A Retrospective Descriptive Analysis of Return to Sport Tests and Outcomes Following Anterior Cruciate Ligament Reconstruction Surgery

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ABSTRACT

This retrospective descriptive analysis investigated return to sport (RTS) test performance, clinical factors, and sport resumption levels in a cohort of 165 individuals in Aotearoa New Zealand following anterior cruciate ligament (ACL) reconstruction surgery. Participants were referred for a standardised testing battery involving strength, horizontal hop, vertical jump, and psychological readiness assessments between 2021 and 2025. Findings revealed that while 75% of participants returned to some form of sport, only 43% resumed their pre-injury levels. Horizontal hop tests showed the highest pass rates, whereas strength and vertical jump tests had the lowest, with fewer than half of participants meeting common symmetry thresholds. Psychological readiness demonstrated the strongest association with successful RTS and was significantly lower in those with prior injury or lateral tenodesis procedures. Bone-patella tendon-bone (BPTB) grafts were associated with lower knee extension symmetry, while pre-surgery rehabilitation was associated with superior hamstring symmetry. Achieving higher limb symmetry thresholds (≥ 95%) was not associated with higher rates of return to pre-injury levels of sport. These results indicate significant functional deficits at a mean of 52 weeks post-surgery and suggest that RTS decisions should integrate physical, psychological, and contextual factors.

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries are common in pivoting and cutting sports such as football, netball, and rugby, and have significant physical, psychological, and performance-related consequences for athletes (Ardern et al., 2014; Grindem et al., 2016; Nagelli & Hewett, 2017). Injury incidence ranges from 30 to 78 per 100,000 person-years (Pryymachenko et al., 2023; Sanders et al., 2016), with ACL reconstruction (ACLR) surgery rates rising, particularly among younger and female populations (Paudel et al., 2023; Sutherland et al., 2019). For those intending to return to high-risk sport, ACLR surgery is the most common treatment pathway (Filbay & Grindem, 2019; Meredith et al., 2020).

While return to sport (RTS) following ACLR surgery is often used as a key rehabilitation milestone, outcomes are variable. Up to 80% of individuals are reported to return to some form of sport (Figueroa et al., 2024), with fewer than half returning to their previous level of performance (Ardern et al., 2014; Ardern et al., 2011; Brophy et al., 2012). Resuming sport is associated with a heightened risk of graft or contralateral ACL injury (Cronström et al., 2021; Webster & Feller, 2020). Secondary injury rates are reported up to 24% in athletes who return to pivoting sports without meeting criterion-based targets (Grindem et al., 2016). In younger cohorts, this can reach 33% within 3 to 5 years after ACLR (Webster et al., 2021).

To support safe RTS, test batteries assessing strength, hop, and jump performance, and psychological readiness are commonly used (Burgi et al., 2019). While meeting RTS criteria is associated with reduced re-injury risk (Grindem et al., 2016; Kyritsis et al., 2016; Webster & Hewett, 2019), the lack of standardised protocols has led to inconsistent test selection and pass rates. A recent meta-analysis found that overall pass rates range widely from 18.8% to 88.1%, with only one third successfully clearing RTS test batteries (Hurley et al., 2022).

These outcomes are complicated as RTS is not determined by physical recovery alone. Theoretical frameworks conceptualise successful RTS as the result of interactions between physical capacity, psychological responses, and contextual factors (Brewer, 2007; Brewer & Redmond, 2016; Wiese-Bjornstal et al., 1998). Consequently, physical testing provides important but incomplete information regarding readiness for sport participation. In Aotearoa New Zealand, contextual factors are uniquely shaped by the Accident Compensation Corporation (ACC), which funds surgical and rehabilitation costs for accident-related injuries (Fausett et al., 2022; O'Brien et al., 2023). To operationalise evidence-based RTS constructs within a pragmatic model of care, Integrated Care Pathways (ICP) have emerged. These pathways aim to standardise rehabilitation processes by reducing financial barriers and mandating objective assessments to guide RTS decisions (Accident Compensation Corporation, 2025; Careway, n. d.).

However, there remains a paucity of literature describing how RTS test batteries perform in routine clinical practice. While several cohort studies have established relationships between standard limb symmetry thresholds and successful sport resumption or reduced re-injury risk (Grindem et al., 2016; Ithurburn et al., 2019), few have assessed whether achieving higher physical test thresholds provides superior value, or whether psychological and contextual factors play a more prominent role.

Therefore, the primary purpose of this study was to provide a retrospective descriptive analysis of RTS test outcomes following ACLR within a specialised physiotherapy clinic in Aotearoa New Zealand (KneeCare). The aims were to:

1) describe RTS test performance and pass rates across a battery of strength, hop, jump, and psychological readiness assessments

2) examine associations between physical performance, psychological readiness, clinical factors, and RTS status

3) explore whether achieving higher limb symmetry thresholds (≥ 95%) is associated with superior RTS outcomes.

METHODS

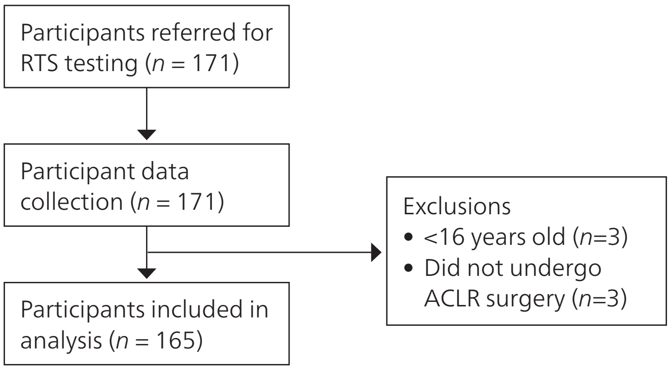
Study design and participants

This retrospective study analysed data collected as part of a RTS test battery from a specialised physiotherapy clinic in Aotearoa New Zealand. The study was approved by Auckland University of Technology Ethics Committee (reference number 24/203).

The data collection process, outlined in Figure 1, ranged from July 2021 to January 2025. A total of 172 patients who had sustained an ACL rupture were initially included. Inclusion criteria for analysis were 1) completion of ACLR surgery, 2) aged 16 years or older, and 3) referral for RTS testing as part of rehabilitation. The final sample size for analysis was 165.

Figure 1

Flow Diagram Illustrating Data Collection Process and Participant Selection Criteria



Note. ACLR = anterior cruciate ligament reconstruction.

Data collection

All testing was conducted in a standardised manner by experienced physiotherapists trained in the test protocol. RTS status was obtained between November 2024 and January 2025 via a structured email and telephone follow-up. Individuals reported whether, at the conclusion of rehabilitation, they 1) returned to full levels of participation in sport, 2) returned to moderate levels, 3) returned to low levels, 4) did not return to sport, or (5) choose a different sport that did not stress the knee.

Written informed consent was obtained from all patients for their data to be used for research purposes. Identifiable data were removed by the clinic administrator, and all analyses were conducted on de-identified datasets.

RTS testing protocol

The RTS test protocol was developed to benchmark rehabilitation outcomes and support RTS decision-making. It evolved over time in line with best practice guidance and technology availability (Kotsifaki et al., 2023; van Melick et al., 2016). Strength and horizontal hop tests were assessed across the collection window, whereas vertical jump testing was integrated in 2023, resulting in smaller sample sizes.

The criteria for passing individual tests were a limb symmetry index (LSI) of ≥ 90%, based on established literature (Filbay & Grindem, 2019; Kotsifaki et al., 2023; Meredith et al., 2020). Variability in test completion was influenced by clinical appropriateness, familiarity with specific tests, and specific instructions from the referring surgeon.

Strength

Strength assessment of the quadriceps and hamstrings was conducted using an isokinetic dynamometer (IKD; Biodex System, Biodex Medical Systems Inc., Shirley, NY, USA). Concentric peak torque was assessed at an angular velocity of 90°/s. While guidelines favour 60°/s for isolating absolute peak torque (van Melick et al., 2016), a testing velocity of 90°/s was pre-established within the clinical infrastructure as a moderate-velocity protocol. This speed captures muscle function under more dynamic conditions than slower speeds, while remaining highly sensitive to persistent asymmetric deficits across the recovery spectrum (Culiver et al., 2025). It is acknowledged that thresholds are protocol specific and should be interpreted within this context.

Participants completed three maximal voluntary contractions for each muscle group, with the highest value used for analysis. LSI was calculated as (involved limb/uninvolved limb) x 100. This method has demonstrated excellent test-retest reliability at an angular velocity of 90°/s (intraclass correlation coefficients; ICC 0.91–0.95) (Ferri-Morales et al., 2014).

Hop and jump performance

Horizontal hop performance was assessed using the single leg hop for distance (SLH) and 30-second timed lateral hop (LH) tests. SLH and LH tests are well established in the literature and have demonstrated good to excellent reliability (ICC 0.84–0.97 and 0.92–1.0) (Fältström et al., 2023; Ross et al., 2002).

Participants were provided with standardised demonstrations and verbal instructions as described in Appendix A. Participants completed two practice trials followed by three recorded trials. The best performance for each limb was used for analysis, and LSI was calculated as previously described.

Vertical jump performance was evaluated using VALD ForceDecks (VALD Performance, Brisbane, Australia) for single leg vertical jump (SLVJ) and single leg drop jump (SLDJ) tests. ForceDecks are validated systems for assessing jump performance with excellent measurement reliability (ICC > 0.90) (Collings et al., 2024; Stålbom et al., 2007). Jump height was calculated using the flight-time method, which utilises a projectile-motion equation ($h = gt2/8$) based on airborne time (Beckham et al., 2014; Cormack et al., 2008). Jump height values were subsequently converted to centimetres, then LSI.

While the flight-time method is reliable when using automated ForceDecks thresholding (Beckham et al., 2014; Cormack et al., 2008), it remains limited by the assumption of fully extended lower limbs at both take-off and landing. Increased joint flexion upon landing can lower the centre of mass relative to take-off, potentially overestimating jump height (Yamashita et al., 2020). The impulse-momentum method is simultaneously compiled by the system and represents the standard for jump height accuracy by eliminating landing-phase joint compensation strategies (Xu et al., 2023). However, flight time was the standardised operational parameter extracted and recorded within the retrospective clinical registry. This should be considered when interpreting the results.

Psychological readiness

Psychological readiness was assessed using the ACL-RTS after Injury (ACL-RSI) scale (Webster et al., 2008). This 12-item questionnaire assesses emotions, confidence, and risk appraisal related to RTS, with scores ranging from 0 to 100. Higher scores indicate greater psychological readiness. Although the ACL-RSI has demonstrated excellent internal consistency and test-retest reliability (ICC 0.93) (Slagers et al., 2017), it was not used as a pass/fail criterion in this cohort.

Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 30). Descriptive statistics were used to summarise participant demographics and clinical characteristics.

Prior to inferential testing, data were examined for statistical assumptions. Normality was assessed using Shapiro-Wilk tests and inspection of Q-Q plots and histograms. Homogeneity of variance for parametric analyses was evaluated using Levene's test. Statistical methods were selected based on the distribution of RTS test performance outcomes. For normally distributed measures, one-way analysis of variance (ANOVA) was used to assess differences across categorical variables. Where significant ANOVA results were found, Bonferroni-adjusted post-hoc tests were applied to control for Type I error inflation.

For outcomes not meeting normality or variance assumptions, non-parametric tests were used: Kruskal-Wallis tests for comparisons involving more than two groups, Mann-Whitney U tests for two-group comparisons, and independent-samples median tests where appropriate. Significant Kruskal-Wallis results were followed by Bonferroni-corrected pairwise Mann-Whitney U tests. Associations between RTS test outcomes and continuous variables that were non-normally distributed were analysed using Spearman's rank correlation.

Chi-square tests of independence were employed to explore associations between passing all tests, passing individual tests, ACL-RSI scores, and RTS status. To explore whether higher RTS test performance was associated with superior RTS outcomes in the secondary analysis, test scores were dichotomised into two groups: < 95% and ≥ 95%. Due to low expected cell counts, RTS status was re-categorised into three groups: (1) full RTS (return to full levels of participation in sport), (2) partial RTS (return to moderate levels of sport), and (3) did not return to previous levels or chose a different sport that did not stress the knee.

A significance level of $p < .05$ was used for all analyses. Effect sizes were calculated for all primary inferential tests. Hedges' g was employed for-group based comparisons to provide a standardised mean difference with magnitudes interpreted as small (0.2), medium (0.5), and large (0.8). For associations between continuous variables, Spearman's rank correlation was utilised. The strength of association was reported using the correlation coefficient (ρ): interpreted as weak (0.10–0.29), moderate (0.30–0.49), and large (≥ 0.50).

RESULTS

A total of 165 participants were included in the final analysis. Participant demographics and clinical characteristics are summarised in Table 1.

Table 1

Participant Demographics and Clinical Characteristics

Demographics and characteristics	*n* [a]	% [a]
Sex		
Male	120	72.7
Female	45	27.3
Age (years), *M (SD)*	28.57	8.82
Height (cm), *M (SD)*	176.0	8.99
Weight (kg), *M (SD)*	81.9	16.16
BMI (kg/m^2) *M (SD)*	26.4	4.55
Ethnicity		
European	88	53.3
Māori	18	10.9
Asian	22	13.3
Middle Eastern, Latin American, and African (MELAA)	7	4.2
Pasifika	8	4.8
Other/not stated	22	13.3
Sport at time of injury		
Football (soccer)	45	27.3
Rugby	42	25.5
Basketball	15	9.1
Netball	14	8.5
Martial arts	5	3.0
Snowsports	4	2.4
Motocross	3	1.8
Badminton	2	1.2
Surfing	2	1.2
Other [b]	8	4.8
Not reported	25	15.2
Injury mechanism		
Contact	33	20.0
Non-contact	113	68.5
Not reported	19	11.5
Return to sport status		
Return to full levels of participation in sport	48	29.1
Return to moderate levels of participation in sport	18	10.9
Return to low levels of participation in sport	10	6.1
Did not return to previous levels of participation in sport	27	16.4
Chose a different sport that did not stress the knee	8	4.8
Not reported	54	32.7
Pre-surgery rehabilitation		
Yes	110	66.7
No	54	32.7
Not reported	1	0.6
Graft type		
Hamstring tendon	109	66.1
Bone-patellar tendon-bone	47	28.5
Quadriceps tendon	9	5.5
Lateral tenodesis performed		
Yes	34	20.6
No	131	79.4
Previous ipsilateral ACL injury		
Yes	33	20.0
No	132	80.0
Previous contralateral ACL injury		
Yes	25	15.2
No	138	83.6
Not reported	2	1.2
Time to surgery (weeks)	21.07	32.85
Time from surgery to return to sport testing (weeks)	52.94	19.06

Note. ACL = anterior cruciate ligament.

[a] Unless otherwise indicated; [b] Other sports included trampoline, Gaelic football, cricket, skateboarding, Australian Football League, ultimate frisbee, athletics, and hockey (1 participant each).

The cohort had a *M* (*SD*) age of 28.57 (8.82) years, height of 176 (8.99) cm, weight of 81.9 (16.16) kg, and body mass index (BMI) of 26.4 (4.55) kg/m^2. The sample was predominantly male (72.7%). The most reported sports at the time of injury were football (27.3%) and rugby (25.5%), with a wide range of other sports represented. Most injuries occurred through non-contact mechanisms (68.5%).

The median time from injury to surgery was 11.1 weeks, and RTS testing was performed at a mean of 52.94 weeks post-surgery. Pre-surgery rehabilitation was completed by 66.7% of participants. Hamstring tendon grafts were the most common reconstruction type (66.1%), followed by bone-patellar tendon-bone (BPTB; 28.5%) and quadriceps tendon grafts (5.5%). A lateral extra-articular tenodesis was performed in 20.6% of cases.

Among the participants who responded with their RTS status (67.9%), 75% returned to some form of sport, yet only 42.9% returned to their pre-injury level. One quarter of respondents did not return to their previous sport, and 7.1% transitioned to a different sport. To evaluate potential attrition bias, baseline characteristics, test performance metrics, and psychological readiness scores were compared between survey responders and non-responders (Appendix B). There were no statistically significant differences between groups across any baseline variables ($p \geq .085$).

RTS test performance and pass rates

The primary outcomes were associations between demographic and clinical variables, RTS test performance and the proportion of participants passing each RTS test, and RTS status. Of the clinical cohort, 28.7% completed all tests. Within this subgroup, 38.3% successfully passed all tests. Individual test pass rates are shown in Table 2.

Horizontal hop tests demonstrated the highest pass rates, with 77.3% of participants achieving ≥ 90% LSI on the SLH and 66.7% on the LH. In contrast, strength and vertical jump tests demonstrated lower pass rates. Knee extension strength symmetry met the ≥ 90% LSI threshold in 48.5% of participants, while knee flexion symmetry met this threshold in 58.9%. Vertical jump performance also demonstrated lower symmetry. Pass rates were 48.6% for the SLVJ and 45.8% for the SLDJ.

Table 2

Return To Sport Test Outcomes and Pass Rates

Outcome measure	*M*	*SD*	Valid	Passed	Pass rate (%)
Single leg hop					
Affected limb (cm)	110.03	27.45	—	—	—
Unaffected limb (cm)	115.36	25.28	—	—	—
Limb Symmetry Index (%)	95.10	10.10	132	102	77.3
Lateral hop			—	—	—
Affected limb (*n*)	42.90	15.89	—	—	—
Unaffected limb (*n*)	45.35	15.01	—	—	—
Limb Symmetry Index (%)	93.84	14.41	108	72	66.7
Single leg vertical jump					
Affected limb (cm)	13.12	4.63	—	—	—
Unaffected limb (cm)	15.09	4.71	—	—	—
Limb Symmetry Index (%)	86.86	14.93	109	53	48.6
Single leg drop jump					
Affected limb (cm)	14.45	5.21	—	—	—
Unaffected limb (cm)	16.42	5.23	—	—	—
Limb Symmetry Index (%)	88.14	15.30	59	27	45.8
Knee extension peak torque 90°/s					
Affected limb (Nm)	191.58	55.09	—	—	—
Unaffected limb (Nm)	221.22	57.53	—	—	—
Limb Symmetry Index (%)	86.88	12.07	163	79	48.5
Knee flexion peak torque 90°/s					
Affected limb (Nm)	97.81	29.56	—	—	—
Unaffected limb (Nm)	106.71	28.46	—	—	—
Limb Symmetry Index (%)	91.63	12.24	163	96	58.9
Psychological Readiness					
ACL-RSI	60	22	143	—	—

Note. ACL-RSI = Anterior cruciate ligament Return to Sport after Injury scale

Age was significantly and negatively associated with SLH (ρ = –.233, *p* = .008), LH (ρ = –.242, *p* = .012), SLVJ (ρ –.274, *p* = .004) and knee extension strength symmetry (ρ = –.162, *p* = .040). Similarly, BMI was significantly and negatively associated with knee extension (ρ = –.211, *p* = .007) and knee flexion strength symmetry (ρ = –.179, *p* = .023). These weak inverse associations suggest that advancing age and higher BMI are associated with lower limb symmetry scores. There were no other significant associations between RTS test performance and demographical variables (Appendix C).

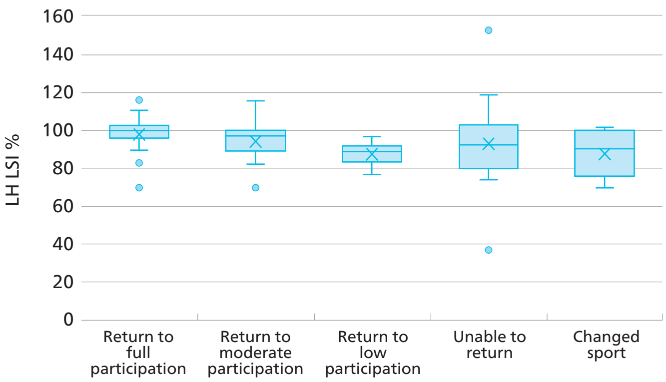
Physical performance, psychological readiness, clinical factors, and RTS status

There were no statistically significant associations between passing all RTS tests and RTS status (*p* = .860). Within the sub-cohort who passed all tests, 33.3% returned to pre-injury sport levels, 16.7% returned to moderate levels, 0% returned to low levels, 16.7% did not return to their previous sport, 5.6% chose an alternative sport minimising knee stress, and 27.8% were unreported. In comparison, among those who completed the battery but did not pass all performance thresholds, 10.3% returned to pre-injury levels, 51.7% returned to moderate levels, 0% returned to low levels or chose an alternative sport, 24.1% did not return to their previous sport, and 13.9% were unreported.

Limb symmetry in the LH differed significantly across RTS categories (*p* = .041; Fig 2). Participants who returned pre-injury sport levels demonstrated the highest median LH symmetry (*Mdn* 100, IQR 95.5–102.9) compared to all other categories. Post-hoc analysis revealed a small-to-medium effect size for the difference between the full RTS and those who did not RTS (*g* = 0.35).

Figure 2

Lateral Hop Limb Symmetry Index Percentages Across Different RTS categories



Note. LH = lateral hop; LSI = Limb Symmetry Index; RTS = return to sport.

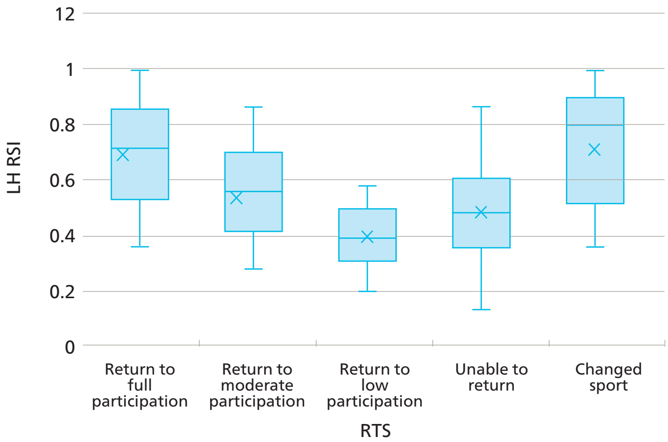
The box plots illustrate *Mdn* scores, interquartile ranges, and outliers for participants who achieved full, moderate, or low return levels, as well as those who did not RTS or changed sports. Participants who fully returned to sport participation demonstrated the highest *Mdn* symmetry scores (*Mdn* = 100) compared to all other return categories.

No consistent associations were observed between RTS status and knee extension strength (*p* = .660), knee flexion strength (*p* = .294), SLVJ (*p* = .503), or single leg drop jump symmetry (*p* = .827).

ACL-RSI scores differed significantly across RTS categories (*p* < .001; Fig 3). Participants who returned to pre-injury sport levels reported higher psychological readiness (*Mdn* 71.7, IQR 53–86.7) compared with those who returned at moderate (*Mdn* 50, IQR 38–70.3) or low levels (*Mdn* 39, IQR 27.9–50.7), and those who did not to return (*Mdn* 47.5, IQR 34.5–60.4). Post-hoc analysis comparing full RTS to those who did not RTS demonstrated a large effect size (*g* = 1.08). Participants who changed sport reported similarly high ACL-RSI scores (*Mdn* 80, IQR 48.3–91.7).

Figure 3

Psychological Readiness Scores (ACL-RSI) According to RTS Status



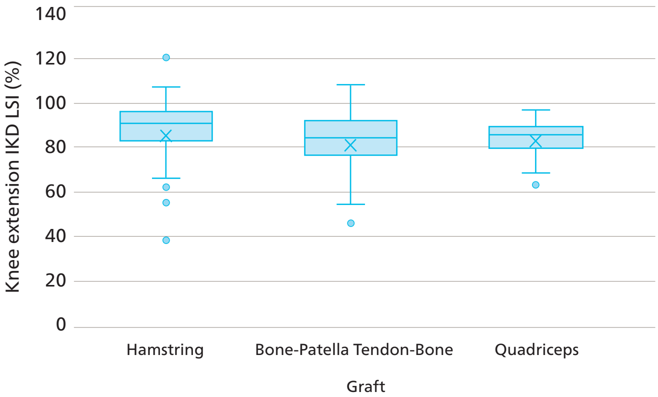
Note. ACL-RSI = ACL Return to Sport After Injury (ACL-RSI) scale; RTS = return to sport. This box plot shows an association between higher psychological readiness and achieving a full return to sport pre-injury sport levels or changing to a different sport, compared to those with lower levels of return.

Participants with a previous ipsilateral ACL injury demonstrated significantly lower ACL-RSI scores compared with those without prior injury (*p* = .024). Similarly, participants who underwent a lateral extra-articular tenodesis reported lower ACL-RSI scores than those who did not (*Mdn* 47.7, IQR 34.1–61.5 vs *Mdn* 60, IQR 43.1–81.4; *p* = .019). Both findings represent small-to-medium effect sizes (*g* = 0.38 and 0.42, respectively).

Graft type was significantly associated with knee extension symmetry (*p* = .002; Fig 4). Post-hoc analysis revealed that participants with BPTB grafts achieved significantly lower extension symmetry compared to those with hamstring tendon grafts (*M* (*SD*) 77.3% (16.6) vs 88.6% (14.9)), representing a medium-to-large effect size (*g* = 0.73). No significant differences were observed between graft types for any other physical performance measures.

Figure 4

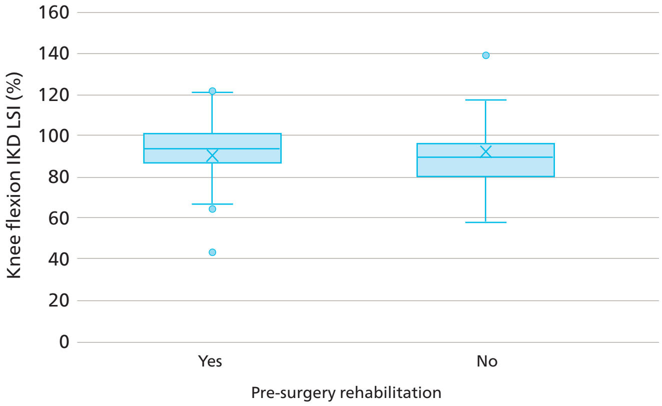
Knee Extension Isokinetic Strength Symmetry (90°/s) Categorised by Surgical Graft Type



Note. IKD LSI = isokinetic dynamometer limb symmetry index. Participants with bone-patellar tendon-bone (BPTB) grafts demonstrated significantly lower knee extension symmetry compared to those with hamstring or quadriceps tendon grafts.

Figure 6

Impact of Pre-surgery Rehabilitation on Knee Flexion Isokinetic Strength Symmetry



Note. IKD LSI = isokinetic dynamometer limb symmetry index. Individuals who completed a structured pre-surgery program demonstrated significantly higher median hamstring strength symmetry at the time of testing.

No statistically significant differences were observed in knee flexion strength symmetry between graft types (p = .106), although a trend toward higher flexion symmetry was observed in the BPTB group (Fig 5).

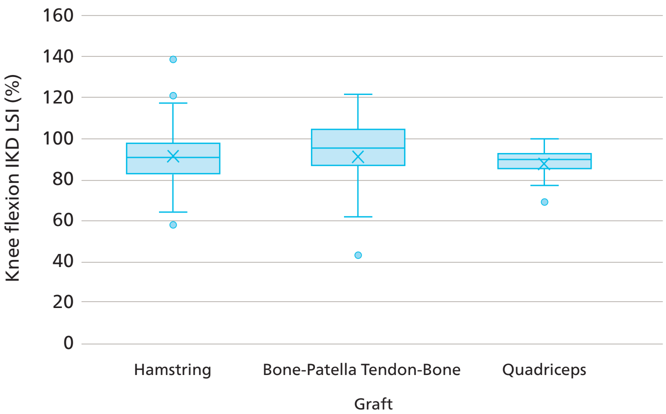
Completing pre-surgery rehabilitation was significantly associated with higher knee flexion strength symmetry (M (SD) 92.4% (10.8)) compared to those who did not (M (SD) 87.2% (12.9); p = .007; Fig 6). This represents a small-to-medium effect size (g = 0.45).

Higher LSI Thresholds and RTS outcomes

In secondary analyses, individual RTS test scores were dichotomised using a ≥ 95% LSI threshold to examine whether higher symmetry values were associated with superior RTS outcomes. Achieving a ≥ 95% LSI threshold in the LH test was significantly associated with RTS outcomes (p = .012). However, there were no statistically significant associations between RTS outcomes and higher LSI thresholds in knee extension or flexion strength (p = .054 and .207), SLH (p = .712), SLVJ (p = .305), or single leg drop jump (p = .649).

Figure 5

Comparison of Median Knee Flexion Isokinetic Strength Symmetry Across Different Graft Types



Note. IKD LSI = isokinetic dynamometer limb symmetry index. No statistically significant differences were observed between participants with hamstring, BPTB, or quadriceps tendon grafts.

DISCUSSION

This study provides a comprehensive description of RTS test performance and outcomes following ACLR surgery within a specialised physiotherapy clinic in Aotearoa New Zealand. Overall, 75% of participants who reported their RTS status returned to some form of sport, though only 43% returned to their pre-injury level. Moreover, passing the entire test battery was not significantly associated with RTS status. These findings are consistent with existing literature indicating that many athletes fail to regain pre-injury levels of sport participation or performance (Ardern et al., 2014; Brophy et al., 2012; Webster & Feller, 2019).

With nearly 70% of injuries in this cohort being non-contact, RTS protocols must prioritise neuromuscular control during deceleration and change of direction (COD) tasks (Waldén et al., 2015). Standard distance-based hop tests often lack the sensitivity required to detect kinetic chain compensations, as underlying quality metrics such as rate of force development (RFD), peak power, reactive strength, and force attenuation often remain impaired (Gokeler, Welling, Benjaminse, et al., 2017; Kotsifaki et al., 2021).

While reactive agility tasks are superior for evaluating neuromuscular control and replicating sport-specific loads (Correa et al., 2023; Kyritsis et al., 2016), traditional metrics based on total elapsed time also lack the sensitivity to detect deficits in the ACLR limb (Buckthorpe et al., 2019; King et al., 2018; Marques et al., 2020). Future RTS protocols should prioritise limb-specific biomechanical assessment, including joint kinematics, ground reaction forces, and contact times, to provide a more robust reflection of functional readiness.

RTS test performance and pass rates

Across the RTS tests used in this study, the highest pass rate was observed in the SLH (77%), while strength and vertical jump performance measures had substantially lower pass rates (< 50%). These findings highlight persistent functional deficits at a mean of 52 weeks post-surgery and reflect ongoing challenges in regaining symmetry in key neuromuscular domains. The observed inverse associations between age, BMI, and strength, hop, and jump symmetry suggest that demographic factors contribute to these deficits by influencing the trajectory of recovery; specifically, older age and higher BMI are prognostic indicators of lower functional recovery plateaus and slower rates of improvement (Price et al., 2026).

The low knee extension strength pass rates are consistent with real-world clinical cohorts balancing outpatient care with daily occupational demands (Rivera-Brown et al., 2022), contrasting with the higher pass rates in tightly controlled trials with elite athletes (Kyritsis et al., 2016). Moreover, earlier restoration of horizontal hop test symmetry relative to quadriceps strength aligns with prior research (Grindem et al., 2016) and reinforces the understanding that limb symmetry may recover differentially depending on the type of task assessed.

Vertical jump testing appeared more sensitive to persistent deficits than horizontal hops. Unlike horizontal hopping, vertical tasks restrict hip- and ankle-dominant strategies that compensate for inadequate knee efficiency (Rivera-Brown et al., 2022). Vertical jumps demand greater concentric and eccentric force production, RFD, and intermuscular coordination compared with horizontal hopping, which may be more reliant on elastic energy storage and limb stiffness strategies (Davies et al., 2020; Gokeler, Dingenen, et al., 2017). Consequently, vertical jump asymmetries may better reflect residual neuromuscular impairments post-ACLR (Gokeler, Dingenen, et al., 2017; Korakakis et al., 2021).

While the single leg drop jump is commonly conceptualised as a fast stretch shortening cycle task, characterised by a rapid transition from an eccentric muscle lengthening phase to a powerful concentric contraction, the absence of contact time data in this study limits the interpretation of reactive strength or energy recycling capacity (Kotsifaki et al., 2021). Accordingly, the single leg drop jump findings should be interpreted primarily as indicators of vertical force production symmetry rather than reactive neuromuscular efficiency. This distinction cautions against over-interpreting this metric based on traditional performance literature as this may risk misinterpreting the results (Davies et al., 2020; Wellsandt et al., 2017).

Physical performance, psychological readiness, clinical factors, and RTS status

Another central finding of this study was that physical performance symmetry measures demonstrated limited ability to discriminate between RTS outcomes. Except for LH symmetry, physical tests were not significantly associated with RTS status when analysing standard or higher LSI. Although a higher proportion of participants who passed the entire battery achieved pre-injury sport resumption compared to those who did not (33.3% vs 10.3%), this association lacked statistical significance due to low statistical power and small sub-cohort cell sizes. These findings challenge the implicit assumption that exceeding symmetry thresholds reflects readiness for sport participation and suggest that LSI alone may be an insufficient marker of functional recovery.

While LSI is widely used in both research and clinical practice, increasing evidence suggests that reliance on LSI alone may overestimate functional recovery due to contralateral deconditioning and global neuromuscular impairment (Davies et al., 2020; Gokeler, Welling, Benjaminse, et al., 2017; Wellsandt et al., 2017; Zwolski et al., 2016). Consequently, individuals may achieve acceptable symmetry despite both limbs performing below relative benchmarks associated with safe sport participation (Davies et al., 2020).

In this study, mean relative knee extension peak torque values were approximately 2.3 Nm/kg on the involved limb and 2.6 Nm/kg on the uninvolved limb. These scores sit below commonly cited benchmarks of ≥ 3.0 Nm/kg (Gokeler, Welling, Zaffagnini, et al., 2017; Kuenze et al., 2015). However, these are often derived from male-dominated analyses, which can oversimplify RTS tracking (Bodkin et al., 2025). When mapping objective progression toward RTS at 9 months post-op, normative values for females are reported as 2.23 Nm/kg (involved) and 2.68 Nm/kg (uninvolved), compared to 2.78 Nm/kg (involved) and 3.18 Nm/kg (uninvolved) in males (Schwery et al., 2022). Relative torque benchmarks should be interpreted alongside standard symmetry indices in RTS decision-making processes to provide a safeguard against the false reassurance of LSI metrics.

Psychological readiness, particularly confidence and fear of re-injury, strongly influences return behaviour and often predicts RTS more accurately than strength, hop, and jump symmetry (Ardern et al., 2013; Kvist et al., 2005). External factors such as team selection, level of competition, time demands, and personal priorities may also prevent RTS even when physical criteria are met (Ardern et al., 2011). Conversely, some athletes return despite failing physical tests due to motivation or competitive pressures (Losciale et al., 2021; Wilk et al., 2023). Physical test thresholds represent only one part of the recovery profile and fail to capture real-world barriers or facilitators of return.

Correspondingly, psychological readiness was significantly associated with RTS status in this study. Participants who achieved full return to pre-injury sport reported significantly higher ACL-RSI scores than those who returned at lower levels or did not return. Participants who changed sport also reported high psychological readiness, suggesting that confidence and emotional readiness may reflect preparedness to engage in sporting activity more broadly. These findings align with biopsychosocial models of RTS, which emphasise that cognitive and emotional responses to injury play a central role in return outcomes (Brewer, 2007; Wiese-Bjornstal et al., 1998).

Further, psychological readiness scores were significantly lower in individuals with previous ipsilateral ACL injury and those who had undergone a lateral extra-articular tenodesis, suggesting an increased psychological burden. Lower readiness among lateral extra-articular tenodesis patients appears paradoxical given the procedure's success in reducing rotatory laxity (Devitt et al., 2017). However, lateral extra-articular tenodesis candidates typically present with greater ligamentous laxity, or a young age combined with an intended return to pivoting sports (Getgood et al., 2020). The awareness of these risks, alongside the increased perceived magnitude of an augmented surgery, may increase kinesiophobia and lower self-efficacy. This is compounded by the short-term morbidity of the procedure, which involves vastus lateralis retraction and an extra lateral incision, resulting in increased early post-operative pain, reduced quadriceps strength, and lower subjective recovery up to six months post-surgery (Getgood et al., 2020).

While it is important to interpret the association between ACL-RSI and RTS status with caution as this study did not account for potential mediators (e.g., pre-injury competitive level, persistent pain, or stiffness), the findings suggest that psychological readiness should be considered a complementary construct rather than a surrogate for physical readiness. RTS decision-making should integrate psychological readiness with objective physical performance and contextual considerations.

Another factor associated with test performance was graft type. Participants with BPTB grafts exhibited lower knee extension LSI compared to those with hamstring or quadricep tendon grafts, consistent with previous research highlighting quadriceps morbidity and anterior knee pain associated with BPTB grafts (Biau et al., 2007; Feller & Webster, 2003). Conversely, knee flexion symmetry was slightly higher in those with BPTB grafts, although this trend did not reach significance. This aligns with expectations, as hamstring grafts typically involve harvesting semitendinosus and/or gracilis, which may impair flexor strength (Ardern et al., 2010; Tashiro et al., 2003).

Progressive pre-surgery neuromuscular loading has been shown to optimise post-operative recovery, including quadriceps strength and objective functional (Eitzen et al., 2010; Potts et al., 2022). In this study, pre-surgery rehabilitation was positively associated with knee flexion strength symmetry, although this effect was not observed across all test domains. A key limitation in explaining this discrepancy is that our data was captured via an intake questionnaire at the time of testing, which documented whether a participant had engaged in pre-surgery rehabilitation, without detailed information regarding the composition, duration, or intensity. It is probable that the unstandardised nature of the rehabilitation completed by this cohort lacked the specific neuromuscular adaptations required to optimise post-operative performance outcomes.

While there were no significant associations were found between test performance and ethnicity, this study’s findings offer an opportunity to contextualise our data within broader national patterns of ACL injury incidence. Pacific peoples are reported to have the highest age- and sex-adjusted cruciate ligament injury incidence rates in Aotearoa New Zealand (214 per 100,000), followed by Europeans (187), Māori (182), and Asians (108) (Pryymachenko et al., 2023). Despite this, Māori and Pasifika together represented only 15% of our cohort. While they experience disproportionately high injury rates, they appear under-represented in this study. A probable explanation for this relates to the clinic's geographical location; however, socioeconomic barriers and healthcare access inequities may reduce the likelihood of receiving surgical intervention or access to rehabilitation services among these populations (Nordenvall et al., 2017; Testa et al., 2023).

Finally, our data reveals a gap between the intended purpose of the ICP and clinical practice. While designed to enforce standardised, uniform testing processes, the variability in test completion rates and tracking milestones demonstrates that a formalised care pathway does not automatically guarantee uniform clinical behaviour. This indicates that real-world execution remains heavily dependent on contextual factors.

Clinical implications

Collectively, these findings emphasise that current RTS test protocols should be used to inform, rather than dictate, RTS decisions. This study suggests that while such testing remains a valuable clinical tool, it is an incomplete one. Many participants demonstrated significant functional deficits at a mean of 52 weeks post-surgery, particularly in strength and vertical jump tests, and test performance was not reliably associated with RTS outcomes.

For clinicians, these results underscore the importance of moving beyond binary "pass/fail" models toward an integrated, individualised decision-making process. Physical performance symmetry thresholds, particularly when used in isolation, were not reliably associated with successful RTS. Instead, physical capacity must be weighed alongside psychological readiness, athlete-specific goals, and contextual sport demands.

Future research and rehabilitation frameworks should embrace an individualised, biopsychosocial approach. This includes integrating sport-specific, reactive, and dual-task assessments that more closely replicate the chaotic nature of sport and assess joint kinematics, ground reaction forces, and contact times, alongside a focus on relative strength benchmarks rather than symmetry alone.

Strengths and limitations

This study’s strengths include a large, heterogeneous clinical cohort reflecting routine rehabilitation practice rather than controlled laboratory conditions, which improves external validity and provides clinical insight. Additionally, using validated physical and psychological assessments supports a biopsychosocial understanding of readiness. The inclusion of diverse sport types, graft types, and demographics also allows for preliminary consideration of equity and healthcare access in Aotearoa New Zealand. Finally, simultaneously reporting test performance and RTS status directly addresses a literature gap regarding whether common symmetry criteria relate to real-world outcomes.

Limitations include the retrospective, cross-sectional design, which restricts causal inference and limits the assessment of functional progression over time. While the sample size was moderate, some subgroup analyses had smaller numbers, increasing the risk of Type II error. Furthermore, RTS status was self-reported by only a subset of participants, potentially introducing response bias, and ceiling effects in some test data may have obscured subtle performance differences.

Methodologically, IKD testing was performed at 90°/s rather than 180 and 60°/s, which may limit direct comparability with other literature. Vertical jump analysis was restricted to peak height because contact time and reactive strength metrics were unavailable, preventing the evaluation of fast stretch shortening cycle performance. Further, using flight-time calculations for jump height may have overestimated the results.

Finally, rehabilitation variables such as programme content and adherence were not standardised. Because these data reflect a pragmatic clinical cohort rather than a controlled experimental design, inconsistent testing frequencies and missing fields may introduce unmeasured confounding and preclude any definitive conclusions.

CONCLUSION

This study highlights the complex, multifactorial nature of returning to sport following ACLR. Substantial functional deficits persist at a mean of 52 weeks post-surgery, particularly in strength and vertical jump performance, and high symmetry thresholds were not reliably associated with a higher level of sport resumption. Crucially, psychological readiness demonstrated the strongest association with RTS outcomes.

Although most participants returned to some level of sport, fewer than half regained their pre-injury participation level. Factors such as psychological readiness, graft type, injury history, and pre-surgery rehabilitation were all associated with outcomes, underscoring the interplay of physical and psychological recovery. Notably, physical test performance did not consistently translate to higher levels of sport resumption, challenging a reliance on isolated symmetry thresholds.

These findings reinforce the need for an individualised decision-making approach integrating quantitative results with psychological readiness, contextual demands, and culturally responsive care to address health inequities among Māori and Pasifika populations.

KEY POINTS

1. Only 43% returned to pre-injury sport levels at a mean of 52 weeks post-ACLR.
2. Higher limb symmetry threshold (≥ 95% LSI) was not reliably associated with higher rates of successful RTS.
3. Psychological readiness was the strongest independent indicator of RTS status.
4. BPTB grafts, prior ACL injury, and lateral extra-articular tenodesis procedures were associated with lower strength and psychological scores.

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PERMISSIONS

This study was approved by Auckland University of Technology Ethics Committee (AUTEC; 24/203).

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CONTRIBUTIONS OF AUTHORS

Conceptualisation, AJW, DR, and GP; methodology, AJW and DR; software, AJW and IZ; validation, AJW, DR, GP, and IZ; formal analysis, AJW, DR, and IZ; investigation, AJW; resources, AJW, DR, and GP; data curation, AJW, GP and IZ; writing – original draft, AJW; writing – review and editing, AJW, DR, GP, and IZ; visualisation, AJW; supervision, DR; project administration, AJW.

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Appendix A

STANDARDISED INSTRUCTIONS FOR HOP AND JUMP TESTS

Test	Participant instructions	Clinical protocol and criteria
Single leg hop for distance	Jump as far forward as possible on one leg and stick the landing under control for 2 s	Uninjured limb assessed first; best of three recorded trials used for analysis
Lateral hop	Hop side-to-side as quickly as possible outside marked lines 40 cm apart using one leg for 30 s with hands behind the back	Hops touching a line are excluded; best of three recorded trials used for analysis
Single leg vertical jump	Jump as high as possible on one leg with hands on the waist and land under control on the same leg for 2 s	Performed on VALD ForceDecks; three maximal-effort trials recorded; peak jump height used for analysis
Single leg drop jump	Step off a 30 cm box onto one leg and immediately perform a maximal vertical jump upon ground contact	Performed on VALD ForceDecks; three maximal-effort trials recorded; peak jump height used for analysis

Note. All tests required a minimum of two practice trials per limb to ensure task familiarisation. Testing was terminated immediately if participants reported pain, instability, or apprehension.

Appendix B

STATISTICAL COMPARISON OF BASELINE CLINICAL AND DEMOGRAPHICAL VARIABLES AND RTS TEST PERFORMANCE BETWEEN SURVEY RESPONDERS AND NON-RESPONDERS

Demographics and clinical history	*p*
Age	.094
Height	.788
Weight	.518
Body mass index	.395
Sex	.848
Ethnicity	.269
Pre-surgery rehabilitation	.772
Graft type	.085
Lateral extra-articular tenodesis	.109
Previous ipsilateral ACL injury	.109
Previous contralateral ACL injury	.601
Single leg hop LSI (%)	.407
Lateral hop LSI (%)	.269
Single leg vertical jump LSI (%)	.404
Single leg drop jump LSI (%)	.983
Knee extension strength LSI (%)	.945
Knee flexion strength LSI (%)	.473
ACL-RSI	.938

Note. ACL = anterior cruciate ligament; LSI = limb symmetry index; ACL-RSI; ACL Return to Sport After Injury scale; RTS = return to sport.

Appendix C

STATISTICAL ASSOCIATION BETWEEN PARTICIPANT DEMOGRAPHICS AND RTS TEST PERFORMANCE

Demographic variable	RTS test performance						
	Single leg hop	Lateral hop	Single leg vertical jump	Single leg drop jump	Knee extension	Knee flexion	ACL-RSI
Age	.008	.012	.004	.879	.040	.352	.189
BMI	.531	.864	.070	.986	.007	.023	.179
Sex	.894	.684	.614	.746	.817	.683	.664
Ethnicity	.294	.066	.326	.629	.186	.373	.632

Note. ACL-RSI = Anterior cruciate ligament Return to Sport after Injury scale; Knee extension = knee extension peak torque 90°/s; Knee flexion = knee flexion peak torque 90°/s; RTS = return to sport.

Values represent significance (p value); statistical significance, $p = .05$.