Lower extremity performance following ACL rehabilitation in the KANON-trial: impact of reconstruction and predictive value at 2 and 5 years

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ABSTRACT

Background The additional effect of anterior cruciate ligament (ACL) reconstruction on muscle strength and physical performance after a structured exercise programme is not well understood.

Objectives To investigate and compare muscle strength and physical performance test results after a structured exercise programme, in young active adults with acute ACL injury, between those treated with and without ACL reconstruction (ACLR) and to evaluate these test results as predictors of clinical outcomes 2 and 5 years after injury.

Study design Prospective cohort study.

Methods In a treatment randomised controlled trial of acute ACL injury (the KANON-study), 87/121 young active adults underwent two muscle strength tests and five physical performance tests after a structured exercise programme (median 37 (IQR 24) weeks after injury). Results were presented and compared as limb symmetry indices (LSI); endpoints in predictive analyses were having a delayed ACLR over the first 5 years and self-reported knee function (Knee injury and Osteoarthritis Outcome Score; KOOS4) at 2 and 5 years.

Results Overall, 74–95% of patients had LSI≥90% in the individual tests, with no difference between treatment groups (p=0.08–0.92). Results of the one-leg rise tests predicted KOOS4 at 2 and 5 years (R²=0.25 and 0.24, p=0.001 and 0.002) and vertical hop results predicted having a delayed ACLR over a 5-year course after injury (p=0.048) in those starting with exercise alone (n=21).

Conclusions After an acute ACL tear, the majority of young active adults regain physical performance and muscle strength after a structured exercise programme, with or without surgical reconstruction. Poor physical performance at the end of rehabilitation predicted worse patient-reported outcomes at 2 and 5 years regardless of treatment.

Registration number: ISRCTN84752559.

INTRODUCTION

Rupture of the anterior cruciate ligament (ACL) may cause long-lasting functional impairment and knee osteoarthritis (OA).1, 2 Optimal treatment after acute ACL injury is debated. A recent randomised controlled trial (RCT) failed to show any clinically significant difference in self-reported knee function, physical activity level and the frequency of radiographic knee OA 2 and 5 years after acute ACL injury between young active adults treated with and without ACL reconstruction (ACLR).3–4

ACLR aims to restore the mechanical stability of the injured knee, whereas a structured exercise programme aims to restore knee function; it is an essential part of treatment whether patients undergo knee reconstruction or not.1–7 Physical performance testing is usually performed to determine if and when the patient may resume sports but there is no consensus on which specific physical performance tests to use in the ACL injured patient.8 Tests of muscle strength and endurance, balance and muscle power are commonly employed in combination. The use of a test battery, including two or more hop tests, has been recommended to assess different aspects of muscle function after ACL injury and reconstruction.9 Test results are often expressed as limb symmetry index (LSI, injured leg divided by uninjured leg results×100), and satisfactory muscular function is usually defined as an LSI≥90%.10

Few studies have compared physical performance of ACL-injured patients treated with and without ACLR. Consequently, the added benefit of ACLR on physical performance remains to be determined. One year after ACL injury, Moksnes and Risberg11 found that non-operated patients performed better than operated patients in two of four single-legged hop tests. Two independent reports found that hop test results obtained during the early phase of a structured exercise programme after ACL injury could predict self-reported outcome after 1 year in both ACL-reconstructed12 and in non-reconstructed patients.13 However, data from high-quality randomised trials are lacking. Early identification of factors that could predict later need of ACLR and longer term self-reported knee function may be important.

Using data from a treatment RCT on acute ACL injury (the KANON study, ISRCTN84752559),3–4 we aimed to (1) compare results of muscle strength and physical performance testing, performed at the end of the exercise period, between patients treated with and without ACLR, (2) evaluate muscle strength and physical performance test results as predictors of self-reported outcome at 2 and 5 years after injury and (3) explore whether muscle strength and physical performance test results predicted the future need of ACLR in those starting with exercise alone.

METHODS

Participants

The KANON study was an RCT that compared a structured exercise programme plus early ACLR against a structured exercise programme alone with the option of having a delayed ACLR if needed. It included 121 active adults with an acute ACL tear...
to a previously uninjured knee and has been reported in detail elsewhere. Major exclusion criteria were professional athlete (10 on the Tegner Activity Score); less than moderately active individuals (0–5 on the same scale); a total collateral liga-
tment rupture; a full-thickness cartilage lesion visualised on MRI.

Physical performance was tested by the treating physical ther-
apist at the end of the exercise period for 87 of the 121
KANON study participants (72%); 42 randomised to exercise
plus early ACLR (performed at a median of 6, range 3–10 weeks after injury) and 45 to initial exercise with optional
delayed ACLR. In the latter group, 23 patients had a delayed
ACLR over the 5-year follow-up period (performed at a median
of 58, range 31–244 weeks after injury). 20/23 completed exercise
and performed physical performance testing before under-
going a delayed ACLR (3 had a delayed ACLR prior to testing,
conducted at a median of 55 weeks after surgery; figure 1).
There were no statistically significant differences in baseline
characteristics between those included (n=87) and those not
included (n=34) in the present analysis (table 1).

In this ancillary study, we used an ‘as treated’ approach rather
than analysing data according to group allocation by randomisa-
tion. Consequently, the 45 patients who were tested after having
had an ACLR (regardless of being an early or delayed proce-
dure) constituted the ‘ACLR group’ and the 42 who were tested
after being treated with exercise constituted the ‘exercise alone
group’. In predefined subanalyses, we also assessed (1) whether
physical performance differed between those who had a delayed
ACLR (‘delayed ACLR group’, n=20) and those who did not
have an ACLR (‘exercise alone group’, n=22) and (2) whether
physical performance predicted delayed ACLR over the 5-year
period (n=42).

Treatment
All patients followed a similar exercise protocol, previously
described in detail and consistent with literature consensus. The
protocol and examples of exercises used are provided as a web
appendix to this report. In addition to exercise, those randomised
to early ACLR underwent surgery within 10 weeks of injury and
those randomised to exercise with the option of delayed ACLR
underwent ACLR when presenting with symptomatic knee
instability as determined by the study protocol. All ACLR were
single bundle, performed by one of four senior knee surgeons
using either a patella-tendon or hamstrings-tendon procedure
depending on the surgeon’s preference. In randomised trials,
these two methods have resulted in similar outcomes.

Structured exercise programme
The exercise programme was initiated before or at the time of
randomisation and was supervised by experienced physical
therapists. The programme (web appendix to be included in BJSM
and discussion in podcast) was goal oriented and included
four levels of progression with predefined goals for ROM,
muscle function and performance. In the early phases, recovery
of range of motion and neuromuscular control as well as train-
ing of gait and balance were emphasised. In the later phases,
muscle strength and endurance of knee stabilisers as well as
functional performance were in focus. 2 Time lines were not
restricted and the exercise period was concluded, with end-tests
performed, when the treating PT presumed that all goals of the
protocol were met.

Physical performance tests after the formal exercise
programme was completed
Postrehabilitation, patients were tested with regard to muscle
strength and physical performance for the injured and contralat-
eral side. The assessors, who were instructed to follow a prespe-
cified test protocol, were all well-experienced physical
therapists. In total, there were eight centres, each testing 1–23
patients. Owing to variety in equipment between centres, alter-
native testing procedures were presented for muscle strength.
Test results were collected as crude values for both sides but
were translated and presented as (LSI (%), injured leg divided
by non-injured leg×100) for each specific test in order to mini-
mise the influence of multiple testers and different testing
devices.

The following tests were performed:

Muscle strength was measured for knee extensors (ie, quadri-
ceps) and knee flexors (ie, hamstrings) using peak torque
derived from either an isokinetic device (BIODEX) or a leg
extension/leg curl machine (according to the principle of one
maximal repetition, 1 RM). 19

Single leg physical performance testing started with the non-
injured leg and then alternating the injured and non-injured legs
for three trials of each leg and test. The best result for each leg
was recorded and the following tests were used:

A. The one-leg hop for distance test: The patient started by
standing on one leg with both hands on the back, was
instructed to jump as far as possible and land on the same
foot. Hands had to remain on back during jump and
landing. Distance (cm) was measured from toes at starting
position to heal at landing position.

B. The square hop test: A 35×35 cm square was marked
with tape on the floor. The patient started by standing on
one leg outside the square base and was instructed to jump
in and out of the square in clockwise rotation during 30 s.
The number of landings inside the square, without touching
the taped lines, was recorded.

C. The vertical hop test: The patient started standing on one
leg on a wooden plate with a belt anchoring a measuring
tape, running through a loop in the plate, around his/her
waist. The instruction was to make a vertical jump, as high
as possible, and measure the distance (cm) recorded.

D. The one-leg rise test: The patient started sitting on a
height-adjustable gurney with the heel of the tested foot
placed on a step-board placed 10 cm in front of the gurney.
The instruction was to rise from sitting to a standing posi-
tion on one leg with the other foot and both arms elevated
in front of the body. Starting height was determined by the
patient with three trials allowed on each height. On success,
height was lowered and the patient was allowed three new
tests on each new height. The test went on until failure or
until a height of 0 cm was recorded; the lowest height
was recorded in centimetres (cm).

E. The closed eyes one-leg balance test: The patient started
standing on one leg inside a marked 35×35 cm square with
the contralateral leg fixed in maximal hip and knee flexion
by hands. The instruction was to remain standing in this
position with eyes closed for as long as possible, time (s)
recorded from closing eyes until failure (ie, touching the borders
of the square with the test foot, touching ground with the
contralateral foot or opening eyes) was recorded

LSI from each individual test was compared between treat-
ment groups and was tested for prediction of self-reported knee
function at 2 and 5 years as well as the need of ACLR in those
tested after exercise alone. In addition, results from four of the five physical performance tests (one-leg hop, square-hop, one-leg rise and closed eyes one-leg balance) with high participation rates (81–83 of 87 tested patients) were aggregated into a test battery. Results of the vertical hop test were available for only 42 of 87 patients and thus were not included. The result of the battery was presented as LSI ≥ 90 (meaning LSI ≥ 90 in all four tests) or LSI < 90.

**Patient-reported outcomes**

The Knee injury and Osteoarthritis Outcome Score (KOOS) is a self-administered questionnaire consisting of five separate subscales: Pain, Other Symptoms, Function in Daily Living (ADL), Function in Sport and Recreation (Sport/Rec) and Knee-Related Quality of Life (QoL). Standardised response options are given on a Likert scale from 0 to 4 and a normalised score (0–100, worst to best) is calculated for each subscale. The psychometric properties of the KOOS are acceptable for evaluation of knee injury including ACLR and reference data are available from several large ACLR cohorts. Consistent with previous publications, we used the mean score of four (Pain, Symptoms, Sport and Recreation Function, Knee-related QoL) of the five KOOS subscales scores (KOOS4) at 2 and 5 years as endpoints in the predictive analyses.

**Statistics**

Statistical analyses were made in SPSS V20. To calculate LSI for the one-leg rise test (which could have a value of 0) we transformed...
adjustments for multiple comparisons were made. A statistical significance level of 5% was used and no adjustments were made.

The predictive value of each individual muscle strength and physical performance test result (LSI, leg symmetry index) on self-reported outcome (KOOS4) at 2 and 5 years (dependent variables) was determined using General Linear Models. First, univariate relations were analysed. Second, test results with a univariate p value less than 0.1 underwent multivariate testing.

RESULTS

Muscle strength and physical performance testing were performed after the exercise programme had been completed, at median 37 (IQR 24) weeks after injury. LSI values were generally high and 74–95% of those who performed individual tests achieved LSI≥90%; 52 of the 74 patients (70%) who completed the ‘test battery’ had LSI≥90% in the battery (ie, LSI≥90% in each of the four included tests, table 2).

ACLR versus exercise alone

Muscle strength and physical performance test results for patients treated with ACLR plus exercise did not differ significantly from those treated with exercise alone expressed as absolute values for the injured leg (p=0.23–0.80), as LSI (p=0.08–0.92; table 2) or as the proportion of patients with LSI≥90% in the test battery (p=0.61; table 2).

Prediction of self-reported knee function 2 and 5 years

LSI of the one-leg rise test predicted self-reported knee function (KOOS4) at 2 and 5 years, unadjusted and adjusted (R²=0.18 and 0.25, 0.17 and 0.24, respectively, p≤0.002; table 3). None of the other individual test results, or results on the test battery, predicted KOOS4 scores at either 2 or 5 years (table 3).

Table 1 Baseline characteristics of those with and without physical performance test results obtained after the exercise programme was completed (N=121)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Patients with test results (included) (N=67)</th>
<th>Patients without test results (N=44)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, year (y)</td>
<td>25.8±5</td>
<td>26.6±5</td>
<td>0.43</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>23 (26)</td>
<td>9 (27)</td>
<td>0.99</td>
</tr>
<tr>
<td>BMI</td>
<td>23.9±2.6</td>
<td>24.7±3.6</td>
<td>0.16</td>
</tr>
<tr>
<td>College education, n (%)</td>
<td>29 (33)</td>
<td>15 (44)</td>
<td>0.27</td>
</tr>
<tr>
<td>Married (living with partner), n (%)</td>
<td>36 (41)</td>
<td>16 (47)</td>
<td>0.57</td>
</tr>
<tr>
<td>Working full time or part time, no (%)</td>
<td>57 (66)</td>
<td>22 (64)</td>
<td>0.93</td>
</tr>
<tr>
<td>Student, n (%)</td>
<td>23 (26)</td>
<td>11 (32)</td>
<td>0.52</td>
</tr>
<tr>
<td>Sports-related injury, n (%)</td>
<td>86 (99)</td>
<td>33 (97)</td>
<td>0.49</td>
</tr>
<tr>
<td>Injury to right knee, n (%)</td>
<td>49 (56)</td>
<td>17 (50)</td>
<td>0.53</td>
</tr>
<tr>
<td>Positive Lachmann test*, n (%)</td>
<td>86 (99)</td>
<td>33 (97)</td>
<td>0.92</td>
</tr>
<tr>
<td>KOOS4 score</td>
<td>37.8 (15)</td>
<td>34.8 (12)</td>
<td>0.29</td>
</tr>
<tr>
<td>SF-36, physical component score</td>
<td>47.3 (14)</td>
<td>46.5 (12)</td>
<td>0.77</td>
</tr>
<tr>
<td>SF-36, mental component score</td>
<td>65.5 (21)</td>
<td>68.5 (15)</td>
<td>0.44</td>
</tr>
<tr>
<td>Tegner Activity Score, m (IQR)</td>
<td>9.0 (2)</td>
<td>9.0 (2)</td>
<td>0.98</td>
</tr>
<tr>
<td>Randomised to ACLR, n (%)</td>
<td>42 (48)</td>
<td>20 (59)</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Values are mean±SD unless otherwise indicated.
*Indicates pathological anteroposterior knee laxity in a semiflexed position.
ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; KOOS4, score, the mean score for four (Pain, Symptoms, Sport and Recreation Function, Knee-related Quality of Life) of the five Knee Injury and Osteoarthritis Outcome subscales scores; SF-36, Short-Form Health Survey.

Table 2 Muscle strength, physical performance test results and proportion of patients with LSI≥90% in each test (n=87)

<table>
<thead>
<tr>
<th>Test</th>
<th>Exercise alone (n=42)</th>
<th>Exercise +ACLR (n=45)</th>
<th>p Value</th>
<th>Proportion of Individuals with LSI ≥90%*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadriceps, n=69 LSI (%)</td>
<td>100 (3)</td>
<td>100 (3)</td>
<td>0.92</td>
<td>69 (87)</td>
</tr>
<tr>
<td>Hamstrings, n=58 LSI (%)</td>
<td>100 (0)</td>
<td>100 (6)</td>
<td>0.19</td>
<td>55 (83)</td>
</tr>
<tr>
<td>Functional performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-leg hop, n=82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)</td>
<td>148 (44)</td>
<td>152 (40)</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>LSI (%)</td>
<td>100 (7)</td>
<td>99.3 (7)</td>
<td>0.21</td>
<td>90 (95)</td>
</tr>
<tr>
<td>Square-hop, n=81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg, no</td>
<td>35 (9)</td>
<td>36.5 (12)</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>LSI (%)</td>
<td>100 (12)</td>
<td>104.9 (9)</td>
<td>0.68</td>
<td>80 (86)</td>
</tr>
<tr>
<td>Vertical hop, n=42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)†</td>
<td>24 (12)</td>
<td>26 (16)</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>LSI (%)</td>
<td>98.8 (12)</td>
<td>93.3 (21)</td>
<td>0.08</td>
<td>36 (74)</td>
</tr>
<tr>
<td>One-leg balance, n=82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)‡</td>
<td>43 (40)</td>
<td>32.5 (44)</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>LSI (%)</td>
<td>100 (50)</td>
<td>100 (53)</td>
<td>0.42</td>
<td>76 (80)</td>
</tr>
<tr>
<td>One-leg rise, n=83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)†</td>
<td>85 (20)</td>
<td>84.5 (20)</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>LSI (%)</td>
<td>100 (0)</td>
<td>100 (4)</td>
<td>0.23</td>
<td>84 (90)</td>
</tr>
<tr>
<td>Test battery, n=74 LSI≥90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(in all 4 tests) n (%)</td>
<td>25 (68)</td>
<td>27 (73)</td>
<td>0.61</td>
<td>60 (70)</td>
</tr>
</tbody>
</table>

Values are the median (IQR) unless otherwise indicated.
*Presented as proportion of total (n=87) study sample (proportion of those who performed the test).
†Absolute values are not presented since two methods were used to assess muscle strength at testing sites.
‡Test values were transformed by subtracting the result from 100, giving a new scale with best results=100, worst result=0.  
ACLR, anterior cruciate ligament reconstruction; LSI, leg symmetry index (injured leg divided by non-injured leg×100).

Ethical considerations

The study protocol was approved by the Lund University ethics committee and all patients gave their written informed consent before entering the study.
Delayed ACLR versus exercise alone and prediction of having delayed ACLR

Patients who had a delayed ACLR after physical performance testing (n=20) had significantly worse results on the vertical hop test than did those who remained with exercise alone over a 5-year period (mean 21 vs 29 cm, p=0.043) and these results also predicted the need for delayed ACLR over 5 years in the regression analysis (p=0.048; table 4). It should, however, be noted that only 50% of the sample (35% of the original RCT sample) performed the test. No other significant differences were found for any of the performed tests or for the test battery (p=0.10–0.98).

DISCUSSION

Using a structured exercise programme as described for the KANON trial (see web appendix), functional recovery (defined as having a LSI≥90%) was achieved in a majority of ACL injured young active adults at a median of 8 months after ACL injury. We could not identify any significant difference in muscle strength or physical performance between those treated with or without additional ACLR. However, the results of the one-leg rise test at the end of the exercise period predicted self-reported knee function at 2 and 5 years after ACL injury, regardless of treatment. Furthermore, our results suggest that poorer results of the vertical hop test may predict the need of delayed ACLR in those starting with exercise alone.

Limitations and strengths

This study had certain limitations. First, the sample is relatively small and tests were only assessed for 72% of patients of the original RCT sample. We did not find any significant difference in baseline characteristics between those tested and those not tested but other potential differences of importance could not be excluded. Second, all tests were assessed by several experienced physical therapists, no standardisation sessions were performed and none of the tests were determined to be more important than the other a priori. Furthermore, two separate methods were employed for assessing muscle strength making comparisons between crude test results difficult.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Crude analysis</th>
<th>Adjusted analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope</td>
<td>95% CI</td>
</tr>
<tr>
<td>KODOS$^+$ at 2 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps LSI (%)</td>
<td>0.39</td>
<td>−0.13 to 0.91</td>
</tr>
<tr>
<td>Hamstrings LSI (%)</td>
<td>0.10</td>
<td>−0.30 to 0.50</td>
</tr>
<tr>
<td>One-leg hop LSI (%)</td>
<td>0.24</td>
<td>−0.32 to 0.79</td>
</tr>
<tr>
<td>Square-hop LSI (%)</td>
<td>0.11</td>
<td>−0.25 to 0.47</td>
</tr>
<tr>
<td>Vertical hop LSI (%)</td>
<td>0.15</td>
<td>−0.13 to 0.43</td>
</tr>
<tr>
<td>One-leg balance LSI (%)</td>
<td>−0.01</td>
<td>−0.08 to 0.06</td>
</tr>
<tr>
<td>One-leg rise LSI (%)</td>
<td>1.32</td>
<td>0.68 to 1.97</td>
</tr>
<tr>
<td>Test battery (LSI≥90% in all 4 tests)$^*$</td>
<td>6.78</td>
<td>−3.44 to 17.0</td>
</tr>
<tr>
<td>KODOS$^+$ at 5 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps LSI (%)</td>
<td>0.40</td>
<td>−0.02 to 0.81</td>
</tr>
<tr>
<td>Hamstrings LSI (%)</td>
<td>0.11</td>
<td>−0.25 to 0.47</td>
</tr>
<tr>
<td>One-leg hop LSI (%)</td>
<td>0.14</td>
<td>−0.30 to 0.59</td>
</tr>
<tr>
<td>Square-hop LSI (%)</td>
<td>0.12</td>
<td>−0.18 to 0.41</td>
</tr>
<tr>
<td>Vertical hop LSI (%)</td>
<td>−0.09</td>
<td>−0.34 to 0.16</td>
</tr>
<tr>
<td>One-leg balance LSI (%)</td>
<td>0.004</td>
<td>−0.05 to 0.06</td>
</tr>
<tr>
<td>One-leg rise LSI (%)</td>
<td>1.04</td>
<td>0.52 to 1.55</td>
</tr>
<tr>
<td>Test battery (LSI≥90% in all 4 tests)$^*$</td>
<td>0.81</td>
<td>−7.43 to 9.04</td>
</tr>
</tbody>
</table>

Univariate regression analyses were performed for crude results; multivariate regression analysis was employed for the adjusted analysis with a model including one-leg rise LSI, sex, age, BMI, surgery/no surgery and baseline KODOS$^+$ scores.

$^*$Tests included were one-leg hop, square-hop, one-leg balance and one-leg rise tests.

BMI, body mass index; LSI, leg symmetry index (injured leg divided by non-injured leg×100).

Table 4 Physical performance test results as predictors of delayed ACLR over 5 years for those initially treated with exercise alone (n=42)

<table>
<thead>
<tr>
<th>Undergoing delayed ACLR within 5 years post injury</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps LSI (n=33)</td>
<td>1.08</td>
<td>0.97 to 1.2</td>
<td>0.18</td>
</tr>
<tr>
<td>Hamstrings LSI (n=27)</td>
<td>1.11</td>
<td>0.98 to 1.26</td>
<td>0.099</td>
</tr>
<tr>
<td>One-leg hop (n=40)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)</td>
<td>1.00</td>
<td>0.99 to 1.02</td>
<td>0.71</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>1.07</td>
<td>0.96 to 1.19</td>
<td>0.26</td>
</tr>
<tr>
<td>Square hop (n=39)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (number of hops)</td>
<td>0.98</td>
<td>0.92 to 1.05</td>
<td>0.58</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>0.98</td>
<td>0.94 to 1.03</td>
<td>0.44</td>
</tr>
<tr>
<td>Vertical hop (n=21)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)</td>
<td>0.85</td>
<td>0.72 to 1.00</td>
<td>0.048</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>0.97</td>
<td>0.90 to 1.05</td>
<td>0.44</td>
</tr>
<tr>
<td>One-leg balance (n=41)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (s)</td>
<td>1.02</td>
<td>0.99 to 1.04</td>
<td>0.24</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>1.01</td>
<td>0.99 to 1.02</td>
<td>0.35</td>
</tr>
<tr>
<td>One-leg rise (n=39)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injured leg (cm)</td>
<td>1.00</td>
<td>0.96 to 1.04</td>
<td>0.98</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>1.00</td>
<td>0.92 to 1.09</td>
<td>0.98</td>
</tr>
<tr>
<td>Test battery (n=37) (LSI≥90% in all 4 tests)$^*$</td>
<td>0.66</td>
<td>0.16 to 2.65</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Univariate logistic regression analyses were performed for each of the potential predictors.

$^*$Tests included were one-leg hop, square-hop, one-leg balance and one-leg rise tests. ACLR, anterior cruciate ligament reconstruction; LSI, leg symmetry index (injured leg divided by non-injured leg×100).
However, we predefined a detailed test protocol for each centre using validated and reliable tests. We used LSI, as opposed to crude results, to minimise the influence of measurement errors and potential bias. Specific strengths of this study were the use of reliable physical performance tests in a prospective study design including both surgically and non-surgically treated young active adults with acute ACL injury to a previously uninjured knee.

Clinically relevant findings

We were surprised to find that LSI values for muscle strength and physical performance 8 months after injury were 90% or higher for the majority of patients in this study. This may be due to the rigorous structured exercise protocol and supervised training used in this high-quality RCT; alternatively, a crossover effect of weakening of the uninjured leg cannot be excluded. Similar LSI values have previously been reported after treatment in young motivated ACL injured patients and this supports our findings. Ageberg et al tested muscle power and physical performance on a subgroup of the present sample at a mean of 3 years after injury using a rigorously standardised test protocol, applied by dedicated and experienced scientists. The LSI of the one-leg hop test and the vertical hop test in that study and this report are within 2% of each other which further support the validity of our results. Both studies failed to find differences in muscle strength and physical performance between those treated with ACLR and those treated with exercise alone. This supports the similarity in self-reported outcomes, activity level, frequency of meniscus surgery and radiographic OA reported at 2 and 5 years in this cohort. The absence of significant differences in physical performance supports the possibility that proper exercise training may be more important than ligament reconstruction with respect to restoring physical function after ACL injury, at least up to 5 years.

Predictors of later clinical outcomes

In the current study, results of the vertical hop test predicted a delayed ACLR over a 5-year period in those who started off in the exercise alone group. It should be noted that only 35% of the original RCT sample were included in the analysis and thus these findings should be interpreted with caution. Fitzgerald et al found that non-reconstructed ACL-injured patients who failed rehabilitation had lower pretraining hop test symmetry scores than did those who succeeded in returning to preinjury activity level after 6 months. Screening examinations, including physical performance testing, has been used to differentiate between copers and non-copers to exercise treatment after ACL injury; however, such efforts had only limited success. The ACL injured patients’ preference for reconstructive surgery may be of importance, and might explain some of the difficulties in predicting the ‘need’ for ACLR.

We found that results of the one-leg rise test predicted knee function as measured by KOOS at both 2 and 5 years, also after adjustment for sex, age, BMI, baseline KOOS and surgical/ non-surgical treatment. A similar predictive value of physical performance test results was found by others year after ACL injury in both surgically treated and non-surgically treated patients. Those reports suggested that the crossover hop test, the 6 m timed hop test and the single hop for distance were the best predictors while we found that none of the individual hop tests could predict self-reported knee function. Our findings of one-leg rise test results being the only significant predictor of self-reported knee function at 2 and 5 years may suggest that functional strength and endurance are important determinants for future knee function after ACL injury. Possibly, results of the one-leg rise test, an easily performed clinical test, could aid clinicians in the screening of ACL injured patients who may benefit from further exercise.

CONCLUSION

In conclusion, restoration of at least 90% of muscle strength and physical performance compared with the uninjured leg was achieved by at least 75% of ACL injured patients at 8 months after injury, regardless of having exercise as the only treatment or in combination with ACLR. Poor results of the one-leg rise test at 8 months predicted worse self-reported outcomes at 2 and 5 years after ACL injury and thus this may be an important test for future studies on ACL injured individuals.

What are the new findings?

- Muscle strength and physical performance can recover (as compared with the uninjured side) after 8 months of supervised exercise in a high proportion of young active individuals with acute anterior cruciate ligament (ACL) injury.
- We failed to identify differences in muscle strength and functional performance test results, performed at the end of the exercise period after ACL injury, between those treated with and without ACL reconstruction (ACLR).
- Results of the one-leg rise test, performed at the end of the exercise period after ACL injury, predicted self-reported outcome at 2 and 5 years after the injury.

How might it impact on clinical practise in the near future?

- Supervised exercise as performed in this study, seems to be recommendable in terms of restoring physical performance after ACL injury regardless of whether an ACLR is performed or not.
- The one-leg rise test is recommended as an important clinical test after ACL injury, as it may predict self-reported outcome after 2 and 5 years.

Contributors YBE contributed to the study design and was responsible for data analysis, interpretation and manuscript preparation. EMR contributed to the data interpretation and manuscript revision. RBF was responsible for the study design and data collection and contributed to the interpretation and manuscript revision.

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