related outcome	Definition of unsuccessful outcome
Return to sport	▶ Not returning to previous level of sport *or* ▶ Not maintaining level of sport (after returning to sport)
Self-reported symptoms and function	▶ The Knee injury and Osteoarthritis Outcome Score 'Englund symptomatic knee criteria' (Englund *et al*)[32]: QOL subscale ≤87.5 and at least two other subscales below following thresholds: pain ≤86.1, symptoms ≤85.7, AD L≤86.8, sport/rec ≤85.0. ▶ International Knee Documentation Committee Subjective Knee Evaluation Form 2000: (1) scores below the 15th percentile of uninjured people[33]; (2) less than 'Patient Acceptable Symptom State' (PASS) threshold (ie, <75.9)[34]
Success with ACL deficiency (successful with non-operative treatment)	▶ Instability or giving way episodes *or* ▶ Subsequent ACLR
Subsequent knee injury after ACLR	▶ Injury to the ipsilateral or contralateral knee
Knee osteoarthritis	▶ Presence of structural features on imaging which reach an established expert or consensus threshold of magnitude and characteristics to be termed osteoarthritis (eg, Kellgren and Lawrence grade)

.ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; ADL, activities of daily living; QOL, quality of life.

meta-analysis was performed (Stata, V.17.0) if the OR and 95% CI could be calculated. The OR represents the likelihood of a higher LSI relating to a successful outcome. We used random-effects models as differences in population, functional test administration and outcome definition were expected. When ORs were not reported in the included studies, or could not be calculated from the number of individuals achieving a successful outcome, the standard mean difference (of functional performance between participants with and without a successful outcome) was calculated and then transformed to an OR; this was done using the method described in the Cochrane Handbook.[29] Data from adjusted analyses were extracted wherever possible. An OR >1 indicates a higher LSI being associated with successful future outcomes for return to sport rates, symptoms and function and success with ACL deficiency, while an OR <1 indicates a higher LSI being associated with successful future outcomes for a subsequent knee injury and knee OA (ie, no further knee injury and no knee OA). Unplanned sensitivity analysis was completed to compare outcomes from The Knee injury and Osteoarthritis Outcome Score (KOOS; Englund symptomatic knee criteria)[32] and International Knee Document Committee Subjective Knee Form (IKDC; not scoring a 'PASS' or scores below the 15th percentile of uninjured)[33 34] as they were combined under the single self-reported symptoms and function construct (detailed definitions in table 1). Fourteen studies used a functional test battery and 13 were able to be included in meta-analysis. Where a battery of tests was used, further unplanned sensitivity analysis was performed to compare the batteries consisting of only hop tests to the batteries that consisted of hop tests and strength tests to ascertain how these measures contributed to prognostic value.

Heterogeneity between studies was evaluated for each outcome measure using standard Q-tests, and was calculated as I^2 statistics, describing the percentage of the variability in effect estimates that is due to heterogeneity rather than chance.[29] Data that could not be included in meta-analyses were summarised using qualitative narrative synthesis.

RESULTS

Study characteristics

From an initial yield of 10 272 studies, 42 were included in this review consisting of a total 13 150 adolescents and adults (44% female) (figure 1, table 2). Of the 42 studies, 38 (95%) assessed functional performance up to 1 year after ACL reconstruction (ACLR) (hop tests conducted at 19 months in one study,[35] 3 years in another[15] and 4 years post-ACL injury in two studies[36 37] with follow-up assessment of outcomes ranging between 1 and 37 years following injury (see online supplemental appendix 3 for study outcome definitions). All but two studies[38 39] reported functional test results as an LSI, of which one[38] could not be estimated and was reported separately. All studies included the single-forward hop and 32 studies (78%) included a repeated forward hop (crossover hop; n=22, triple hop; n=17; 6m-timed hop; n=15) (online supplemental appendix 4). It was not feasible to analyse subgroups due to insufficient data for stratification.

Risk of bias and certainty of evidence

Our risk of bias assessment had excellent interrater reliability between the two independent assessors (k=97%). Only four studies conducted power analysis, 10 had acceptable loss to follow-up (mean lost to follow-up for all included studies was 19%) and 16 adjusted for potential confounders (online supplemental appendix 5). The overall certainty of evidence for all estimates was rated as very low using the GRADE tool. Evidence was downgraded based on study limitations, study design (observational studies), risk of bias, inconsistency, indirectness and publication bias (online supplemental appendices 6, 7).

Synthesis of results for limb symmetry as a continuous score

Return to sport

Meta-analysis of nine studies (1020 participants) revealed that higher single-forward and repeated-forward hop test scores reported as an LSI up to 1 year following ACLR were associated with higher return to sport rates 1.5–3 years post-ACLR (OR 2.15; 95% CI 1.30 to 3.54; I^2 70.6% and OR 2.11; 95% CI 1.23 to 3.60; I^2 72.7%, respectively) (figures 2 and 3). One study not included in meta-analysis reported no association between single-forward hop test scores 3 years post-ACL injury or reconstruction, and level of sports participation at 5 years.[15]

Self-reported symptoms and function

Meta-analysis of 10 studies (3107 participants) indicated that higher LSI scores on the single-forward and repeated-forward hop tests up to 4 years post-ACL injury were associated with better self-reported knee symptoms and function 1–37 years post-ACL injury (OR 2.51; 95% CI 1.62 to 3.88; I^2 69.2% and OR 4.28; 95% CI 1.65 to 11.08; I^2 69.2%, respectively) (figures 2 and 3). Sensitivity analysis separating studies reporting data from the KOOS (Englund symptomatic knee criteria)[32] and IKDC (not scoring a 'PASS' or scores below the 15th percentile of uninjured),[33 34] indicated that higher LSI scores for the single-forward hop were associated with better KOOS (OR 1.44;

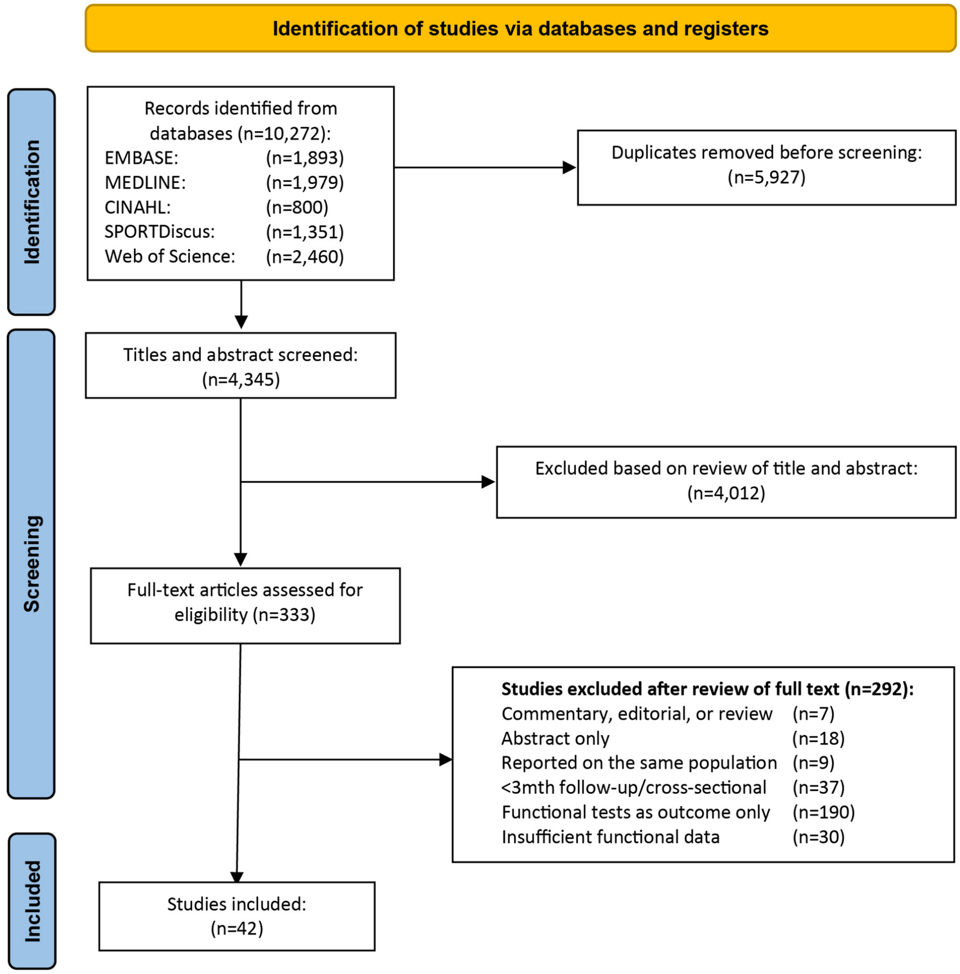

Figure 1 PRISMA flow diagram of study selection. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

95% CI 1.21 to 1.71; I^2 4.0%) and IKDC scores independently (OR 6.47; 95% CI 3.45 to 12.15; I^2 0.0%) (online supplemental appendix 8). Higher LSI scores on the one-leg rise test within 1 year post-ACLR were also associated with better self-reported symptoms and function at 3–5 years post-ACLR (OR 3.04; 95% CI 1.56 to 5.92; I^2 0.0%) (online supplemental appendix 9).

Success with ACL deficiency

Meta-analysis of seven studies (419 participants) showed no association between single-forward hop LSI up to 2 years post-ACL injury and success for individuals with an ACL deficient knee 1–8 years later (OR 1.32; 95% CI 0.75 to 2.32; I^2 54.1%) (figure 2). Higher scores on a repeated-forward hop test were not associated with increased odds of successful outcome (ie, no ACLR) 1–8 years after ACL injury (OR 1.51; 95% CI 0.94 to 2.44; I^2 27.4%) (figure 3). One study's results reporting on the vertical hop, were not included in meta-analyses and found that higher scores were prognostic for success with ACL deficiency.[18]

Subsequent knee injury after ACLR

Meta-analysis of seven studies (7549 participants) found that a higher LSI on single- or repeated-forward hop tests at 6–12 months post-ACLR was not associated with reduced odds of subsequent knee injury to either knee 2–5 years later (OR 1.24; 95% CI 0.90 to 1.71; I^2 47.2% and OR 1.03; 95% CI 0.74 to 1.44; I^2 0.0%, respectively) (figures 2 and 3).

Knee osteoarthritis

Meta-analysis of four studies (444 participants) revealed no association between single-forward and repeated-forward hop tests and developing knee OA between 1 and 37 years after ACL injury (OR 0.60; 95% CI 0.25 to 1.43; I^2 75.8% and OR 0.39; 95% CI 0.13 to 1.20; I^2 76.7%, respectively) (figures 2 and 3). Sensitivity analysis indicated that higher scores on the crossover hop (but not other repeated-forward hop tests) may be prognostic for structural knee OA (OR 0.14 95% CI 0.05 to 0.34) (online supplemental appendix 10).

Other outcomes

Single studies reported the association between functional tests and outcomes of knee biomechanics and self-efficacy. Higher scores on a single-leg step-down test at 3 months post-ACLR significantly correlated with greater knee flexion excursion (r=0.65, p=0.001) and knee extensor moment (r=0.54, p=0.001) during running 6 months post-ACLR.[38] LSI for the single-forward hop, within the first year after ACL injury, was moderately correlated with worse knee-related self-efficacy after 1 year of rehabilitation alone or ACLR (r=0.31, p=0.001).[40]

Synthesis of results for dichotomised limb symmetry scores

Meta-analyses of studies using a dichotomous threshold of ≥90% limb symmetry demonstrated consistent findings compared with using continuous LSI measures for outcomes of

Table 2 Characteristics of included studies grouped by outcome

Study	Study design	Participants*†	Female‡ (%)	Time of functional test§¶	Age±SD, years**	BMI±SD, kg/m^2**	Functional tests	Mean follow-up¶
Return to sport								
Ardern et al, 2015[65]†† Australia	Prospective	ACLR: 94	38%	1 year	29±8	NR	Single hop Triple hop	2 years
Ebert and Annear, 2019[66]††‡‡ Australia	Prospective	ACLR: 50	36%	1 year	26±10	24.8±4.0	Single hop Crossover hop 6m-timed hop Triple hop	2 years
Faleide et al, 2021[67] Norway	Prospective	ACLR: 103	47%	9 months	29±10	NR	Test battery only§§	2 years
Kitaguchi et al, 2020[68] Japan	Prospective	ACLR: 124	59%	6 months	17±2¶¶	NR	Single hop	1 year
Moksnes and Risberg, 2009[69]*** Norway	Prospective	ACLD: 52 ACLR: 50	45%	6 months	28±9	NR	Single hop Crossover hop Triple hop 6m-timed hop	1.5 years
Nawasreh et al, 2017[13]†† USA	Prospective	ACLR: 95	34%	6 months	27±10	24.9±3.6	Single hop Crossver hop Triple hop 6m-timed hop Test battery	1–2 years
Toole et al, 2017 USA[70]	Prospective	ACLR: 115	77%	8 months	17±2	NR	Single hop Crossover hop Triple hop 6m-timed hop Test battery	1.5 years
Webster et al, 2019 Australia[71]††	Prospective	ACLR: 222	40%	1 year	26±9	NR	Single hop Crossover hop	3 years
Welling et al, 2020[72]‡‡†† Netherlands	Prospective	ACLR: 64	31%	10 months	27±8	NR	Single hop Triple hop Side hop Test battery	2 years
Symptoms and function								
Cristiani et al, 2020[73]†† Sweden	Prospective	ACLR: 2335	49%	6 months	29±10	NR	Single hop	2 years
Culvenor et al, 2016[74]†† Australia	Prospective	ACLR: 93	40%	1 year	27 (13) (median and IQR)	NR	Single hop Triple hop One-leg rise	3 years
Ericsson et al, 2013[18]††‡‡ Denmark	Prospective	ACLD: 42 Delayed ACLR: 20 Early ACLR: 45	26%	37 weeks (median)	26±5	23.9±2.6	Single hop Square hop Vertical hop One-leg rise Test battery	5 years
Filbay et al, 2021[36]†† Sweden	Prospective	ACLR or ACLD: 109	28%	4 years	24±6†††	27 (24–29) (median and IQR)¶¶	Single hop	32–37 years
Logerstedt et al, 2012[12]†† USA	Prospective	ACLR: 85	45%	6 months	26 (15–54) (median and range)	NR	Single hop Crossover hop Triple hop 6m-timed hop	1 year
Månsson et al, 2013[75]†† Sweden	Prospective	ACLR: 73	30%	Pre-ACLR	24 (14–40) (median and range)	NR	Single hop	2 years
McGrath et al, 2017[76]†† Australia	Prospective	ACLR: 64	31%	24 weeks	28	25	Single hop 6m-timed hop Test battery	2 years
Øiestad et al, 2012[77]††‡‡‡ Norway	Prospective	ACLR: 181	42%	1 year	27±9	NR	Single hop Triple hop	15 years
Stropnik et al, 2020[78] Slovenia	Prospective	ACLR: 60	31%	Pre-ACLR	32±11§§§	25.7±3.5§§§	Single hop	6 months
Success with ACL deficiency								
Button et al, 2006[39]†† Wales	Prospective	ACLD: 42¶¶¶	40%	5 months	28±7	NR	Single hop	2–3 years
Eitzen et al, 2010[79] Norway/USA	Prospective	ACLD: 145	52%	60 days	26 (14–47) (median and range)	NR	Single hop Crossover hop Triple hop 6m-timed hop	15 months
Ekås et al, 2019[80] Norway	Prospective	ACLD: 44	34%	2 years	11±1	24.7 (range: 16.6–40.8)	Single hop Crossover hop Triple hop 6 m-timed hop	8 years
Fitzgerald et al, 2000[81] USA	Prospective	ACLD: 28	25%****	4 weeks (median)	29±11		Single hop Crossover hop Triple hop 6m-timed hop	8 months
Grindem et al, 2018[82] Norway/USA	Prospective	ACLD 118	51%	2 months	28±10	24.2±3.8	Single hop Cross-over hop Triple hop 6m-timed hop	2 years
Subsequent injury after ACLR								
Beischer et al, 2020[83] Sweden	Prospective	ACLR: 159	44%	9 months	20±3	NR	Test battery only§§	2 years
Cristiani et al, 2021[84] Sweden	Prospective	ACLR: 6510	44%	6 months	28±10	24.2±3.4	Single hop	2 years
Fältström et al, 2021[35] Sweden	Prospective	ACLR: 117	100%	19 months	20±2	NR	Single hop Side hop Test battery	2 years

Continued

Table 2 Continued

Study	Study design	Participants*†	Female‡ (%)	Time of functional test§¶	Age±SD, years**	BMI±SD, kg/m^2**	Functional tests	Mean follow-up¶
Grindem et al, 2016[25]†† Norway/ USA	Prospective	ACLR: 106	51%	6 months††††	25±7	NR	Single hop Crossover hop Triple hop 6m-timed hop Test battery	2 years
King et al, 2021[85]‡‡‡‡ Ireland	Prospective	ACLR: 115	0%	9 months	21±4	NR	Single hop Test battery	2 years
Kyritsis et al, 2016[26]‡‡‡‡†† Qatar	Prospective	ACLR: 158	0%	247 days	21±4	NR	Single hop Crossover hop Triple hop Test battery	2 years
Nawasreh et al, 2016[86] USA	Prospective	ACLR:95	32%	6 months	27±10	25±3.8	Test battery only§§	2 years
Sousa et al, 2017[42] USA	Retrospective	ACLR: 223	59%	6 months	26±11	25.8±4.5	Test battery only§§	2 years
van Melick et al, 2021[87] Netherlands	Prospective	ACLR: 144	31%	1 year	24±7	NR	Single hop Vertical hop Side hop Test battery	2 years
Webster et al, 2019[88] Australia	Prospective	ACLR: 329	39%	1 year	17±2	NR	Single hop Crossover hop	5 years
Wellsandt et al, 2017[51] USA	Prospective	ACLR: 70	33%	6 months	26±10	24.9±3.8	Single hop Crossover hop Triple hop 6m-timed hop Test battery	2 years
Knee osteoarthritis								
Filbay et al, 2021[37]†† Sweden	Prospective	ACLR or ACLD: 127	28%	4 years	23 (19–28) (median and IQR)†††	27 (24–29) (median and IQR)¶¶	Single hop	32–37 years
Janssen et al, 2013[89]†† Netherlands	Prospective	ACLR: 86	34%	Pre-ACLR	31±8§§§	24.5±3.1§§§	Single hop	10 years
Patterson et al, 2018[16]†† Australia	Prospective	ACLR: 78	38%	1 year	28±14	25.7±4.2	Single hop Crossover hop Side hop One-leg rise	5 years
Pinczewski et al, 2007[90]†† Australia	Prospective	ACLR: 149	47%****	1 year	25 (13–52) (median and range)****	NR	Single hop	10 years
Wellsandt et al, 2018[14]†† USA	Prospective	ACLR or ACLD: 58	35%****	6 months	28±11	NR	Single hop 6m-timed hop	5 years
Other (studies not included in meta-analysis)								
Flosadottir et al, 2016[15] Sweden	Prospective	ACLR or ACLD: 54	28%	3 years	29±5	24.6±3.4	Single hop Square hop Vertical hop	5 years
Flosadottir et al, 2018[40]§§§§ Sweden (Knee self-efficacy)	Prospective	ACLD: 20 ACLR: 69	28%	37 weeks (median)	25±5	23.8±2.8	Single hop Square hop Vertical hop	5 years
Kline et al, 2016[38]¶¶¶¶ USA (Knee biomechanics)	Prospective	ACLR: 30	53%	3 months	21±7	NR	Single leg step down	6 months

*As listed in the original paper (may differ with extra data provided by the author).
†Studies were of mixed sporting populations apart from those indicated otherwise.
‡Most studies reported on percentage of male vs female sex though used female/women and men/male terminology interchangeably.
§Mean, unless indicated otherwise.
¶Test or follow-up was number of years from the time of injury (deficient cohorts) or ACLR (reconstructed cohorts) unless indicated otherwise.
**Assessed at time of functional assessment unless indicated otherwise.
††Extra data provided by authors to enable synthesis of results and dichotomous outcome comparison.
‡‡Hop test results also compared to self-reported symptoms and function.
§§Only results from test battery able to be included for analysis.
¶¶Assessed at time of follow-up.
***Hop test results also compared to success with ACL deficiency.
†††Assessed at time of injury.
‡‡‡Hop test results also compared with knee osteoarthritis.
§§§Assessed at time of primary ACLR.
¶¶¶Only 32 participants included in analysis of hopping data because 10 were unable to hop on ACLD limb.
****Estimated from data describing total cohort.
††††Functional testing was taken at 6 and 12 months post-ACL injury.
‡‡‡‡Studies included professional male athletes (all other studies were of a general population).
§§§§Outcome used was knee self-efficacy.
¶¶¶¶Outcome used was biomechanical variables.
ACLD, anterior cruciate ligament deficient; ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; NR, not reported.

return to sport (online supplemental appendices 11, 12). Effect sizes for self-reported symptoms and function and success with ACL deficiency outcomes were attenuated where dichotomous LSI data were used (online supplemental appendices 11, 12). Meta-analysis of two studies also found no association with side hop 2 years post-ACLR and subsequent knee injury (online supplemental appendix 13). The notable exception was knee OA, with meta-analysis of six studies (679 participants) demonstrating that achieving LSI ≥90% on the single-forward hop up to 4 years post-ACL injury was associated with reduced odds of radiographic knee OA at 5–37 years after ACL injury/reconstruction (LSI ≥90%: OR 0.46; 95% CI 0.23 to 0.94; I^2 54.5%) (online supplemental appendix 11).

Synthesis of results for a test battery

Passing a test battery (ie, achieving LSI ≥90% on all tests) was associated with greater odds of returning to sport (OR 3.33; 95% CI 1.05 to 10.53; I^2 55.3%) (online supplemental appendix 14). Passing a battery of tests was not associated with reduced odds of subsequent knee injury after ACLR (OR 0.62; 95% CI 0.26 to 1.48; I^2 67.3%) (online supplemental appendix 14). Sensitivity analysis revealed that passing test batteries made up exclusively of hop tests was associated with avoiding subsequent knee injury (OR 0.29, 95% CI 0.10 to 0.85; I^2 44.3%). Conversely, passing test batteries that included strength measures along with hops tests was not associated with avoiding

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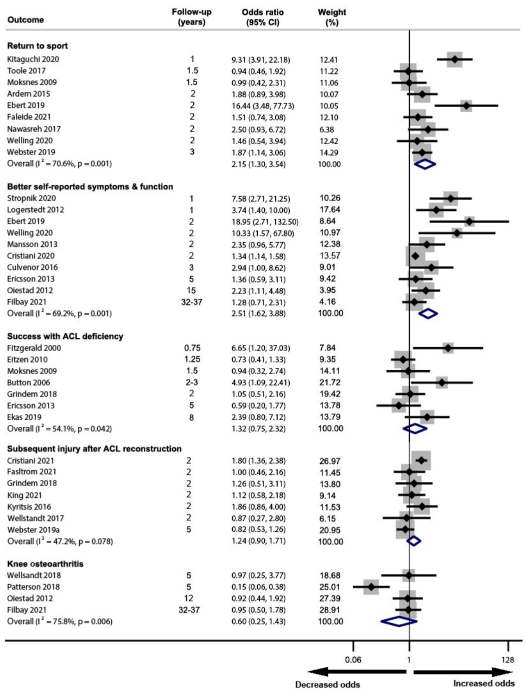

Figure 2 Forest plot displaying the association between single-forward hop results (continuous Limb Symmetry Index scores) and future outcomes.

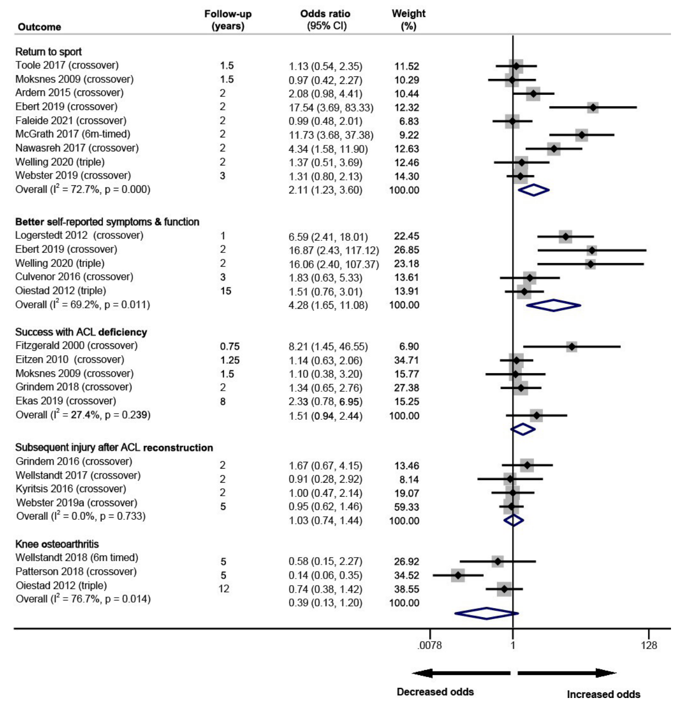

Figure 3 Forest plot displaying the association between repeated-forward hop results (continuous Limb Symmetry Index scores) and future outcomes. In brackets are the specific repeated-forward hop used in analysis.

subsequent knee injury (1.31; 95% CI 0.63 to 2.71 I^2 22.4%) (online supplemental appendix 15).

Sensitivity analysis of associations found between hop test and knee-related outcomes

Sensitivity analysis separating each repeated-forward hop test demonstrated that triple hop, crossover hop and 6m- timed hop had similar effect sizes for each outcome, with no significant between-test heterogeneity observed: RTS (I^2 71.8%, p=0.645), self-reported symptoms and function (I^2 51.9%, p=0.978), success with ACL deficiency (I^2 19.6%, p=0.843) and subsequent injury after ACLR (I^2 1.2%, p=0.175). Between test heterogeneity was significantly different with individual repeated-forward hop tests and knee OA, with the crossover hop demonstrating a significantly larger association with knee OA than the 6m-timed hop or triple hop test (I^2 76.7%, p=0.014) (online supplemental appendix 10). Meta-regression indicated that follow-up time and proportion of females did not influence the relationship between single-forward and repeated-forward hop tests and all outcomes (online supplemental appendix 16).

DISCUSSION

This systematic review of 42 studies and 13 150 adolescents and adults following ACL injury, found an increased odds of poor knee-related outcomes after 1–37 follow-up years in individuals not achieving adequate LSI on unilateral functional tests. These findings highlight the need to optimise knee function in the first 1–2 years post-ACL injury and reconstruction to reduce the long-term burden. Caution is warranted when interpreting these findings given the very low certainty of evidence associated with the results. The low certainty of evidence points to the need for high quality longitudinal data that is well controlled for confounders existing (and/or changing) during the long duration between exposure (hop tests) and outcomes (eg, physical activity, muscle strength).

What is the prognostic value of hop tests for return to sport, reinjury and self-reported outcomes?

Achieving a higher LSI on the singleforward and repeated-forward hop tests was associated with twice the odds of future return to sport (OR 2.15; 95% CI 1.30 to 3.54; I^2 70.6% and OR 2.11; 95% CI 1.23 to 3.60; I^2 72.7%, respectively) (figures 2 and 3) with 9/10 studies in this analysis using pre-injury level of sport as the measure of successful return. While this indicates the potential importance of achieving adequate functional performance to facilitate a return to preinjury sport, those who return to high-impact and pivoting sports are known to be at higher risk of reinjury.[25] Our pooled results suggest a slightly elevated risk of reinjury in those with a higher hop score, which may reflect higher return to sport rates in those with better hop performance. There is much debate regarding the importance of achieving common return to sport criteria (ie, LSI ≥90% on a functional test battery including hop tests) to reduce reinjury risk.[20 41] For example, some original studies and systematic reviews report that meeting functional criteria increases reinjury risk,[20 42] while others report a reduced risk of reinjury on passing return to sport criteria.[21 25] Inconsistencies are likely explained by whether sport participation (both level and type of sport) exposure was accounted for and whether some participants who may initially fail test batteries continued rehabilitation until passing.[41 43] Individuals following ACL injury and reconstruction should be educated about the risk of reinjury when returning to sport regardless of adequate functional performance and consider other factors known to increase re-injury risk (eg, time postsurgery, younger age, symmetry of quadriceps strength, fear).[25 44 45]

We also observed that higher LSI on single-forward and repeated-forward hop tests was associated with more than twofold and fourfold higher odds of better self-reported symptoms and function, respectively (OR 2.51; 95% CI 1.62 to

3.88; I² 69.2% and OR 4.28; 95% CI 1.65 to 11.08; I² 69.2%) (figures 2 and 3). These findings suggest that hop tests provide important prognostic value for longer-term symptomatic and functional outcomes and may provide targets to reduce the burden of symptoms following ACL injury. Original studies did not account for baseline symptoms and function that may have altered results. Self-reported symptoms and function at follow-up may reflect higher scores at baseline rather than improvement over time, although other studies have shown only fair cross-sectional correlation between functional tests and self-reported symptoms and function.[46] Nevertheless, our results demonstrate the prognostic value of these functional tests, which may aid clinicians in identifying those at higher risk of longer-term burden.

Can hop tests tell us who is going to get post-traumatic structural OA?

Knee OA is a burdensome sequelae of traumatic knee injury with its risk not reduced with reconstruction.[47] We found achieving LSI ≥90% on the single-forward hop was associated with reduced odds of developing structural knee OA (LSI ≥90%: OR 0.46; 95% CI 0.23 to 0.94; I² 54.5%) (online supplemental appendix 11), though this was attenuated when analysing hop test scores as continuous variables. The stronger association with OA when using a dichotomous hop score, may be due to including different studies in each meta-analysis (n=2 not included in both meta-analyses). In sensitivity analysis data from a single study[16] indicated that higher scores on the crossover hop may be prognostic for structural knee OA (OR 0.14; 95% CI 0.05 to 0.34) (online supplemental appendix 10). Structural knee OA was defined differently across included studies (eg, joint space narrowing, Kellgren and Lawrence classification and adding symptoms to definition) and there was no observable trend for the impact of hop test performance and structural OA based on length of follow-up. In the context of OA prevention, addressing impairments in hop tests (ie, quadriceps weakness) may provide a target for intervention though RCTs are required to confirm this.[48 49]

Is one test better than another or is a battery of tests needed?

Generally, results were similar between single- and repeated-forward hop tests for most outcomes. As studies often included multiple tests, we created a hierarchy for reporting repeated-forward hop tests (ie, crossover hop, triple hop, 6m-timed hop). Despite tests measuring somewhat different constructs (ie, crossover hop includes lateral and forward movement and 6m-timed hop measuring speed of completion) each individual repeated-forward hop tests found similar associations (online supplemental appendix 10). Current clinical trial evidence suggests that trialling rehabilitation without surgery is not inferior to having early ACLR.[50] In this context, our results highlight the importance of conducting hop tests during the initial rehabilitation period to monitor function, which might help to determine an individual's ability to cope with an ACL deficient knee, alongside other factors such as desired level of activity (eg, return to cutting sports).

A battery of tests is recommended to determine readiness to return to sport, although it is difficult to compare batteries given the inconsistency in tests included across different studies.[23] The common definition for 'passing' a test battery is LSI ≥90% on all tests included.[25 26 51] Results from our review suggest that both single-forward and repeated-forward hops are similar to a test battery as prognostic indicators of return to sport. Passing a test battery (consisting only of hop tests) was associated with reduced odds of further knee injury more than threefold compared with not passing (OR 0.29; 95% CI 0.10 to 0.85) (online supplemental appendix 15). In contrast, we found that a higher LSI on individual hop tests (figures 2 and 3) or passing test batteries (including those with hop tests and strength measures) was not associated with subsequent knee injury (online supplemental appendix 14). There is no agreement across our analyses reflective of findings from various recent systematic reviews.[20–22 46] Compared with these reviews, we included different studies and we also pooled knee injuries under one outcome (eg, ipsilateral and contralateral reinjury, other knee injury). Given our results and those from previous reviews, we suggest that a test battery is likely needed to identify those at higher risk of future knee injury. Unfortunately for clinicians, exactly how many and what particular combination of tests to use remains unclear but current guidelines recommend using test batteries that include hop tests and measures of strength.[3 52]

The prognostic capacity of less common functional tests

Less common tests of functional performance included in this review were the one-leg rise, side hop and vertical hop. We found that performance on the one-leg rise was associated with future self-reported symptoms and function. The one-leg rise test may be a surrogate of quadriceps (and lower-limb) strength[53] and is becoming more popular in clinical settings due to the lack of equipment required compared with isokinetic dynamometry. Higher side hop performance was not associated with subsequent knee injury after ACLR (online supplemental appendix 13). Higher LSI on the vertical hop was associated with success with an ACL deficient knee[18] and may be a better alternative to forward hop tests to assess knee function because the knee contributes more to vertical height than horizontal distance (which is more a function of hip/ankle power).[54–56]

In our review, we only compared the quantitative achievement of a functional test and results do not account for movement quality or other aspects of how tests were completed. Sixty-five per cent of included studies were deemed high risk of bias in terms of how the hop tests were assessed or completed, identifying the need for greater consistency to strengthen comparisons. It is also becoming more apparent that poor movement quality (eg, measured using two-dimensional or three-dimensional kinematics) is another important construct to assess given its association to poor outcome despite restoration of quantitative function (eg, LSI ≥90%).[57] The importance of qualitative assessment also highlights the limitation of the LSI as a measure of recovered function. The contralateral (reference) limb may deteriorate after ACL injury with disuse and central inhibition[58 59] and thus not be an accurate preinjury reference standard. For this reason, other criteria, such as an estimated preinjury capacity (ie, contralateral hop test result immediately after ACL injury) have been proposed as a more suitable measure of preinjury function as well as normative values from well-matched controls.[51 58]

Limitations

Results from our review are limited by the very low certainty of evidence. The level of evidence (GRADE assessment) required downgrading due to observational studies and large I^2 values. These values indicated heterogeneity among pooled studies that was largely unexplained as our sensitivity analyses were unable to determine a source of this. Most studies had unacceptable lost to follow-up (eg, >15%), which may indicate attrition bias skewing results. While eight of the 42 included studies accounted for baseline differences (eg, age, sex, body mass index), the majority did not account for these factors and their potential impact on results. Indirectness was also found with time between test and follow-up differing across studies and though this enhances generalisability, it also reduces confidence in the estimated effects. Graft type used for ACLR was also not able to be included as part of our analysis to compare surgery types as the data were not available. Finally, we were unable to provide an estimate of the relationship between functional test results and future psychological recovery (eg, confidence, fear) as no studies had available data evaluating this. However, we recognise the growing awareness of the importance of restoring confidence and reducing fear after ACL injury[60–64] and this should be investigated further.

CONCLUSION

In this systematic review, we found unilateral tests of lower-limb function can be prognostic for future knee-related outcomes in individuals after ACL injury, though with very low certainty evidence. Early in rehabilitation, hop testing may be used as part of criteria to consider non-operative management and along with other tests may provide insight into potential future symptoms and function over the long term, including the development of post-traumatic knee OA. Hop tests are also recommended to be used as part of return to sport testing, though achieving adequate performance may not reduce subsequent knee injuries.

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Appendix 1.

Systematic search strategy

MEDLINE	Anterior Cruciate Ligament [MeSH] OR Anterior Cruciate Ligament Injuries [Mesh] OR Anterior Cruciate Ligament Reconstruction [Mesh] OR "anterior cruciate ligament" [mp] ACL [mp] **AND** Leg adj4 function* [mp] OR leg adj4 performance [mp] OR "lower extremity" adj4 function* [mp] OR "lower extremity" adj4 performance [mp] OR "lower-extremity" adj4 function* [mp] OR "lower-extremity" adj4 performance [mp] OR "lower limb" adj4 function* [mp] OR "lower limb" adj4 performance [mp] OR "lower-limb" adj4 function* [mp] OR "lower-limb" adj4 performance [mp] OR hop* [mp] OR squat* [mp] OR "one-leg rise" [mp] OR "one leg rise" [mp] OR "single leg rise" [mp] OR jump* [mp] OR "knee bend" [mp] OR battery [mp] OR stair* [mp]
Embase	Anterior Cruciate Ligament [MeSH] OR Anterior Cruciate Ligament Injury [Mesh] OR Anterior Cruciate Ligament Reconstruction [MeSH] OR Anterior Cruciate Ligament Rupture [MeSH] OR "anterior cruciate ligament" [mp] ACL [mp] **AND** Leg adj4 function* [mp] OR leg adj4 performance [mp] OR "lower extremity" adj4 function* [mp] OR "lower extremity" adj4 performance [mp] OR "lower-extremity" adj4 function* [mp] OR "lower-extremity" adj4 performance [mp] OR "lower limb" adj4 function* [mp] OR "lower limb" adj4 performance [mp] OR "lower-limb" adj4 function* [mp] OR "lower-limb" adj4 performance [mp] OR hop* [mp] OR squat* [mp] OR "one-leg rise" [mp] OR "one leg rise" [mp] OR "single leg rise" [mp] OR jump* [mp] OR "knee bend" [mp] OR battery [mp] OR stair* [mp]
CINAHL	Anterior Cruciate Ligament Injuries [MeSH] OR Anterior Cruciate Ligament Reconstruction [MeSH] OR ACL [tiab] OR "anterior cruciate ligament" [tiab] **AND** Leg n4 function* [tiab] OR leg n4 performance [tiab] OR "lower extremity" n4 function* [tiab] OR "lower extremity" n4 performance [tiab] OR "lower-extremity" n4 function* [tiab] OR "lower-extremity" n4 performance [tiab] OR "lower limb" n4 function* [tiab] OR "lower limb" n4 performance [tiab] OR "lower-limb" n4 function* [tiab] OR "lower-limb" n4 performance [tiab] OR hop* [tiab] OR squat* [tiab] OR "one-leg rise" [tiab] OR "one leg rise" [tiab] OR "single leg rise" [tiab] OR jump* [tiab] OR "knee bend*" [tiab] OR battery [tiab] OR stair* [tiab]
Scopus **Web of Science** **SPORTDiscus**	ACL [tiab] OR "anterior cruciate ligament" [tiab] **AND** Leg W/4 function* [tiab] OR leg W/4 performance [tiab] OR "lower extremity" W/4 function* [tiab] OR "lower extremity" W/4 performance [tiab] OR "lower-extremity" W/4 function* [tiab] OR "lower-extremity" W/4 performance [tiab] OR "lower limb" W/4 function* [tiab] OR "lower limb" W/4 performance [tiab] OR "lower-limb" W/4 function* [tiab] OR "lower-limb" W/4 performance [tiab] OR hop* [tiab] OR squat* [tiab] OR "one-leg rise" [tiab] OR "one leg rise" [tiab] OR "single leg rise" [tiab] OR jump* [tiab] OR "knee bend*" [tiab] OR battery [tiab] OR stair* [tiab]

Appendix 2. Risk of Bias Tool

Modified Newcastle-Ottawa Scale from Wells, G. et al, The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. *http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp* 2013;

Selection	
1. Definition of ACL injured population Low risk of bias = a High risk of bias = b	a) Clearly described if the inclusion/exclusion criteria of an ACL injured person stated **both** of the following criteria: i) Diagnosed ACL injury with clinical/imaging or surgical confirmation (e.g. Lachman's or pivot shift test ± MRI/arthroscopic confirmation), ii) Reports of surgical or non-surgical management b) Not described OR used minimal criteria for inclusion/exclusion.
2. Source population Low risk of bias = a High risk if = b, c	a) A consecutive sample or random selection from a source population that is well described and representative of the condition under study (e.g. surgeon's clinic, outpatient clinic). b) A consecutive sample or random selection from a population that is not highly representative of the condition under study. c) Cannot be defined or enumerated (i.e. volunteering or self-recruitment).
3. Typical of the average ACL injured population (representativeness of cohort) Low risk of bias = a High risk if = b	a) Truly representative of the average ACL injured person in the community if **all** of the following criteria are present: i) Including men and women, ii) Typical age range at time of ACL injury/surgery (mean age = 16-35), iii) If surgery, then 'typical' surgical procedure (arthroscopic and not synthetic graft*) **If non-surgical management then N/A for this point* b) Above criteria are not present then not truly representative of the average ACL injured population.
4. Sample size Low risk of bias = a High risk if = b, c	a) Power analysis completed and sample size adequate to detect meaningful difference. b) Power analysis completed but sample size not adequate to detect meaningful difference. c) No power analysis completed.

Exposure	
5. Methods for assessment of functional performance (i.e. ascertainment of exposure) Low risk of bias = a High risk if = b, c	a) Well described methods for functional tests - including an appropriately trained or appropriate profession as assessor **AND** describes or cites reliability. b) Well described methods for functional tests including an appropriately trained or appropriate profession as assessor) **OR** describes or cites reliability. c) Not described.
6. Demonstration that outcome of interest was not present at ascertainment of exposure (i.e. outcome that is compared to exposure) Low risk = a High risk if = b	a) **True** if baseline score of outcome of interest for both exposed/non-exposed (poor/good functional performance) has been accounted for (for example as a covariate or change in score or not present at ascertainment of exposure). b) No demonstration that the baseline score of outcome of interest has been accounted for.

Comparability	
7. Comparability of cohorts on the basis of the design or analysis Low risk = a High risk if = b	a) Comparability exists if study cohort (exposed/non-exposed) was a priori matched for **at least one covariate**, or confounding controlled for in statistical analysis. Covariate examples: i) Age, ii) BMI, iii) Sex b) Study not controlled in design or analysis and no confounders acknowledged. (Statements of no differences between groups or that differences were not statistically significant are not sufficient for establishing comparability)

Outcome	
8. Validity and reliability of outcome(s) of interest Low risk = a High risk if = b	a) Outcome measure(s) of interest are clearly described, and references other article(s) which found outcome measure to be valid & reliable **OR** demonstrates the outcome measure(s) of interest are valid and reliable. (note all outcome(s) of interest must be valid and reliable for (a)) b) If outcome measure(s) of interest were not explained in reproducible detail, or validity and reliability not proven/reported.
9. Assessment of outcome(s) of interest Low risk = a High risk if = b	a) Assessor has suitable qualification to interpret findings (e.g. musculoskeletal radiologist) **AND** blind to participant baseline exposure/non-exposure. **N/A: Blinding not needed for self-reported outcomes* b) Poor or no description.
10. Adequacy of follow-up of cohorts Low risk = a High risk if = b	a) Adequacy of follow-up if **either** of the following are satisfied: i) <15% lost to follow up + description of those lost, ii) <5% lost to follow up with no description b) >15% lost to follow up or not explicitly stated with number of participants lost to follow-up **OR** characteristics of those lost to follow-up were not described.

*risk of bias assessed from published paper, not considering extra data if provided by the authors

Appendix 3. Measures used for outcomes presented

Paper	Measure used
Return to Sport	
Ardern et al, 2015*	Are you currently playing sport at the same level that you played pre-injury?
Ebert and Annear, 2019*	Tegner activity scale – Pre-injury level
Faleide et al, 2021	At what level do you perform your main sport/activity now? (pre-injury)
Kitaguchi et al, 2020	Tegner activity scale – Pre-injury level
McGrath et al, 2017*	Tegner activity scale – Pre-injury level
Moksnes and Risberg, 2009*	IKDC - pre-injury activity level
Nawasreh et al, 2017*	Global Rating scale – pre-injury level
Toole et al, 2017*	Tegner activity scale – maintain or improve
Webster et al, 2019*	Marx Scale – Pre-injury level
Welling et al, 2020*	Did you return to the pre-injury level of sport?
Symptoms and function	
Cristiani et al, 2020*	KOOS – Meeting Englund criteria
Culvenor et al, 2016*	KOOS – Meeting Englund criteria
Ebert and Annear, 2019*	IKDC – PASS (>75.9)
Ericsson et al, 2013*	KOOS – Meeting Englund criteria
Filbay et al, 2021*	KOOS – Meeting Englund criteria
Logerstedt et al, 2012*	IKDC – Below 15th percentile
Mansson et al, 2013*	KOOS – Meeting Englund criteria
Oiestad et al, 2012*	KOOS – Meeting Englund criteria
Stropnik et al, 2020	IKDC – Below 15th percentile
Welling et al, 2020*	IKDC – PASS (>75.9)
Success with ACL deficiency	
Button et al, 2006*	Return to pre-injury activity level (phone questionnaire)
Eitzen et al, 2010	Not having delayed ACLR up to 15/12 post-injury
Ekas et al, 2019	Not having delayed ACLR up to 8-years post-injury
Ericsson et al, 2013*	Not having delayed ACLR up to 5-years post-injury
Fitzgerald et al, 2000	Ability to return to preinjury levels of activity without experiencing an episode of giving-way at the knee
Grindem et al, 2018*	Delayed ACLR up to 2-years post-injury
Subsequent knee injury	

Beischer et al, 2020	ACLR re-rupture or contralateral injury up to 46-months post-surgery
Cristiani et al, 2021	Revision ACLR within 2-years post-ACLR
Faleide et al, 2021	ACLR re-rupture or contralateral ACL rupture up to 2-years post-surgery
Faltstrom et al, 2021	ACLR re-rupture, contralateral re-rupture or “severe” injury (absence from soccer play ≥28 days) up to 2-years post-surgery
Grindem et al, 2016*	ACLR re-rupture and other injuries to ACLR knee or contralateral rupture/injury up to 2-years post-surgery
King et al, 2021	Contralateral ACL injury within 2-years post-ACLR
Kyritsis et al, 2016*	ACL graft re-rupture up to 2.5 years after surgery
Nawasreh et al, 2016	ACLR re-rupture or contralateral injury up to 2-years post-surgery
Sousa et al, 2017	ACLR re-rupture or contralateral injury 4-years post-surgery
van Melick et al, 2021*	ACLR re-rupture or contralateral ACL injury up to 2-years post-surgery
Webster et al, 2019	ACLR re-rupture or contralateral ACL injury up to 5-years post-surgery
Wellsandt et al, 2017*	ACLR re-rupture or contralateral injury ≥2-years post-surgery
Knee Osteoarthritis	
Filbay et al, 2021*	Kellgren & Lawrence OA grading ≥2 and defined symptoms
Janssen et al, 2013*	A combination of Ahlbäck grade 1 and Kellgren & Lawrence (K&L) grade 3 was defined as ‘radiographic signs of knee OA‘
Oiestad et al, 2012*	Kellgren & Lawrence OA grading score ≥2 (Extra data received from author for this analysis)
Patterson et al, 2018*	OARSI criteria; i) JSN of grade 2 or higher, ii) Sum of osteophyte grades ≥2, iii) Grade 1 JSN in combination with a grade 1 osteophyte
Pinczewski et al, 2007*	IKDC OA grading
Wellsandt et al, 2018*	Kellgren & Lawrence OA grading ≥2

Studies not included in meta-analysis

Flosadottir et al, 2016	Tegner activity scale
Flossadottir et al, 2018	Knee – self efficacy scale
Kline et al, 2016	Biomechanical variables

KOOS, The Knee Injury and Osteoarthritis Outcome Score, IKDC, International Knee Documentation Committee score, ACLR, anterior cruciate ligament reconstruction, OA, osteoarthritis, JSN, joint space narrowing,
*Extra data received from author to report outcomes in this format for our analysis

Appendix 4. Tests used in each study

Study	Single-forward hop (n=42)	Repeated forward hops			Side hop (n=5)	One leg rise (n=4)	Vertical or square hop (n=2)	Battery of tests (n=15)
		Triple hop (n=18)	Crossover hop (n=23)	6-m timed hop (n=15)				
Return to Sport								
Ardern et al, 2015	■		■					
Ebert et al, 2019	■	■	■	■				
Faleide et al, 2019	■							■
Kitaguchi et al, 2020	■							
McGrath et al, 2017	■							
Moksnes et al, 2009	■	■	■	■				
Nawasreh et al, 2017	■	■	■	■				■
Toole et al, 2017	■	■	■	■				■
Webster et al, 2019	■		■					
Welling et al, 2020	■	■			■			■
Patient-reported symptoms and function								
Cristiani et al, 2020	■							
Culvenor et al, 2016	■		■			■		
Ericsson et al, 2013	■					■	■	■
Filbay et al, 2021	■							
Logerstedt et al, 2012	■	■	■	■				
Mansson et al, 2013	■							

Oiestad et al, 2012								
Stropnik et al, 2020								
Success with ACL deficiency								
Button et al, 2006								
Eitzen et al, 2010								
Ekas et al, 2019								
Fitzgerald et al, 2000								
Grindem et al, 2018								
Subsequent knee injury after ACLR								
Beischer et al, 2020								
Cristiani et al, 2021								
Faltstrom et al, 2021								
Grindem et al, 2016								
King et al, 2021								
Kyritsis et al, 2016								
Nawasreh et al, 2016								
Sousa et al, 2017								
van Melick et al, 2021								
Webster et al, 2019								
Wellsandt et al, 2017								
Knee osteoarthriits								
Filbay et al, 2021								
Janssen et al, 2013								

Patterson et al, 2018								
Pinczewski et al, 2007								
Wellsandt et al, 2018								
Studies not included in meta-analysis								
Flosadottir et al, 2016								
Flosadottir et al, 2018								
Kline et al, 2016								

ACLR, anterior cruciate ligament reconstruction
Green (darker) shaded cells indicate where test was used within study

Appendix 5. Risk of bias using a Modified Newcastle Ottawa Scale

Article	Selection bias				Exposure bias		Comparability bias	Outcome bias		
	Definition of ACL injured population	Source population	Typical of average ACL injured population	Sample Size	How performance using a functional test was decided	Demonstrates outcome was not present at time of functional test	Comparability of cohorts on the basis of the design or analysis	Validity and reliability of outcomes	Assessment of outcome*	Adequacy of follow up
Return to Sport										
Ardern et al, 2015	Low	Low	Low	High	Low	Low	High	High	Low	High
Ebert et al, 2019	Low	High	High	High	High	Low	High	Low	Low	High
Faleide et al, 2019	Low	Low	Low	High	High	Low	Low	High	Low	High
Kitaguchi et al, 2020	Low	Low	Low	High	Low	Low	High	High	Low	High
McGrath 2017	Low	High	High	Low	Low	Low	Low	Low	Low	High
Moksnes et al, 2009	Low	Low	Low	High	Low	Low	High	Low	Low	High
Nawasreh et al, 2017	Low	High	Low	High	High	High	Low	High	High	High
Toole et al, 2017	Low	High	Low	High	High	Low	High	Low	Low	Low
Webster et al, 2019	Low	Low	Low	High	High	Low	High	Low	Low	High
Welling et al, 2020	Low	Low	Low	High	High	High	High	High	Low	High
Patient-reported symptoms and function										
Cristiani et al, 2020	Low	Low	Low	Low	High	High	Low	Low	Low	High
Culvenor et al, 2016	Low	Low	Low	High	High	Low	Low	Low	Low	Low
Ericsson et al, 2013	Low	Low	Low	High	Low	Low	Low	Low	Low	High
Filbay et al, 2021	Low	Low	Low	Low	High	Low	Low	Low	Low	High
Logerstedt et al, 2012	Low	Low	Low	High	Low	Low	High	Low	Low	High
Mansson et al, 2013	Low	High	Low	High	High	High	High	Low	Low	High
Oiestad et al, 2012	Low	High	Low	High	High	High	Low	Low	Low	High

Stropnik et al, 2020	Low	Low	Low	High	High	Low	High	Low	Low	Low
Success with ACL deficiency										
Button et al, 2006	Low	High	Low	High	High	Low	High	High	Low	High
Eitzen et al, 2010	Low	Low	Low	High	Low	Low	High	High	High	Low
Ekas et al, 2019	Low	Low	High	High	High	Low	High	Low	Low	Low
Fitzgerald et al, 2000	Low	Low	Low	High	High	Low	High	High	High	Low
Grindem et al, 2018	Low	Low	Low	High	High	Low	Low	Low	High	Low
Subsequent knee injury after ACLR										
Beischer et al, 2020	Low	Low	Low	High	Low	Low	High	High	High	High
Cristiani et al, 2021	Low	Low	Low	High	Low	Low	Low	Low	Low	High
Faltstrom et al, 2021	Low	High	High	High	Low	Low	Low	Low	High	Low
Grindem et al, 2016	Low	Low	Low	High	High	Low	Low	Low	Low	High
King et al, 2021	Low	Low	High	High	High	Low	Low	Low	High	High
Kyritsis et al, 2016	Low	Low	High	High	High	Low	Low	High	High	Low
Nawasreh et al, 2016	Low	High	Low	High	High	Low	High	High	High	High
Sousa et al, 2017	Low	Low	Low	Low	High	Low	High	High	High	High
van Melick et al, 2021	Low	Low	Low	High	Low	Low	High	High	Low	High
Webster et al, 2019	Low	Low	Low	High	Low	Low	High	High	Low	High
Wellsandt et al, 2017	Low	High	Low	High	High	Low	High	High	High	High
Knee Osteoarthritis										
Filbay et al, 2021	Low	Low	Low	High	High	High	Low	Low	Low	High
Janssen et al, 2013	Low	Low	Low	High	Low	Low	High	Low	Low	Low
Patterson et al, 2018	Low	High	Low	High	High	Low	Low	Low	Low	High
Pinczewski et al, 2007	Low	High	Low	High	High	High	High	High	High	High

Wellsandt et al, 2018	Low	High	Low	High	High	High	High	Low	High	High
Studies not included in meta-analysis										
Flosadottir et al, 2016	Low	Low	Low	High	Low	Low	Low	Low	Low	High
Flosadottir et al, 2018	Low	Low	Low	High	Low	High	Low	Low	Low	Low
Kline et al, 2016	Low	High	Low	High	High	High	High	High	High	High

Appendix 6. GRADE assessment for the single leg hop test applied to all outcomes*

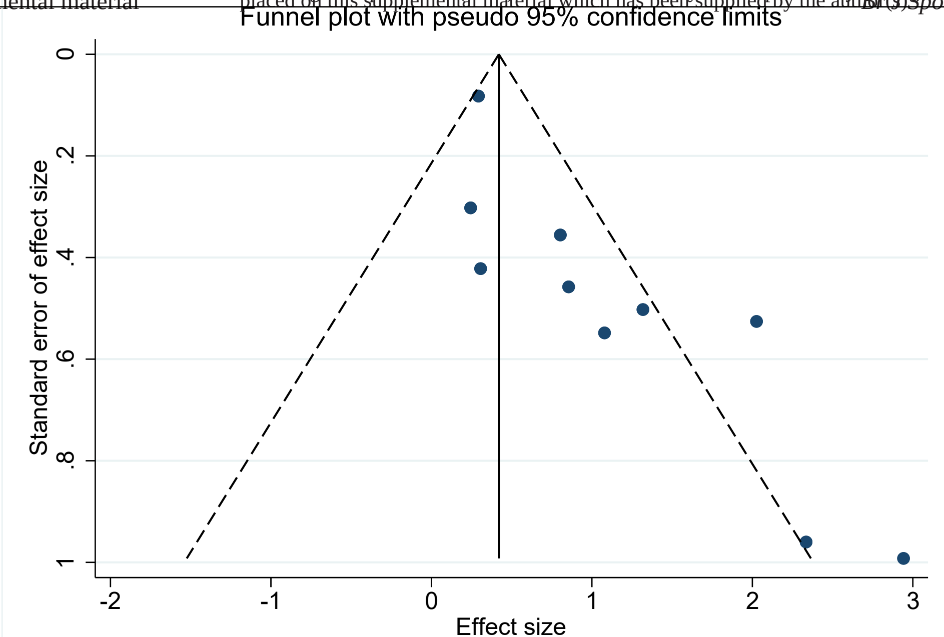
	Study design	Risk of bias	Inconsistency (I^2)	Indirectness	Imprecision	Publication bias	Odds Ratio	GRADE
Return to Sport								
Ardern et al, 2015 Ebert et al, 2019 Moksnes et al, 2009 Nawasreh et al, 2017 Toole et al, 2017 Faleide et al, 2021 Kitaguchi et al, 2020 Webster et al, 2019 Welling et al, 2020	**(-2)** Prospective	**(-1) Serious:** Most did not control for confounders, had inadequate sample size and poor follow-up	**(-1) Not serious:** I^2 = 70.6% (P= 0.001) Overlapping confidence intervals from 8/10 studies. Odds ratio between 0.94 to 16.44 without large discrepancies in weighting	**(0) Not serious** Similar populations, timepoints of testing and outcomes	**(0)** **Total n= 638** **CI (1.30, 3.54)**	N/A	**(0)** 1.97 (1.24, 3.13)	Very low
Patient-reported symptoms and function								
Cristiani et al, 2020 Culvenor et al, 2016 Ebert et al, 2019 Ericsson et al, 2013 Filbay et al, 2021 Logerstedt et al, 2012 Mansson et al, 2013 McGrath et al, 2017 Oiestad et al, 2012 Stropnik et al, 2020 Welling et al, 2020	**(-2)** Prospective	**(-1) Serious:** Most did not control for confounders, had inadequate sample size and poor follow-up	**(-1) Serious:** I^2 = 69.2% (P= 0.001) Overlapping confidence intervals of most studies with two outlying studies. Odds ratio between 1.28 to 18.95. Discrepancies in weighting.	**(-1) Serious** Differing populations (age), differing timepoints of outcome, and outcomes used (IKDC and KOOS)	**(0)** **Total n=1737** **CI (1.62, 3.88)**	**(-1) Serious** P = 0.002 Eggers test for small study effects (as there were 10 studies)	**(+1)** 2.51 (1.62, 3.88)	Very low
Success with ACL deficiency								
Button et al, 2006 Eitzen et al, 2010 Ekas et al, 2019 Ericsson et al, 2013 Fitzgerald et al, 2000 Grindem et al, 2018 Mosknes et al, 2009	**(-2)** Prospective	**(-1) Serious:** Most did not control for confounders, had inadequate sample size and poor follow-up	**(0) Not serious:** I^2 = 54.1% (P= 0.042) Overlapping confidence intervals from 5/7 studies. Odds ratio between 0.59 to 6.65 without large discrepancies in weighting	**(-1) Serious** Differing outcome definitions	**(0)** **Total n= 228** **CI (0.75, 2.32)**	N/A	**(0)** 1.32 (0.75, 2.32)	Very low
Subsequent knee-injury after ACLR								
Cristiani et al, 2021 Falstrom et al, 2021 Grindem et al, 2016 King et al, 2021 Kyritsis et al, 2016 Webster et al, 2019 Wellstandt et al, 2017	**(-2)** Prospective	**(-1) Serious:** Most did not control for confounders, had inadequate sample size and poor follow-up	**(0) Not serious:** I^2 = 47.2% (P= 0.078)	**(-1) Serious** Different outcome definition for knee-injury or re-injury	**(0)** **Total n= 6970** **CI (0.58, 1.11)**	N/A	**(0)** 0.81 (0.58, 1.11)	Very low

Knee Osteoarthritis								
Filbay et al, 2021 Janssen et al, 2013 Patterson et al, 2018 Pinczewski et al, 2007 Wellstandt et al, 2018	**(-2)** Prospective	**(-1) Serious:** Most did not control for confounders, had inadequate sample size and poor follow-up	**(-1) Serious:** I^2 = 75.8% (P= 0.006)	**(-1)** ? maybe high due to timing of outcome (and therefore population) and outcome definition	**(-1)** **Total n= 222** **CI (0.70, 3.98)* wide**	N/A	**(0)** 1.67 (0.70, 3.98)	Very low

Grade of evidence was assigned using the GRADE system, which has 4 categories HIGH, MODERATE, LOW or VERY LOW. Evidence is initially assigned as HIGH from randomised trials. The grade of evidence was then reduced if there was serious (-1) or very serious (-2) limitations to study quality or uncertainties about directness of association; important inconsistency (-1), imprecise or sparse data (-1) or a high probability of reporting bias (-1). Grade of evidence was increased if strong evidence of association was seen (e.g., RR >2 or <0.5) from ≥2 observational studies with no plausible confounders (+1) or very strong direct evidence (RR >5 or <0.2) with no major threats to validity (+2); if there was evidence of a dose-response gradient (+1) or if all plausible confounders would have reduced the effect/association seen (+1). The interpretation of GRADE evidence assessments is that for HIGH certainty evidence further research is very unlikely to change our confidence in the estimate of effect; for MODERATE certainty evidence further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate; for LOW certainty evidence further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate; and for VERY LOW certainty evidence any estimate of effect is very uncertain.

*Only level of evidence of the single-forward hop test was assessed as this was used across all outcomes and studies. The level of evidence was found to be very low across all outcomes using this test and so we decided there was not need to complete this assessment for other tests as they would likely yield the same result and have less data from which to draw conclusions of evidence certainty.

KOOS, Knee osteoarthritis outcome score, IKDC, international knee documentation committee score

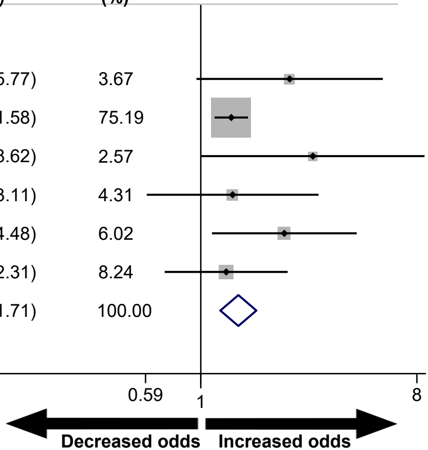


Number of studies = 10 Root MSE = 1.042

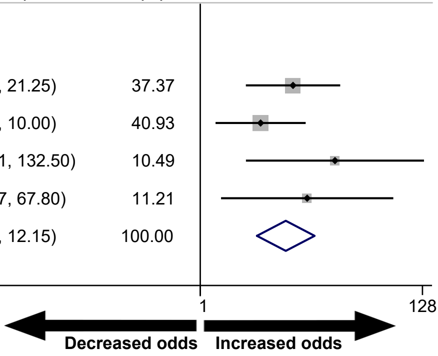
Std_Eff	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
slope	.095743	.1061769	0.90	0.394	-.1491014	.3405874
bias	2.014122	.4626747	4.35	0.002	.9471918	3.081052

Test of H0: no small-study effects P = 0.002

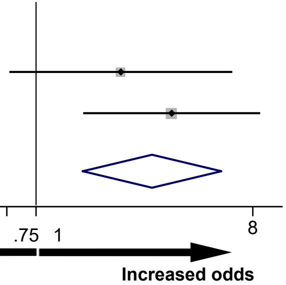
Outcome (KOOS)	Follow-up (years)	Odds ratio (95% CI)	Weight (%)
Better self-reported symptoms & function (KOOS)			
Mansson 2013	2	2.35 (0.96, 5.77)	3.67
Cristiani 2020	2	1.34 (1.14, 1.58)	75.19
Culvenor 2016	3	2.94 (1.00, 8.62)	2.57
Ericsson 2013	5	1.36 (0.59, 3.11)	4.31
Oiestad 2012	15	2.23 (1.11, 4.48)	6.02
Filbay 2021	32-37	1.28 (0.71, 2.31)	8.24
Overall (I^2 = 4.0%, p = 0.391)		1.44 (1.21, 1.71)	100.00



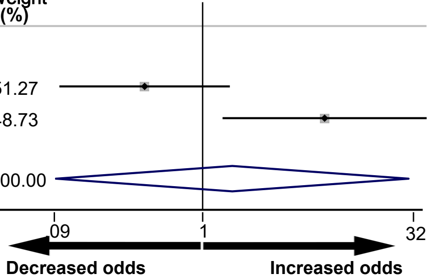
Outcome (IKDC)	Follow-up (years)	Odds ratio (95% CI)	Weight (%)
Better Self-reported symptoms & function (IKDC)			
Stropnik 2020	1	7.58 (2.71, 21.25)	37.37
Logerstedt 2012	1	3.74 (1.40, 10.00)	40.93
Ebert 2019	2	18.95 (2.71, 132.50)	10.49
Welling 2020	2	10.33 (1.57, 67.80)	11.21
Overall (I^2 = 0.0%, p = 0.441)		6.47 (3.45, 12.15)	100.00



Outcome (continuous)		(years)	(95% CI)	(%)
Better self-reported symptoms and function				
Culvenor	2016	3	2.26 (0.77, 6.58)	38.67%
Ericsson 2013		5	3.67 (1.57, 8.59)	61.33%
Overall (I^2 = 0.0%, p = 0.484)			3.04 (1.56, 5.92)	100.00%



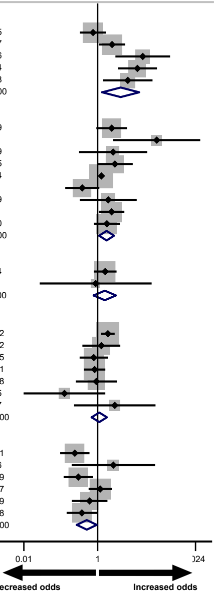
Outcome (dichotomous)	Successful outcome LSI% (n)		Unsuccessful outcome LSI% (n)		Follow-up (years)	Odds ratio (95% CI)	Weight (%)
Better self-reported symptoms and function	**≥90%**	**<90%**	**≥90%**	**<90%**			
Culvenor 2016	38	8	37	3	3	0.39 (0.09, 1.56)	51.27
Ericsson 2013	52	21	2	6	5	7.43 (1.39, 39.80)	48.73
Overall (I^2 = 85.8%, p = 0.008)						1.63 (0.09, 29.59)	100.00



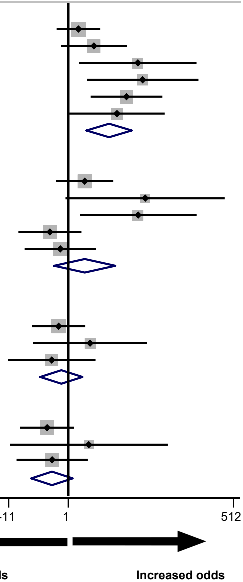
Appendix 10. Sensitivity analysis of repeated forward hop tests (i.e., crossover, triple, 6m-timed) - stratified meta-analysis

Outcomes (Individual hop test subgroup totals)	Odds ratio (95%CI)	Study (n)	Participants (n)	Between hop test heterogeneity (I^2 & p-value)
Return to sport				I^2 = 71.8% p=0.645
Crossover	1.77 (1.05, 296)	7	781	
Triple	2.54 (1.09, 5.92)	6	443	
6m-timed	2.55 (1.2, 5.54)	6	529	
Self-reported symptoms and function				I^2 = 51.9% p=0.978
Crossover	4.96 (1.55, 15.85)	3	228	
Triple	4.48 (1.5, 13.33)	4	380	
6m-timed	5.2 (2.16, 12.53)	2	135	
Success with ACL deficiency				I^2 = 19.6% p=0.843
Crossover	1.51 (0.94, 2.44)	5	437	
Triple	1.27 (0.87, 1.86)	5	337	
6m-timed	1.43 (0.78, 2.63)	5	385	
Subsequent injury after ACL reconstruction				I^2 = 1.2% p=0.175
Crossover	1.03 (0.74, 1.44)	4	663	
Triple	0.85 (0.47, 1.54)	3	334	
6m-timed		2	176	
Knee osteoarthritis				I^2 = 76.7% p=0.014
Crossover	0.141 (0.05, 0.34)	1	78	
Triple	0.737 (0.38, 1.42)	1	181	
6m-timed	0.584 (0.15, 2.27)	1	58	

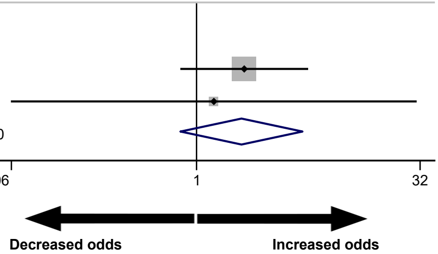
Outcome	Follow-up (years)	Successful outcome LSI% (n) ≥90%	Successful outcome LSI% (n) <90%	Unsuccessful outcome LSI% (n) ≥90%	Unsuccessful outcome LSI% (n) <90%	Odds ratio (95% CI)	Weight (%)
Return to sport							
Toole 2017	1.5	56	20	31	18	0.72 (0.29, 1.83)	22.85
Ardern 2015	2	35	9	28	20	2.78 (1.10, 7.04)	20.07
Ebert 2019	2	39	4	2	5	24.38 (3.52, 168.94)	22.86
Nawasreh 2017	2	36	4	7	13	16.71 (4.19, 66.61)	16.54
Welling 2020	2	44	2	13	5	8.46 (1.47, 48.82)	17.68
Overall (I^2 = 80.8%, p = 0.000)						5.10 (1.37, 18.97)	100.00
Better self-reported symptoms & function							
Logerstedt 2012	1	48	20	8	9	2.70 (0.91, 8.00)	10.99
Ebert 2019	2	41	5	0	4	65.60 (3.01, 1431.81)	5.44
Welling 2020	2	54	6	3	1	3.00 (0.27, 33.58)	14.69
Mansson 2013	2	12	23	4	26	3.39 (0.96, 11.99)	12.35
Cristiani 2020	2	833	395	499	309	1.31 (1.08, 1.57)	10.44
Culvenor 2016	3	28	52	8	5	0.34 (0.10, 1.13)	2.65
Ericsson 2013	5	53	2	25	2	2.12 (0.28, 15.93)	24.89
Oiestad 2012	15	48	26	11	16	2.69 (1.09, 6.63)	4.05
Filbay 2021	32-37	48	7	82	23	1.92 (0.77, 4.82)	14.50
Overall (I^2 = 55.9%, p = 0.020)						1.88 (1.11, 3.20)	100.00
Success with ACL deficiency							
Grindem 2018	2	30	22	20	25	1.70 (0.76, 3.81)	96.04
Ericsson 2013	5	20	0	23	0	0.87 (0.02, 45.87)	3.96
Overall (I^2 = 0.0%, p = 0.744)						1.66 (0.75, 3.65)	100.00
Subsequent injury after ACL reconstruction							
Cristiani 2021	2	3120	1489	91	21	2.07 (1.28, 3.34)	31.22
Falstrom 2021	2	77	12	25	3	1.30 (0.34, 4.98)	11.72
Grindem 2016	2	29	22	11	11	0.76 (0.28, 2.07)	17.15
King 2021	2	39	21	33	22	0.81 (0.38, 1.72)	22.91
Wellstandt 2017	2	44	15	8	3	0.91 (0.21, 3.88)	10.48
van Melick 2021	2	63	6	1	1	0.10 (0.01, 1.72)	3.25
Kyritsis 2016	2	98	11	15	0	3.37 (0.19, 60.33)	3.27
Overall (I^2 = 39.9%, p = 0.125)						1.12 (0.65, 1.93)	100.00
Knee osteoarthritis							
Patterson 2018	5	47	20	7	15	0.20 (0.07, 0.56)	19.11
Wellstandt 2018	5	42	8	8	0	3.05 (0.16, 58.55)	4.86
Pinczewski 2007	10	69	8	22	10	0.26 (0.09, 0.73)	18.99
Oiestad 2012	10-15	20	16	39	26	1.20 (0.53, 2.73)	22.57
Jannssen 2013	10	-	-	-	-	0.56 (0.16, 2.00)	15.99
Filbay 2021	32-37	54	5	53	15	0.33 (0.11, 0.96)	18.48
Overall (I^2 = 54.5%, p = 0.052)						0.46 (0.23, 0.94)	100.00



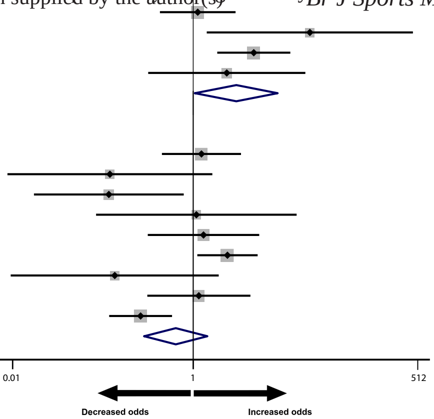
Outcome	Follow-up (years)	Successful outcome LSI% (n) ≥90%	Successful outcome LSI% (n) <90%	Unsuccessful outcome LSI% (n) ≥90%	Unsuccessful outcome LSI% (n) <90%	Odds ratio (95% CI)	Weight (%)
Return to sport							
Toole 2017 (crossover)	1.5	55	21	25	14	1.47 (0.64, 3.35)	26.19
Ardern 2015 (triple)	2	40	4	38	10	2.63 (0.76, 9.11)	20.02
Ebert 2019 (crossover)	2	30	13	1	6	13.85 (1.51, 126.83)	10.43
McGrath 2017 (6m-timed)	2	28	22	1	13	16.55 (2.01, 136.37)	11.16
Nawasreh 2017 (crossover)	2	36	4	10	10	9.00 (2.32, 34.88)	18.54
Welling 2020 (triple)	2	44	2	14	4	6.29 (1.04, 38.06)	13.67
Overall (I^2 = 51.4%, p = 0.067)						4.66 (1.98, 10.97)	100.00
Better self-reported symptoms and function							
Logerstedt 2012 (crossover)	1	46	42	9	8	1.86 (0.63, 5.47)	26.25
Ebert 2019 (crossover)	2	32	14	0	4	18.29 (0.90, 369.61)	10.31
Welling 2020 (triple)	2	56	4	2	2	14.00 (1.54, 127.23)	15.19
Culvenor 2016 (crossover)	3	24	56	6	7	0.50 (0.15, 1.64)	25.01
Oiestad 2012 (triple)	15	84	10	34	3	0.74 (0.19, 2.86)	23.24
Overall (I^2 = 63.5%, p = 0.027)						1.86 (0.59, 5.91)	100.00
Subsequent injury after ACL reconstruction							
Grindem 2016 (crossover)	2	30	21	11	11	0.70 (0.26, 1.91)	63.07
Wellstandt 2017 (crossover)	2	48	11	10	1	2.29 (0.26, 19.82)	13.68
Kyritsis 2016 (crossover)	2	92	9	11	2	0.54 (0.10, 2.82)	23.25
Overall (I^2 = 0.0%, p = 0.550)						0.77 (0.35, 1.72)	100.00
Knee osteoarthritis							
Patterson 2018 (crossover)	5	34	33	7	15	0.45 (0.16, 1.25)	59.23
Wellstandt 2018 (6-m timed)	5	44	6	8	0	2.18 (0.11, 43.03)	6.89
Oiestad 2012 (triple)	10-15	41	3	77	10	0.56 (0.15, 2.16)	33.88
Overall (I^2 = 0.0%, p = 0.619)						0.54 (0.25, 1.19)	100.00



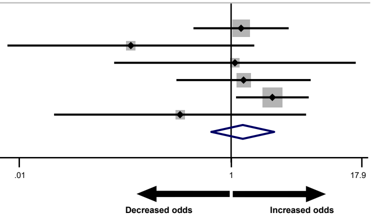
Outcome	Follow-up (years)	Successful outcome LSI% (n)		Unsuccessful outcome LSI% (n)		Odds ratio (95% CI)	Weight (%)
		≥90%	<90%	≥90%	<90%		
Subsequent injury after ACL reconstruction							
Falstrom 2021 (Side hop)	2	63	36	22	6	2.10 (0.78, 5.65)	90.97
van Melick 2021 (Side hop)	2	52	17	2	0	1.31 (0.06, 30.43)	9.03
Overall (I^2 = 0.0%, p = 0.779)						2.01 (0.78, 5.17)	100.00



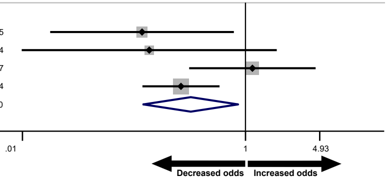
Return to sport							
Toole 2017 (single, cross, triple, 6m-timed hop)	1.5	13	63	6	33	1.13 (0.40, 3.26)	34.76
McGrath 2017 (single, cross, triple, 6m-timed hop)	2	24	26	0	14	25.85 (1.46, 458.12)	12.10
Nawasreh 2017 (single, cross, triple, 6m-timed hop, strength)	2	30	19	7	24	5.41 (1.95, 15.00)	35.45
Welling 2020 (single, triple, side hop, jump/land LESS, strength)	2	6	40	1	17	2.55 (0.28, 22.83)	17.68
Overall (I^2 = 55.3%, p = 0.082)						3.33 (1.05, 10.53)	100.00
Subsequent injury after ACL reconstruction							
Beischer 2020 (single hop, vertical, side hop, strength)	2	33	108	5	13	1.26 (0.42, 3.79)	14.71
Faleide 2021 (single, cross, triple, 6m-timed hop, strength)	2	29	74	0	13	0.10 (0.01, 1.71)	6.34
Grindem 2016 (single, cross, triple, 6m-timed)	2	17	34	1	21	0.10 (0.01, 0.77)	9.21
King 2021 (single hop, SLCJ, SLDJ, strength)	2	1	59	1	54	1.09 (0.07, 17.90)	6.52
Nawasreh 2016 (single, cross, triple, 6m-timed hop, strength)	2	44	44	4	3	1.33 (0.28, 6.31)	11.98
Sousa 2017 (single, vertical, triple hop, strength)	2	41	155	11	16	2.60 (1.12, 6.03)	16.28
van Melick 2021 (single, vertical, side hop)	2	35	55	0	7	0.11 (0.01, 2.04)	6.21
Wellstandt 2017 (single, cross, triple, 6m-timed)	2	41	18	8	3	1.17 (0.28, 4.93)	12.66
Kyritsis 2016 (single, cross, triple hop)	2	104	28	12	14	0.23 (0.10, 0.55)	16.08
Overall (I^2 = 67.3%, p = 0.002)						0.62 (0.26, 1.48)	100.00



Outcome (including strength and other tests)	Follow-up (years)	Successful outcome LSI% (n) ≥90%	Successful outcome LSI% (n) <90%	Unsuccessful outcome LSI% (n) ≥90%	Unsuccessful outcome LSI% (n) <90%	Odds ratio (95% CI)	Weight (%)
Subsequent injury after ACL reconstruction							
Beischer 2020 (single, vertical, side hop, strength)	2	33	108	15	13	1.26 (0.42, 3.79)	27.59
Faleide 2021 (single, cross, triple, 6m-timed hop, strength)	2	29	74	0	13	0.10 (0.01, 1.71)	5.97
King 2021 (single hop, SLC, SLDJ, strength)	2	1	59	1	54	1.09 (0.07, 17.90)	6.21
Nawasreh 2016 (single, cross, triple, 6m timed hop, strength)	2	44	44	4	3	1.33 (0.28, 6.31)	16.97
Sousa 2017 (single, vertical, triple hop, strength)	2	41	16	11	16	2.60 (1.12, 6.03)	37.53
van Melick 2021 (single, vertical, side hop, strength)	2	17	73	0	7	0.31 (0.02, 5.67)	5.74
Overall (I^2 = 22.4%, p = 0.265)						1.31 (0.63, 2.71)	100.00



Outcome (with hops only)	Follow-up (years)	Successful outcome LSI% (n) ≥90%	Successful outcome LSI% (n) <90%	Unsuccessful outcome LSI% (n) ≥90%	Unsuccessful outcome LSI% (n) <90%	Odds ratio (95% CI)	Weight (%)
Subsequent injury after ACL reconstruction							
Grindem 2016 (single, cross, triple, 6m-timed hop)	2	17	34	1	21	0.10 (0.01, 0.77)	18.25
van Melick 2021 (single, vertical, side hop)	2	35	55	0	7	0.11 (0.01, 2.04)	11.14
Wellstandt 2017 (single, cross, triple, 6m-timed hop)	2	41	18	8	3	1.17 (0.28, 4.93)	28.57
Kyritsis 2016 (single, cross, triple hop)	2	104	28	12	14	0.23 (0.10, 0.55)	42.04
Heterogeneity, (I^2 = 44.3%, p = 0.146)						0.29 (0.10, 0.85)	100.00



Appendix 16. Meta-regression results for studies reporting continuous hop scores and association to each outcome

Single-forward hop scores

Outcome	Coefficient (95%CI)	P-value	Adjusted r^2
Follow-up time			
Return to sport	-0.01 (-0.07, 0.04)	0.63	20.74%
Self-reported symptoms and function	-0.00 (-0.003, 0.001)	0.22	3.79%
Success with ACL deficiency	0.00 (-0.003, 0.001)	0.90	52.48%
Subsequent injury after ACL reconstruction	-0.01 (-0.01, 0.01)	0.11	68.43%
Knee osteoarthritis	-0.00 (-0.006, 0.009)	0.48	8.08%
Proportion of females			
Return to sport	-0.49 (-3.48, 2.48)	0.70	23.22%
Self-reported symptoms and function	-0.84 (-5.12, 3.43)	0.66	23.97%
Success with ACL deficiency	-1.63 (-6.09, 2.82)	0.39	9.15%
Subsequent injury after ACL reconstruction	-0.14 (-0.96, 0.67)	0.67	20.15%
Knee osteoarthritis	-2.14 (-26.73, 22.43)	0.74	60.84%

Repeated-forward hop scores

Outcome	Coefficient (95%CI)	P-value	Adjusted r^2
Follow-up time			
Return to sport	0.00 (-0.08, 0.09)	0.90	28.73%
Self-reported symptoms and function	0.00 (-0.01, 0.005)	0.21	39.40%
Success with ACL deficiency	0.00 (-0.01, 0.02)	0.57	-*
Subsequent injury after ACL reconstruction	0.00 (-0.02, 0.01)	0.61	-*
Knee osteoarthritis	0.00 (-0.06, 0.07)	0.52	1.72%
Proportion of females			
Return to sport	-1.77 (-4.77, 1.21)	0.20	15.36%
Self-reported symptoms and function	-6.73 (-26.14, 12.68)	0.35	2.81%
Success with ACL deficiency	-2.89 (-7.33, 1.53)	0.13	-*
Subsequent injury after ACL reconstruction	0.21 (-2.22, 2.65)	0.74	-*
Knee osteoarthritis	3.93 (-170.94, 178.81)	0.82	95.31%

ACL, anterior cruciate ligament
*Indicates values that were not able to be calculated