# 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; $KOOS_4$) 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 $KOOS_4$ at 2 and 5 years ($R^2$=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.[5–7] 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 Risberg[11] 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-reconstructed[12] 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

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to a previously uninjured knee and has been reported in detail elsewhere.[3 4 14] Major exclusion criteria were professional athlete (10 on the Tegner Acivity Score)[15]; less than moderately active individuals (0–5 on the same scale); a total collateral ligament rupture; a full-thickness cartilage lesion visualised on MRI.

Physical performance was tested by the treating physical therapist 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),[4] 20/23 completed exercise and performed physical performance testing before undergoing 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 randomisation. Consequently, the 45 patients who were tested after having had an ACLR (regardless of being an early or delayed procedure) 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.[3 6] 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.[3] 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.[3] In randomised trials, these two methods have resulted in similar outcomes.[16 17]

## 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 training 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.[3] 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 contralateral side. The assessors, who were instructed to follow a prespecified 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, alternative 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 minimise the influence of multiple testers and different testing devices.

The following tests were performed:

*Muscle strength* was measured for knee extensors (ie, quadriceps) and knee flexors (ie, hamstrings) using peak torque derived from either an isokinetic device (BIODEX[18]) or a leg extension/leg curl machine (according to the principle of one maximal repetition, 1 RM).[19 20]

*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*:[21 22] 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*:[22 23] 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*:[22] 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 the distance (cm) was recorded.
D. *The one-leg rise test*:[22] 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 position 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 trials 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*:[22] 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) 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 treatment 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

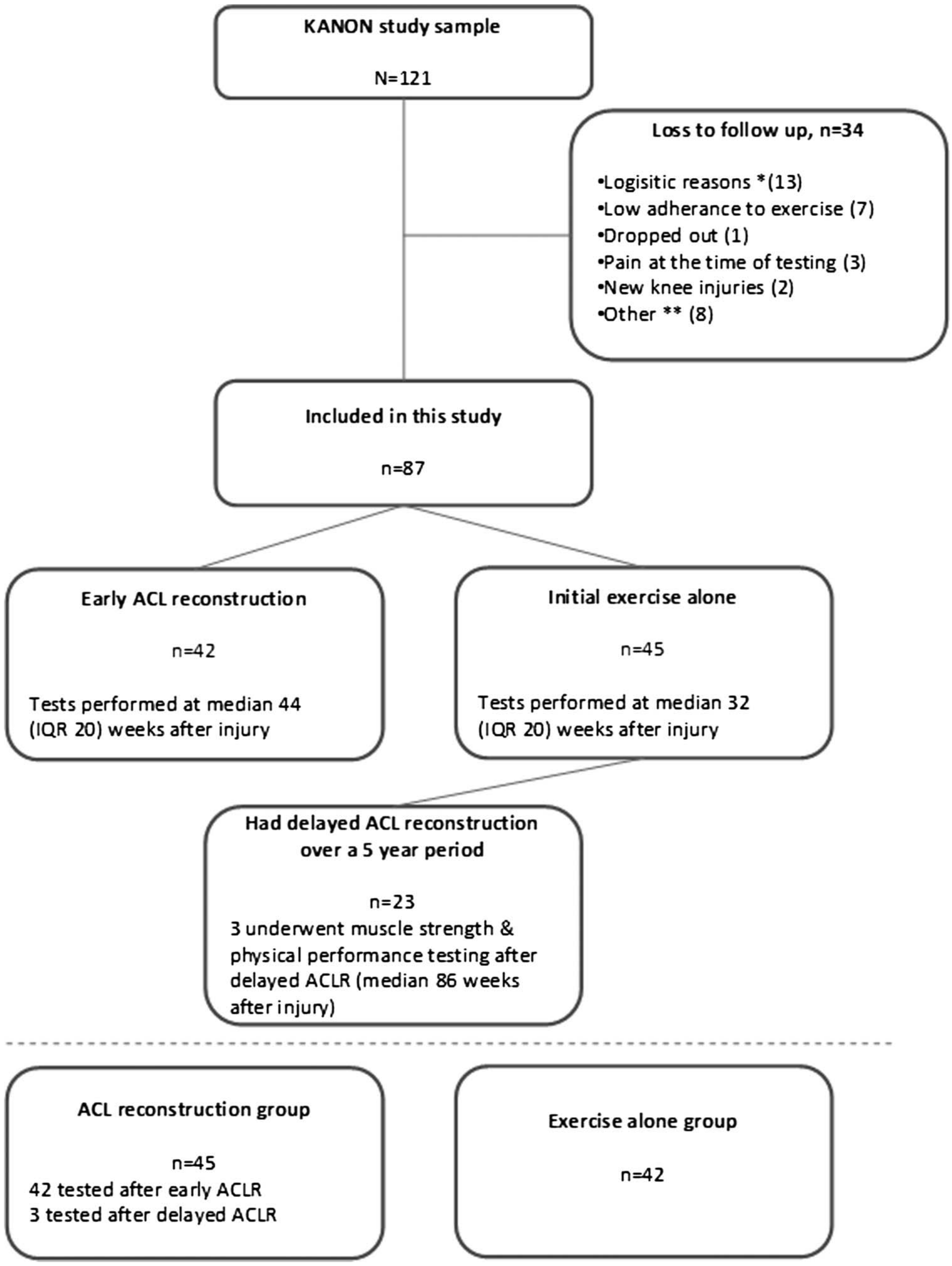


**Figure 1** Flow chart over patients included in the study. *Indicates moving from town or shifting to a physiotherapist not involved in the study. **Indicates that one was pregnant and one suffered from disc herniation at the time of testing; three were refrained from testing, by treating PT as they "had not achieved the rehabilitation goals" according to the exercise protocol; three had missing test protocols. Access the article online to view this figure in colour.

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).[24] 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[25] including ACLR[26 27] and reference data are available from several large ACLR cohorts.[28–30] Consistent with previous publications,[3 4] we used the mean score of four (Pain, Symptoms, Sport and Recreation Function, Knee-related QoL) of the five KOOS subscales scores ($KOOS_4$) at 2 and 5 years as endpoints in the predictive analyses.

## Statistics

Statistical analyses were made in SPSS V.20. To calculate LSI for the one-leg rise test (which could have a value of 0) we transformed

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

| | Patients with test results (included) (N=87) | Patients without test results (N=34) | p Value |
|---|---|---|---|
| Characteristics | | | |
| Age, year | 25.8±5 | 26.6±5 | 0.43 |
| Female sex, n (%) | 23 (26) | 9 (27) | 0.99 |
| BMI | 23.9±2.6 | 24.7±3.6 | 0.16 |
| College education, n (%) | 29 (33) | 15 (44) | 0.27 |
| Married (living with partner), n (%) | 36 (41) | 16 (47) | 0.57 |
| Working full time or part time, no (%) | 57 (66) | 22 (64) | 0.93 |
| Student, n (%) | 23 (26) | 11 (32) | 0.52 |
| Sports-related injury, n (%) | 86 (99) | 33 (97) | 0.49 |
| Injury to right knee, n (%) | 49 (56) | 17 (50) | 0.53 |
| Positive Lachmann test*, n (%) | 86 (99) | 33 (97) | 0.23 |
| $KOOS_4$ score | 37.8 (15) | 34.8 (12) | 0.29 |
| SF-36, physical component score | 47.3 (14) | 46.5 (12) | 0.77 |
| SF-36, mental component score | 65.5 (21) | 68.5 (15) | 0.44 |
| Tegner Activity Score, md (IQR) | 9.0 (2) | 9.0 (2) | 0.98 |
| Randomised to ACLR, n (%) | 42 (48) | 20 (59) | 0.30 |

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; $KOOS_4$ 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)

| | Exercise alone (n=42) | Exercise +ACLR (n=45) | p Value | Proportion of Individuals with LSI ≥90%* |
|---|---|---|---|---|
| Muscle strength† | | | | |
| Quadriceps, n=69 LSI (%) | 100 (3) | 100 (3) | 0.92 | 69 (87) |
| Hamstrings, n=58 LSI (%) | 100 (0) | 100 (6) | 0.19 | 55 (83) |
| Functional performance | | | | |
| One-leg hop, n=82 | | | | |
| Injured leg (cm) | 148 (44) | 152 (40) | 0.23 | |
| LSI (%) | 100 (7) | 99.3 (7) | 0.21 | 90 (95) |
| Square-hop, n=81 | | | | |
| Injured leg, no | 35 (9) | 36.5 (12) | 0.39 | |
| LSI (%) | 100 (12) | 104.4 (9) | 0.68 | 80 (86) |
| Vertical hop, n=42 | | | | |
| Injured leg (cm) | 24 (12) | 28 (16) | 0.48 | |
| LSI (%) | 98.8 (12) | 93.3 (21) | 0.08 | 36 (74) |
| One-leg balance, n=82 | | | | |
| Injured leg (s) | 43 (40) | 32.5 (44) | 0.80 | |
| LSI (%) | 100 (50) | 100 (53) | 0.42 | 76 (80) |
| One-leg rise, n=83 | | | | |
| Injured leg (cm)‡ | 85 (20) | 84.5 (20) | 0.57 | |
| LSI (%) | 100 (0) | 100 (4) | 0.23 | 84 (90) |
| Test battery, n=74 (LSI≥90% in all 4 tests) n (%) | 25 (68) | 27 (73) | 0.61 | 60 (70) |

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 result=100, worst result=0.
ACLR, anterior cruciate ligament reconstruction; LSI, leg symmetry index (injured leg divided by non-injured leg×100).

values by subtracting the result from 100. Between-group comparisons were made using the Mann-Whitney U test for continuous variables and the $\chi^2$ test for dichotomous variables.

The predictive value of each individual muscle strength and physical performance test result (LSI, independent variables) on self-reported outcome ($KOOS_4$) 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 with adjustment for age, sex, body mass index (BMI), baseline $KOOS_4$ score and surgical treatment (yes/no, all independent variables).

To determine whether individual physical performance tests results (independent) could predict having a delayed ACLR (yes/no, dependent) in those starting with exercise alone, we used univariate logistic regression analyses with one model for each test result. In these models, n ranged between 22 and 42 individuals. Sex, age, BMI and baseline $KOOS_4$ score were not associated with surgical treatment and thus no adjustments were made. A statistical significance level of 5% was used and no adjustments for multiple comparisons were made.

## 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.

## 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 ($KOOS_4$) at 2 and 5 years, unadjusted and adjusted ($R^2$=0.18 and 0.25 and 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 $KOOS_4$ scores at either 2 or 5 years (table 3).

**Table 3** Physical performance tests as predictors of self-reported knee function at 2 and 5 years

| | Crude analysis | | | | Adjusted analysis | | | |
|---|---|---|---|---|---|---|---|---|
| Predictor | Slope | 95% CI | $R^2$ | p Value | Slope | 95% CI | $R^2$ | p Value |
| $KOOS_4$ at 2 years | | | | | | | | |
| Quadriceps LSI (%) | 0.39 | −0.13 to 0.91 | 0.03 | 0.14 | – | – | – | – |
| Hamstrings LSI (%) | 0.10 | −0.30 to 0.50 | 0.004 | 0.63 | – | – | – | – |
| One-leg hop LSI (%) | 0.24 | −0.32 to 0.79 | 0.009 | 0.40 | – | – | – | – |
| Square-hop LSI (%) | 0.11 | −0.25 to 0.47 | 0.005 | 0.55 | – | – | – | – |
| Vertical hop LSI (%) | 0.15 | −0.13 to 0.43 | 0.03 | 0.28 | – | – | – | – |
| One-leg balance LSI (%) | −0.01 | −0.08 to 0.06 | 0.002 | 0.72 | – | – | – | – |
| One-leg rise LSI (%) | 1.32 | 0.68 to 1.97 | **0.18** | <0.001 | 1.12 | 0.46 to 1.79 | 0.25 | 0.001 |
| Test battery (LSI≥90% in all 4 tests)* | 6.78 | −3.44 to 17.0 | 0.024 | 0.19 | – | – | – | – |
| $KOOS_4$ at 5 years | | | | | | | | |
| Quadriceps LSI (%) | 0.40 | −0.02 to 0.81 | 0.05 | 0.06 | 0.35 | −0.08 to 0.79 | 0.11 | 0.11 |
| Hamstrings LSI (%) | 0.11 | −0.25 to 0.47 | 0.007 | 0.55 | – | – | – | – |
| One-leg hop LSI (%) | 0.14 | −0.30 to 0.59 | 0.005 | 0.52 | – | – | – | – |
| Square-hop LSI (%) | 0.12 | −0.18 to 0.41 | 0.008 | 0.42 | – | – | – | – |
| Vertical hop LSI (%) | −0.09 | −0.34 to 0.16 | 0.01 | 0.48 | – | – | – | – |
| One-leg balance LSI (%) | 0.004 | −0.05 to 0.06 | 0.00 | 0.88 | – | – | – | – |
| One-leg rise LSI (%) | 1.04 | 0.52 to 1.55 | 0.17 | <0.001 | 0.88 | 0.34 to 1.42 | 0.24 | 0.002 |
| Test battery (LSI≥90% in all 4 tests)* | 0.81 | −7.43 to 9.04 | 0.001 | 0.85 | – | – | – | – |

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 $KOOS_4$ 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).

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

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

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 adult patients 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 uninvolved leg[31 32] cannot be excluded. Similar LSI values have previously been reported after treatment in young motivated ACL injured patients and this supports our findings.[11–13] Ageberg *et al*[33] 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.[3 4] 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*[34] 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;[35 36] however, such efforts had only limited success.[37] The ACL injured patients' preference for reconstructive surgery may be of importance,[38] 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 $KOOS_4$ at both 2 and 5 years, also after adjustment for sex, age, BMI, baseline $KOOS_4$ and surgical/ non-surgical treatment. A similar predictive value of physical performance test results was found by others 1 year after ACL injury in both surgically treated[12] and non-surgically treated patients.[13] 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 uninvolved 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.

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# Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about our work.

Supplement to: **Ericsson, Roos, Frobell**
Strength and Performance after Exercise Therapy for Acute Anterior Cruciate Ligament Injury in Patients Treated with and without Reconstructive Surgery:
An ancillary Analysis from a Randomized Controlled Trial

# APPENDIX A: REHABILITATION PROTOCOL OF THE KANON STUDY

The protocol included four levels described by exercise examples and goals for range of motion, muscle function, and functional performance for the first 24 weeks of rehabilitation. Goals for each level should be met prior to progression to the next level. Time intervals for each level were suggested but not superior to the goals. A slower progression was expected in those assigned to rehabilitation plus ACL reconstruction. Pain, swelling and discomfort slowed the progression, and if persistent a visit to the treating clinician was scheduled. Use of anti- inflammatory drugs (NSAID) was allowed if needed.

Examples of exercises appropriate for each phase are presented. These exercises are examples and the Physical Therapist also used complementary exercises complying with the guidelines for each phase.

| | **0-4 weeks** | **5-8 weeks** | **9-12 weeks** | **13-16 weeks** | **17-24 weeks** |
|---|---|---|---|---|---|
| **Unloaded range of motion (ROM)**<br><br>***Goals*** | As tolerated<br><br>*Full extension Flexion > 120 deg* | As tolerated<br><br>*Full extension Flexion comparable to other side* | Normal<br><br>*Comparable to other side* | Normal<br><br>*Comparable to other side* | Normal<br><br>*Comparable to other side* |
| **Muscle function**<br><br>***Goals*** | Quadriceps: unloaded full control Hamstrings: loaded exercises Exercises for other lower limb muscles and trunk are initiated<br><br>*Full quadriceps control in sitting and standing* | Quadriceps: loaded non-weight bearing in 40-120 deg and closed-chain (weight bearing) exercises in 0-80 Hamstrings: full ROM Exercises for other lower limb muscles and trunk | Quadriceps: closed-chain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk | Quadriceps: open-chain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk<br><br>*Non-surgical: Less than 10% difference in quadriceps and hamstrings strength between legs* | Quadriceps: open-chain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk<br><br>*Surgical: Less than 10% difference in quadriceps and hamstrings strength between legs* |

| | 0-4 weeks | 5-8 weeks | 9-12 weeks | 13-16 weeks | 17-24 weeks |
|---|---|---|---|---|---|
| **Symptoms** | Pain: tolerated, treated if necessary<br>Swelling: tolerated, treated if necessary | Pain: tolerated, treated if necessary<br>Swelling: tolerated, treated if necessary | No pain<br>Occasional activity-related swelling tolerated | No pain<br>Occasional activity-related swelling tolerated | No pain<br>Occasional activity-related swelling tolerated |
| ***Goals*** | *No morning swelling* | *No pain*<br>*Occasional activity-related swelling* | *No activity-related pain*<br>*Occasional activity-related swelling* | *No activity-related pain*<br>*Occasional activity-related swelling* | *No activity-related pain*<br>*Occasional activity-related swelling* |
| **Walking** | As tolerated forward and backwards without pain* and limping (initially with crutches) | Full weight-bearing<br>Daily walking without restrictions | Full weight-bearing<br>Slow and fast walking on treadmill | Full weight-bearing<br>Running on treadmill/even surface<br>Non-surgical: Unrestricted running | Full weight-bearing<br>Surgical: Unrestricted running |
| ***Goals*** | *Full weight-bearing without pain or limping*<br>*Crutches may be discharged when patient is able to walk backwards without limping* | *Full weight-bearing*<br>*Walking without pain or limping* | *Full weight-bearing*<br>*Walking without pain, swelling or limping* | *Full weight-bearing*<br>*Non-surgical: Running without pain, swelling or limping* | *Full weight-bearing*<br>*Surgical: Running without pain, swelling or limping* |

| | 0-4 weeks | 5-8 weeks | 9-12 weeks | 13-16 weeks | 17-24 weeks |
|---|---|---|---|---|---|
| **Balance/ Coordination** | One-leg standing in functional positions | One-leg standing in functional positions on soft ground and Babs-board | One-leg standing in functional positions on more demanding surfaces and Babs-board | One-leg standing in functional positions on more demanding surfaces<br>Two legged bounces<br>Easy sport-specific movements<br>Easy agility exercises | One-leg standing in functional positions on more demanding surfaces<br>One legged bounces<br>Provoked sport-specific movements<br>Provoked agility exercises |
| ***Goals*** | *One-leg standing without difficulties* | *Comparable to other side* | *Comparable to other side* | *Non-surgical: One-legged hop and square-hop[1] less than 10% difference between legs* | *Surgical: One-legged hop and square-hop[1] less than 10% difference between legs* |

| | 0-4 weeks | 5-8 weeks | 9-12 weeks | 13-16 weeks | 17-24 weeks |
|---|---|---|---|---|---|
| **Activities**<br><br><br><br><br><br><br><br><br><br>***Goals*** | Unloaded and loaded biking on stationary bike backwards and forwards with clips<br><br><br><br><br><br><br>*Unloaded biking forward with clips* | Biking on stationary bike without restrictions<br>Wet-vest exercises and running in deep water<br>Non-surgical: Outdoor biking without restrictions | Biking on stationary bike without restrictions<br>Wet-vest exercises and running in deep water<br>Slide-board training | Non-surgical: Introduction of sport-specific exercises<br>Surgical: Outdoor biking without restrictions<br><br><br><br>*Non-surgical: Back to pre-injury activity level* | Surgical: Introduction of sport-specific exercises<br><br><br><br><br><br><br>*Surgical: Back to pre-injury activity level* |
| **Action if goal is not reached** | | If ROM, Symptoms, Weightbearing goals are not reached: Doctors Visit | | | |

*As tolerated = acceptable pain according to Pain Monitoring System Visual Analog Scale 5 (0-10) (Thomee, R. A comprehensive treatment approach for patellofemoral pain syndrome in young women. Phys Ther 1977(12): 1690-703.

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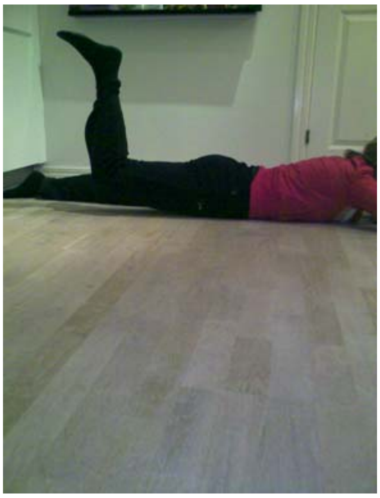
# Phase 1 and 2, 0-8 weeks.

## Home program; 2-7 days after injury/operation.

***Knee flexion:***



Lay on your stomach, bend your injured knee to about 90 degrees and lift your foot and lower leg towards the ceiling.

***Knee extension:***

Sit in front of a wall with your injured leg slightly bent and a ball under the knee.
Put the foot against the wall and press the knee towards the floor. Keep the tension in the knee extensors.

***Muscle function:***

Sit on a chair/stool. Stand up slowly with full muscle control, equally distributed load on both feet.

**Phase 1 and 2. 2-8 weeks after injury/reconstructive surgery**

Lay on your back with hips and knees in 90 degrees with your feet against the wall. Slide your injured leg up and down along the wall by extending and flexing your knee.

Stand with your back against the wall and a soft ball behind your injured knee. Squeeze the ball against the wall by extending your knee.

"Norwegian push-ups".
Press a soft ball between your knees, flex and extend your hips and knees. Keep back straight.

Stand on a step board, step down by flexing foot, knee and hip…
Important! Neutral alignment of foot, knee and hip.
Do not lean trunk forward.

…forward

… to the side

Leg press, start at 90 degrees and extend your legs.

Kneebendings with a stick.
Important! Neutral alignment of foot, knee and hip.
Do not lean trunk forward.

Lay on your back with the injured leg on a hard pillow,
keep your hands around your other knee. Lift your pelvis.

Lay on your back with both legs on the hard pillow. Lift your pelvis using one leg, move your other leg sideways.
Alternate between legs.

A. Stand with your injured leg slightly bent on the step board.

B. Take one step up with your injured leg
and extend your knee. Continue the rise until on your toes,
keep the knee extended.

Lean against the board on your injured side. Lift your hip up
from the board. Simultaneously, extend
and lift the other leg in abduction.

Stand on your injured leg on a balance board
with your knee semi flexed.

Stand on your injured leg on a trampoline,
flex and extend your knee slightly and slowly with full control.

Stand on your injured leg and slide sideways and back again
with your other leg. Use a small towel under the other shoe for sliding.

## Phase 4 and 5. 13-24 weeks after injury/reconstruction

Lunges while moving medicine ball from side to side.

Stepping down to the side from stepboard with deep kneebendings.

Leg extentions with resistance.

Stand on your injured leg with your other lower leg resting on a pillow. Flex your injured knee with dumbbells in your hands.
Important! Neutral alignment of foot, knee and hip.

Squeeze a soft ball between your knees.
Jump forward on both legs over a series of step boards.