

# Effect of Isokinetic Strength Training on Musculoskeletal Recovery in Post-ACL Reconstruction Athletes: A Randomized Controlled Trial

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## Abstract

### Background

Quadriceps and hamstring weakness following anterior cruciate ligament reconstruction (ACLR) persists well beyond the early rehabilitation phase and is a major determinant of delayed return to sport and re-injury risk. Isokinetic strength training allows accommodating resistance through the full range of motion at controlled angular velocities and has been proposed as a superior modality to conventional resistance training for restoring quadriceps-hamstring strength ratios after ACLR.

### Objective

To compare the effect of a 12-week isokinetic strength training programme with conventional strength training, both added to standard rehabilitation, on musculoskeletal recovery in athletes following unilateral ACLR.

### Methods

In this assessor-blinded, parallel-group randomized controlled trial, 60 athletes (mean age  $24.1 \pm 4.0$  years) who were 6-8 weeks post unilateral hamstring-autograft ACLR were randomly allocated to an isokinetic strength training group (Group A,  $n = 30$ ) or a conventional strength training group (Group B,  $n = 30$ ) for 12 weeks, three sessions per week, in addition to a standardized rehabilitation protocol. Outcomes were quadriceps and hamstring peak torque ( $60^\circ/\text{s}$  and  $180^\circ/\text{s}$ ) on isokinetic dynamometry, limb symmetry index (LSI), International Knee Documentation Committee (IKDC) subjective score, Lysholm Knee Scoring Scale, single-leg hop test LSI, pain (Visual Analog Scale), and active knee flexion range of motion, recorded at baseline and after 12 weeks.

### Results

Both groups improved significantly from baseline ( $p < 0.001$  for all outcomes, within-group). Group A demonstrated significantly greater gains than Group B at 12 weeks for quadriceps peak torque at  $60^\circ/\text{s}$  (mean difference 26.4 Nm, 95% CI 18.9–33.9,  $p < 0.001$ , Cohen's  $d = 1.68$ ), quadriceps LSI ( $92.6 \pm 5.8\%$  vs.  $81.4 \pm 7.2\%$ ,  $p < 0.001$ ), IKDC score ( $88.4 \pm 6.2$  vs.  $78.9 \pm 7.0$ ,  $p < 0.001$ ), Lysholm score ( $91.3 \pm 5.4$  vs.  $82.7 \pm 6.8$ ,  $p < 0.001$ ), and single-leg hop LSI ( $93.1 \pm 6.0\%$  vs.  $83.6 \pm 7.4\%$ ,  $p < 0.001$ ). No serious adverse events occurred in either group.

### Conclusion

A 12-week isokinetic strength training programme produced significantly greater improvements in muscle strength, limb symmetry, and functional and subjective knee outcomes than conventional strength training in athletes recovering from ACL reconstruction, supporting its incorporation into structured post-operative rehabilitation protocols.

### Keywords

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## 1. Introduction

The anterior cruciate ligament (ACL) is the most frequently reconstructed ligament of the knee in athletically active populations, with global reconstruction volumes exceeding 100,000 procedures annually and rising by approximately 2% each year.[1] Despite advances in surgical technique and graft fixation, functional recovery after ACL reconstruction (ACLR) remains prolonged, with persistent quadriceps and hamstring strength deficits, impaired neuromuscular control, and an inability to return to competitive sport for at least six to nine months in a substantial proportion of athletes.[1,2]

Quadriceps strength deficits of 10-30% relative to the uninvolved limb are commonly reported even a year after surgery and are strongly associated with altered landing biomechanics, poorer patient-reported outcomes, and an elevated risk of second ACL injury.[2,3] Hamstring weakness is compounded when a hamstring tendon autograft is harvested, as donor-site morbidity can further delay flexor strength recovery relative to quadriceps recovery.[3] Consequently, restoring symmetrical quadriceps and hamstring strength has become a central, evidence-based target of post-operative rehabilitation and a key criterion used to guide return-to-sport decisions.[4]

Conventional strength training following ACLR typically employs isotonic resistance exercises using free weights, resistance bands, or weight-stack machines. While effective, isotonic training provides variable resistance that is limited by the weakest point in the range of motion (the 'sticking point'), which may under-load the muscle through the remainder of the arc of movement.[5] Isokinetic strength training, delivered through a dynamometer that maintains a constant angular velocity while accommodating resistance to the force generated by the patient, allows maximal muscular loading throughout the entire range of motion and permits precise, reproducible quantification of torque output.[5,6] Several trials have reported that isokinetic training produces greater gains in knee flexor-extensor peak torque, proprioception, and postural balance than conventional resistance or pneumatic-resistance training in ACLR athletes.[6,7] Eccentric isokinetic protocols in particular have been shown to be more

effective than constant-load eccentric training for quadriceps rehabilitation after ACLR.[8]

Functional performance measures, including the single-leg hop test and limb symmetry index (LSI), are widely used adjuncts to isokinetic strength testing when determining readiness for return to sport, with an LSI threshold of  $\geq 90\%$  commonly recommended, although symmetry in hop performance is typically achieved earlier than symmetry in isokinetic strength and may overestimate true recovery if used in isolation.[9–11] Patient-reported outcome measures such as the International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form and the Lysholm Knee Scoring Scale remain essential complements to objective strength and performance testing, since strength recovery alone does not consistently reduce residual knee pain or fully capture perceived function.[12,13] Despite this growing body of evidence, few adequately powered randomized controlled trials have directly compared a structured isokinetic strength training programme with conventional strength training across this combined battery of strength, functional, and patient-reported outcomes within a single cohort of post-ACLR athletes, and data from South Asian sporting populations are particularly limited.

The present study was therefore designed to evaluate the effect of a 12-week isokinetic strength training programme, added to standard rehabilitation, on musculoskeletal recovery in athletes following unilateral ACL reconstruction, compared with conventional strength training plus standard rehabilitation. We hypothesized that isokinetic strength training would produce significantly greater improvements in quadriceps and hamstring peak torque, limb symmetry, and functional and subjective knee outcomes than conventional strength training.

## 2. Materials and Methods

### 2.1 Study design and setting

This was a prospective, assessor-blinded, parallel-group randomized controlled trial conducted in the outpatient sports rehabilitation unit of the Department of Physiotherapy, over a period of 14 months. The study was approved by the Institutional Ethics Committee and conducted in accordance with the Declaration of Helsinki.

### 2.2 Participants

Athletes referred for physiotherapy following unilateral, primary ACL reconstruction using a hamstring tendon (semitendinosus-gracilis) autograft were screened for eligibility.

Inclusion criteria: (i) age 18–35 years (ii) unilateral, primary ACLR with hamstring autograft, 6–8 weeks post-surgery at enrolment (iii) pre-injury participation in pivoting or field sport at a recreational or competitive level (pre-injury Tegner Activity Scale score  $\geq 6$ ) (iv) medically cleared by the operating surgeon to begin progressive resistance training (v) willingness to provide written informed consent and comply with the 12-week programme.

Exclusion criteria: (i) revision ACLR or multiligament knee injury (ii) concomitant meniscal repair or collateral ligament reconstruction requiring a restricted weight-bearing or range-of-motion protocol (iii) history of contralateral knee surgery or pathology (iv) uncontrolled systemic illness, neurological deficit, or musculoskeletal condition affecting the lower limb (v) body mass index  $> 30 \text{ kg/m}^2$  (vi) pregnancy.

### 2.3 Sample size calculation

Sample size was calculated using G\*Power software (version 3.1.9.7) for an independent-samples t-test, based on the mean difference in quadriceps peak torque reported between isokinetic and conventional training groups in a comparable prior trial, yielding a large expected effect size ( $d = 0.80$ ). With  $\alpha = 0.05$  (two-tailed) and power  $(1 - \beta) = 0.80$ , a minimum of 26 participants per group was required. Anticipating an attrition rate of approximately 15%, 32 participants were allocated to each group at randomization, targeting a minimum of 30 completers per arm for final analysis.

### 2.4 Randomization and blinding

Eligible, consenting participants were allocated in a 1:1 ratio to Group A (isokinetic strength training) or Group B (conventional strength training) using a computer-generated random number sequence with permuted blocks of 4 and 6, prepared by an investigator not involved in recruitment or assessment. Allocation was concealed using sequentially numbered, opaque, sealed envelopes, opened only after baseline assessment was completed. The outcome assessor, who performed all isokinetic dynamometry, functional testing, and administered patient-reported outcome measures at baseline and post-intervention, was blinded to group allocation. Because of the nature of the intervention, participants and treating physiotherapists could not be blinded to group assignment, statisticians analyzing the coded, de-identified dataset were blinded to group labels.

### 2.5 Interventions

Both groups received an identical standardized post-operative rehabilitation protocol comprising range-of-motion exercises, patellar mobilization, closed and

open kinetic chain exercises within pain-free limits, proprioceptive and balance training, gait re-education, cryotherapy as needed, and progressive functional and agility drills, delivered three times per week for 12 weeks under physiotherapist supervision. In addition to this common protocol, participants received one of the following group-specific strengthening interventions.

**Group A** – Isokinetic strength training: Concentric quadriceps and hamstring strengthening of the operated limb was performed on an isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems) three sessions per week for 12 weeks. Each session comprised a standardized warm-up, followed by 3 sets of 10 repetitions of concentric knee extension-flexion at  $60^\circ/\text{s}$ , 3 sets of 12 repetitions at  $120^\circ/\text{s}$ , and 3 sets of 15 repetitions at  $180^\circ/\text{s}$ , with 60–90 seconds rest between sets, progressing in volume across the intervention period as tolerated and guided by pain and effusion response. Verbal encouragement and visual torque-curve feedback were provided during each session.

**Group B** – Conventional strength training: Quadriceps and hamstring strengthening of the operated limb was performed using isotonic resistance exercises (weighted ankle cuffs, resistance bands, and leg-press/leg-curl machines) three sessions per week for 12 weeks, matched to Group A for exercise frequency, session duration, and rest intervals, with resistance progressed according to the Oxford or DeLorme progressive resistance principle as tolerated (3 sets of 8–15 repetitions per exercise).

### 2.6 Outcome measures

All outcomes were recorded at baseline (week 6–8 post-surgery, prior to randomized intervention) and at the end of the 12-week intervention (week 18–20 post-surgery), by the same blinded assessor.

**Primary outcomes:** Quadriceps and hamstring peak torque (Newton-metres, Nm) of the operated limb, measured concentrically at  $60^\circ/\text{s}$  and  $180^\circ/\text{s}$  on the isokinetic dynamometer, and the limb symmetry index (LSI), calculated as (operated limb value / non-operated limb value)  $\times 100\%$ .

**Secondary outcomes:** (i) IKDC Subjective Knee Evaluation Form (score 0–100, higher indicating better function) (ii) Lysholm Knee Scoring Scale (score 0–100, higher indicating better function) (iii) single-leg hop for distance, expressed as LSI (%) (iv) knee pain intensity on a 10-cm Visual Analog Scale (VAS, 0 = no pain, 10 = worst imaginable pain) (v) active knee flexion range of motion (degrees), measured with a universal goniometer. Adverse events (graft-related complications, effusion requiring intervention, or exercise-related injury) were recorded throughout the intervention period.

### 2.7 Statistical analysis

Data were analyzed using IBM SPSS Statistics, version 26.0, on an intention-to-treat basis with last-observation-carried-forward imputation for missing post-intervention data. Normality of distribution was assessed using the Shapiro-Wilk test. Baseline characteristics were compared between groups using the independent-samples t-test for continuous variables and the chi-square test for categorical variables. Within-group pre-to-post changes were analyzed using the paired-samples t-test. Between-group differences in outcome measures at 12 weeks were analyzed using the independent-samples t-test (or Mann-Whitney U test where distributional assumptions were not met), with effect sizes reported as Cohen's d. A two-tailed p-value < 0.05 was considered statistically significant for all analyses.

### 3. Results

#### 3.1 Participant flow and baseline characteristics

Seventy athletes were screened for eligibility, of whom 6 did not meet the inclusion criteria and 4 declined to participate; 64 participants were randomized (32 to Group A, 32 to Group B). During the intervention period, 2 participants in Group A were lost to follow-up (relocation, n = 1, withdrawal of consent, n = 1) and 2 in Group B (non-compliance with sessions, n = 1, loss of contact, n = 1). Final analysis included 30 participants in Group A and 30 in Group B. Baseline demographic and clinical characteristics were comparable between groups with no statistically significant differences (Table 1).

**Table 1. Baseline demographic and clinical characteristics of participants (n = 60)**

| Characteristic                                  | Group A – Isokinetic (n = 30) | Group B – Conventional (n = 30) | p-value |
|-------------------------------------------------|-------------------------------|---------------------------------|---------|
| Age (years), mean ± SD                          | 24.3 ± 4.1                    | 23.8 ± 3.9                      | 0.62    |
| Sex, male / female, n                           | 22 / 8                        | 21 / 9                          | 0.78    |
| Body mass index (kg/m <sup>2</sup> ), mean ± SD | 23.6 ± 2.1                    | 23.9 ± 2.3                      | 0.58    |
| Time since ACLR (weeks), mean ± SD              | 7.1 ± 0.8                     | 7.0 ± 0.9                       | 0.71    |
| Pre-injury Tegner Activity Scale, mean ± SD     | 7.2 ± 1.0                     | 7.1 ± 1.1                       | 0.69    |
| Graft type, hamstring                           | 30 (100%)                     | 30 (100%)                       | —       |

| autograft, n (%)                           |             |             |      |
|--------------------------------------------|-------------|-------------|------|
| Baseline quadriceps peak torque 60°/s (Nm) | 98.4 ± 14.2 | 99.1 ± 13.8 | 0.85 |
| Baseline quadriceps LSI (%)                | 68.3 ± 7.9  | 67.6 ± 8.4  | 0.74 |
| Baseline IKDC score                        | 52.6 ± 8.1  | 53.4 ± 7.6  | 0.70 |
| Baseline Lysholm score                     | 61.2 ± 7.4  | 62.0 ± 6.9  | 0.68 |

#### 3.2 Isokinetic strength outcomes

Both groups showed statistically significant within-group improvement in quadriceps and hamstring peak torque and LSI from baseline to 12 weeks (p < 0.001 for all comparisons). Between-group comparison at 12 weeks demonstrated significantly greater gains in Group A than Group B across all isokinetic strength parameters (Table 2).

**Table 2. Isokinetic peak torque and limb symmetry index of the operated limb, baseline and 12 weeks**

| Outcome                   | Group A baseline | Group A 12 wk | Group B baseline | Group B 12 wk | Between-group p (12 wk) | Cohen's d |
|---------------------------|------------------|---------------|------------------|---------------|-------------------------|-----------|
| Quadriceps PT 60°/s (Nm)  | 98.4 ± 14.2      | 168.7 ± 16.5  | 99.1 ± 13.8      | 142.3 ± 15.1  | <0.001                  | 1.68      |
| Quadriceps PT 180°/s (Nm) | 72.1 ± 10.8      | 121.6 ± 12.4  | 71.6 ± 11.2      | 103.8 ± 11.9  | <0.001                  | 1.46      |
| Hamstring PT 60°/s (Nm)   | 58.3 ± 8.6       | 96.4 ± 9.8    | 57.9 ± 9.1       | 82.6 ± 9.4    | <0.001                  | 1.42      |
| Hamstring PT 180°/s (Nm)  | 44.7 ± 7.2       | 73.9 ± 8.1    | 45.1 ± 7.5       | 63.2 ± 7.9    | <0.001                  | 1.34      |
| Quadriceps LSI (%)        | 68.3 ± 7.9       | 92.6 ± 5.8    | 67.6 ± 8.4       | 81.4 ± 7.2    | <0.001                  | 1.72      |

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|                             |                  |                   |                  |                   |            |      |
|-----------------------------|------------------|-------------------|------------------|-------------------|------------|------|
| Hams<br>tring<br>LSI<br>(%) | 72.1<br>±<br>8.0 | 94.<br>8 ±<br>5.1 | 71.5<br>±<br>8.3 | 85.<br>7 ±<br>6.4 | <0.0<br>01 | 1.60 |
|-----------------------------|------------------|-------------------|------------------|-------------------|------------|------|

Values are mean ± SD. Within-group change from baseline to 12 weeks was significant at  $p < 0.001$  for all outcomes in both groups (paired t-test). Between-group p-values (independent-samples t-test) compare 12-week values. PT = peak torque; LSI = limb symmetry index (operated/non-operated limb  $\times 100$ ).

### 3.3 Functional and patient-reported outcomes

Group A demonstrated significantly greater improvement in IKDC score, Lysholm score, and single-leg hop LSI at 12 weeks compared with Group B (Table 3). Pain scores decreased significantly in both groups, with a small but statistically significant additional reduction in Group A. Active knee flexion range of motion improved in both groups, with a modestly greater gain in Group A.

**Table 3. Functional performance and patient-reported outcomes, baseline and 12 weeks**

| Outcome                       | Group A baseline | Group A 12 wk | Group B baseline | Group B 12 wk | Between-group p (12 wk) |
|-------------------------------|------------------|---------------|------------------|---------------|-------------------------|
| IKDC subjective score (0–100) | 52.6 ± 8.1       | 88.4 ± 6.2    | 53.4 ± 7.6       | 78.9 ± 7.0    | <0.001                  |
| Lysholm score (0–100)         | 61.2 ± 7.4       | 91.3 ± 5.4    | 62.0 ± 6.9       | 82.7 ± 6.8    | <0.001                  |
| Single-leg hop LSI (%)        | 64.8 ± 9.2       | 93.1 ± 6.0    | 65.3 ± 8.7       | 83.6 ± 7.4    | <0.001                  |
| Pain, VAS (0–10)              | 3.8 ± 1.1        | 0.6 ± 0.5     | 3.9 ± 1.0        | 1.2 ± 0.7     | 0.002                   |
| Knee flexion ROM (degrees)    | 118.4 ± 8.2      | 138.6 ± 5.1   | 117.9 ± 8.6      | 132.4 ± 6.3   | 0.001                   |

Values are mean ± SD. Within-group change from baseline to 12 weeks was significant at  $p < 0.001$  for all outcomes in both groups (paired t-test). Between-group p-values by independent-samples t-test. IKDC = International Knee Documentation Committee; LSI =

limb symmetry index; VAS = Visual Analog Scale; ROM = range of motion.

### 4. Discussion

This randomized controlled trial found that a 12-week isokinetic strength training programme, added to standard post-operative rehabilitation, produced significantly greater improvements in quadriceps and hamstring peak torque, limb symmetry index, and functional and patient-reported outcomes than conventional isotonic strength training in athletes recovering from unilateral ACL reconstruction. These findings support and extend earlier observations that isokinetic training confers strength and neuromuscular benefits beyond those achieved with pneumatic or constant-load resistance training in this population.[6,7]

The magnitude of between-group difference in quadriceps peak torque at 60°/s observed in the present study (mean difference 26.4 Nm,  $d = 1.68$ ) is consistent with, and in the same direction as, prior work demonstrating superior quadriceps and hamstring torque gains with regular isokinetic training compared with pneumatic resistance training over a shorter 4-week period.[6] The comparatively larger absolute gains observed here likely reflect the longer, 12-week intervention duration and the inclusion of multiple angular velocities (60°/s, 120°/s, and 180°/s), which may better replicate the range of contraction speeds required for functional and sporting activity than training at a single velocity. Similarly, eccentric isokinetic protocols have previously been shown to outperform constant-load eccentric training for quadriceps rehabilitation after ACLR, reinforcing the principle that accommodating, velocity-controlled resistance may recruit and load muscle more effectively across the full range of motion than fixed external resistance.[8]

The greater gain in quadriceps and hamstring LSI in the isokinetic group is clinically relevant, given that an LSI threshold of 90% or higher is the most widely used, though imperfect, criterion for guiding return-to-sport decisions after ACLR.[9,11] Notably, mean quadriceps LSI in Group A reached 92.6% by 12 weeks, exceeding this commonly cited threshold, whereas Group B remained below it (81.4%) at the same time point. This distinction is important clinically, since persistent quadriceps strength deficits at the time of return to sport have been associated with abnormal landing mechanics and elevated re-injury risk, and low proportions of patients meeting composite return-to-sport criteria, including strength LSI, have been reported even up to nine months after ACLR.[3,16] However, it should be emphasized that hop-based symmetry can be achieved before true strength symmetry and may not fully reflect underlying limb biomechanics, underscoring the value

of combining isokinetic strength testing with functional hop assessment, as performed in the present study, rather than relying on either measure in isolation.[10,11]

Improvements in IKDC and Lysholm scores paralleled the objective strength gains in both groups but were significantly larger in the isokinetic group, suggesting that the additional strength and symmetry gained through isokinetic training translated into meaningfully better perceived knee function rather than strength improvement alone. This is broadly consistent with meta-analytic evidence that structured strengthening exercise after ACLR improves quadriceps and hamstring strength together with functional performance and Lysholm scores, although the same review noted that strengthening exercise does not consistently reduce pain.[13] In the present trial, both groups achieved clinically meaningful pain reduction, with only a small additional benefit in the isokinetic group, which may reflect a ceiling effect given the already low absolute pain scores by 12 weeks in both arms.

Several mechanisms may explain the superior outcomes observed with isokinetic training. The accommodating-resistance nature of isokinetic exercise ensures near-maximal muscular effort is elicited throughout the entire joint range, in contrast to isotonic training where resistance is limited by the weakest point in the range of motion.[5] Isokinetic training also provides real-time visual torque-curve feedback, which may enhance motor learning, voluntary muscle activation, and patient engagement, potentially contributing to the proprioceptive and neuromuscular benefits reported with this modality in prior work.[6,7] Additionally, standardized, reproducible dosing of angular velocity and repetition volume on the dynamometer may allow more precise progression than free-weight or resistance-band training, where external load calibration is comparatively imprecise.

This trial has several strengths, including its randomized design, assessor blinding, a priori sample size calculation, standardized concurrent rehabilitation protocol common to both arms, and a comprehensive outcome battery spanning isokinetic strength, functional performance, and patient-reported measures. Nonetheless, several limitations warrant consideration and are discussed below.

### 5. Limitations

First, participants and treating physiotherapists could not be blinded to group allocation given the nature of the intervention, which may introduce performance bias, although the primary outcome assessor remained blinded throughout. Second, the 12-week follow-up period does not capture longer-term outcomes such as return-to-sport rate, re-injury incidence, or strength

retention beyond the intervention period, longer-term follow-up (6–12 months) is needed to determine whether the strength advantage observed with isokinetic training translates into superior return-to-sport rates or reduced re-injury risk. Third, the trial was conducted at a single centre with participants who had all undergone hamstring-autograft ACLR, limiting generalizability to patients receiving patellar tendon or quadriceps tendon autografts, in whom flexion and extension strength recovery trajectories differ.[3] Fourth, access to isokinetic dynamometry is resource-intensive and may not be feasible in all clinical settings, which should be weighed against the observed benefits when considering implementation. Finally, although both groups received a matched frequency and duration of strengthening exercise, precise equating of total mechanical work between isokinetic and isotonic modalities is inherently difficult, and residual differences in training dose cannot be entirely excluded as a contributor to the between-group effect.

### 6. Conclusion

A 12-week isokinetic strength training programme, delivered in addition to standard post-operative rehabilitation, produced significantly greater gains in quadriceps and hamstring peak torque, limb symmetry index, and functional and subjective knee outcomes than conventional strength training in athletes recovering from unilateral ACL reconstruction, without an increase in adverse events. These findings support incorporating isokinetic strength training into structured rehabilitation protocols where dynamometry resources are available, while future multi-centre trials with longer-term return-to-sport and re-injury follow-up are needed to confirm the durability and clinical impact of these gains.

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