Published in final edited form as:

J Orthop Sports Phys Ther. 2010 November ; 40(11): 705–721. doi:10.2519/jospt.2010.3345.

A Progressive 5-Week Exercise Therapy Program Leads to Significant Improvement in Knee Function Early After Anterior Cruciate Ligament Injury

INGRID EITZEN, PT, PhD¹, HÅVARD MOKSNES, PT, MSc², LYNN SNYDER-MACKLER, PT, ScD³, and MAY ARNA RISBERG, PT, PhD⁴

¹Researcher, NAR, Department of Orthopaedics, Oslo University Hospital, Oslo, Norway; Physical Therapist, Hjelp24 Norwegian Sports Medicine Clinic (Hjelp24 NIMI), Oslo, Norway

²PhD student, Norwegian School of Sports Sciences, Oslo, Norway; Physical Therapist, Hjelp24 Norwegian Sports Medicine Clinic (Hjelp24 NIMI), Oslo, Norway

³Alumni Distinguished Professor, Department of Physical Therapy, University of Delaware, Newark, US

⁴Professor and Chair, NAR, Norwegian School of Sports Sciences, Oslo, Norway; Hjelp24 Norwegian Sports Medicine Clinic (Hjelp24 NIMI), Oslo, Norway; Department of Orthopaedics, Oslo University Hospital, Oslo, Norway

Abstract

STUDY DESIGN—Prospective cohort study without a control group.

OBJECTIVES—Firstly, to present our 5-week progressive exercise therapy program in the early stage after anterior cruciate ligament (ACL) injury. Secondly, to evaluate changes in knee function after completion of the program for patients with ACL injury in general and also when classified as potential copers or noncopers, and, finally, to examine potential adverse events.

BACKGROUND—Few studies concerning early-stage ACL rehabilitation protocols exist. Consequently, little is known about the tolerance for, and outcomes from, short-term exercise therapy programs in the early stage after injury.

METHODS—One-hundred patients were included in a 5-week progressive exercise therapy program, within 3 months after injury. Knee function before and after completion of the program was evaluated from isokinetic quadriceps and hamstrings muscle strength tests, 4 single-leg hop tests, 2 different self-assessment questionnaires, and a global rating of knee function. A 2-way mixed-model analysis of variance was conducted to evaluate changes from pretest to posttest for the limb symmetry index for muscle strength and single-leg hop tests, and the change in scores for the patient-reported questionnaires. In addition, absolute values and the standardized response mean for muscle strength and single-leg hop tests were calculated at pretest and posttest for the injured and uninjured limb. Adverse events during the 5-week period were recorded.

RESULTS—The progressive 5-week exercise therapy program led to significant improvements ($P < .05$) in knee function from pretest to posttest both for patients classified as potential copers and noncopers. Standardized response mean values for changes in muscle strength and single-leg hop performance from pretest to posttest for the injured limb were moderate to strong (0.49–0.84),

indicating the observed improvements to be clinically relevant. Adverse events occurred in 3.9% of the patients.

CONCLUSION—Short-term progressive exercise therapy programs are well tolerated and should be incorporated in early-stage ACL rehabilitation, either to improve knee function before ACL reconstruction or as a first step in further nonoperative management.

Keywords

ACL; adverse events; copers; hop tests; noncopers

Due to differing clinical practice in the management of anterior cruciate ligament (ACL) ruptures, there is no universal agreement as to what is the ideal treatment algorithm for individuals with ACL injury.^{5,23,43} In our outpatient clinic, our general recommendation to individuals with an acute ACL injury is to go through 10 sessions of a progressive exercise therapy program for a period of 5 weeks after initial impairments are resolved, before the final decision for either ACL reconstruction (ACLR) or further nonoperative management is made. This is recommended, independent of whether patients are classified as potential copers or noncopers.⁴⁵ Potential copers are characterized as having good knee stability and the ability to compensate well after injury, whereas noncopers have poor knee stability and less potential for compensation.²⁵

Recent studies from our own research group have supported the underlying rationale for advising all patients with ACL injuries to perform a progressive exercise therapy program. Moksnes et al⁴⁵ demonstrated that patients with ACL injury, who initially have poor knee function, demonstrate good potential for functional improvement after rehabilitation. Further, Eitzen et al¹⁷ found that preoperative quadriceps strength was the single most important predictor for knee function 2 years after ACLR, and that preoperative deficits were persistent 2 years after surgery. These findings seem to justify postponing the decision for ACLR for a short period, to optimize preoperative knee function. Still, very few evidence-based protocols for early-stage ACL injury management, including explicit descriptions of the rehabilitation programs and evaluation of outcome, exist.^{11,56,65} As a consequence, little is known about the tolerance for, and potential benefit from, short-term progressive exercise therapy programs in the early stage after ACL injury.

In the present study, our purpose was to evaluate a 5-week progressive exercise therapy program either as a preoperative optimization of knee function, or as the first step in further nonoperative management, in patients with ACL injury. We wanted to examine changes in general, but, additionally, to analyze individuals classified as potential copers or noncopers in accordance to the criteria described by Fitzgerald et al.¹⁹ The first aim of the study was to present in detail our 5-week progressive exercise therapy program for patients with ACL injury. Secondly, to evaluate changes in isokinetic quadriceps and hamstrings muscle strength, single-leg hop tests, and self-assessment of knee function from pretest to posttest after completion of the exercise therapy program, including potential differences between patients classified as potential copers and noncopers. The third and final aim was to examine the potential risk of adverse events for such an intensive program in the early stage after ACL injury. We hypothesized the following: (1) patients with ACL injury completing a 5-week progressive exercise therapy program in the early stage after injury would significantly improve knee function assessed from isokinetic muscle strength tests, single-leg hop tests, and self-assessment questionnaires; (2) patients initially classified as noncopers would improve knee function assessed from isokinetic muscle strength tests, single-leg hop tests, and self-assessment questionnaires significantly more than subjects classified as potential copers; (3) early after injury, patients with ACL rupture would tolerate a progressive exercise therapy program without adverse events.

METHODS

Participants consisted of the first 100 included patients in an ongoing prospective cohort study. The patients were enrolled between January 2007 and August 2009. Patients were referred to our outpatient clinic from the emergency room or their physician, or they came on their own initiative. To be considered eligible for inclusion, patients must have had a complete unilateral rupture of the ACL within the past 90 days. Complete rupture of the ACL was confirmed by both magnetic resonance imaging and at least 3 mm of bilateral difference in anterior knee joint laxity, as measured by a KT-1000 knee arthrometer (MED Metric, San Diego, CA).⁷⁰ Patients had to be between 13 and 60 years of age, participate regularly in pivoting sports, which is an activity level I or level II, as defined by Hefti et al²⁷ (TABLE 1), and be able to come to our clinic at least twice a week for participation in the exercise therapy program. Patients were excluded if they had symptomatic meniscal injuries, range-of-motion (ROM) deficits that were not resolved within 90 days after the date of injury, a quadriceps muscle strength index less than or equal to 70%, grade III or IV injury to collateral ligaments, injury to the posterior cruciate ligament, previous injuries of any kind to the injured or uninjured knee, cartilage lesions affecting the subchondral bone (assessed from magnetic resonance imaging), fractures, or did not agree to the compliance requirements of performing the exercise therapy program at least twice a week for 5 weeks.

The study was designed and carried out in accordance to the Declaration of Helsinki and approved by The Regional Ethical Committee for Eastern Norway. Prior to inclusion, all patients signed a written informed consent.

Outcome Measures

Before testing, patients performed a standard 10-minute warm-up on a stationary ergometer cycle. The test battery in this study included isokinetic muscle strength tests for quadriceps and hamstrings^{28,29,35} (Biodex 6000; Biodex Medical Systems Inc, Shirley, NY), using 5 repetitions at 60° per second. This velocity is considered adequate for assessment of muscle strength after ACL injury.^{14,29,38,52} Patients performed 4 repetitions for practice for each limb before the test. Isokinetic absolute torque values were measured in newton meters (Nm) for both peak torque and torque at 30° knee flexion angle,¹⁶ and total work was expressed in joules (J). Four single-leg hop tests^{15,19,47} were included: the one-leg hop for distance, the triple crossover hop for distance, the triple-hop for distance, and the 6-meter timed hop test. A stopwatch was used for timing the 6-meter timed hop test. Single-leg hop tests have been considered to reflect both strength, coordination, and confidence after ACL injury.^{36,53} Patients performed 1 practice trial for each limb to familiarize themselves with the tests. Two trials were performed for each hop test, and the average score of the 2 trials was used in the analyses. Absolute hop lengths were measured in centimeters, and time for the 6-meter timed hop test in seconds. Immediately after the hop tests, patients answered 2 self-assessment questionnaires: the Knee Outcome Survey Activities of Daily Living Scale (KOS-ADLS)³⁴ and The International Knee Documentation Committee Subjective Knee Form (IKDC2000).³¹ These 2 questionnaires were selected due to the previously shown reliability, validity, and responsiveness for individuals with ACL injury.^{31–34} Patients also stated their activity level, number of episodes of giving way, and a global rating of knee function from a numeric visual analogue scale (VAS).²¹ Patients were classified as either potential copers or noncopers, according to the criteria described by Fitzgerald et al.¹⁹ To fulfill the criteria of a potential coper, patients had to have greater than or equal to 80% score on the KOS-ADLS, a global rating numeric VAS score greater than or equal to 60, single-leg hop performance on the 6-meter timed hop test of greater than or equal to 80%, and maximum 1 episode of giving way since the injury.^{19,45}

Data collection procedures for the above tests are described in detail in a recent publication from our research group.¹⁸ The baseline pretest, including the screening examination for classification into potential copers and noncopers, was performed as soon as initial impairments were resolved, whereas the posttest was to be performed within 6 weeks after the screening examination.

Exercise Therapy Program

ACL-rehabilitation in our outpatient clinic is divided into 3 subsequent phases, where the described progressive 5-week program represents phase 2. In the initial phase (phase 1), the goal is to resolve knee impairments related to swelling and ROM deficits. As soon as knee joint effusion is eliminated and full ROM is restored, phase 2 is initiated. Patients were excluded from this study if impairments were not eliminated within the first 3 months of phase 1 rehabilitation after their injury.

The primary aim of phase 2 rehabilitation is to restore muscle strength and adequate neuromuscular responses. Consequently, this phase emphasizes intensive muscle strength training, plyometric exercises,⁹ and advanced neuromuscular exercises. Because specific evidence-based guidelines for strength training in the early stage after ACL injury do not exist, the strength training part of our phase 2 program is developed based on the principles outlined in the American College of Sports Medicine position stand for progression models for resistance training for healthy adults.⁴⁰ The strength training was standardized and performed as multiple sets of exercises for a minimum of 2 and a maximum of 4 sessions a week, with maximal effort for 3 or 4 sets of 6 to 8 repetitions. These guidelines are consistent with recent recommendations for training frequency, recovery, and exercise volume for recreational athletes at an intermediate level.^{40,50,54,69} Progression was guided by a dose-response theoretical framework, where the absolute load is increased from a targeted repetition number in each set.⁴⁰ To assure progressive overload, we used the “+2 principle.” This principle implies that the patients are told to perform as many repetitions as they can manage in the last of the third or fourth sets. If they are able to add 2 extra repetitions, load will be increased in the next treatment session. Both single- and multiple-joint exercises, open and closed kinetic chain exercises, as well as concentric, eccentric, and isometric strength exercises, were included.⁴⁰ Open kinetic chain exercises have been shown to be of considerable importance for quadriceps strength improvement,^{44,62} and threaten unwanted anterior translation of the tibia less than previously assumed.^{41,46,49} Specific single-limb exercises for the injured limb were performed on custom strength training equipment (Technogym, Gambettola, Italy), using leg press, knee extension, and leg curl machines. The strength training program was individualized based on the specific needs of each patient. In addition to progressive strength training, plyometric exercises were included in the program for enhancement of neuromuscular performance and strength development.^{9,59} Plyometric exercises were performed through variations of single-leg hops and drills focusing on maintaining the knee-over-toe position with soft landings to avoid landings with injurious dynamic loads.⁴⁸ Further, neuromuscular challenges were assured through balance and proprioception exercises such as single-legged squats on balance pads or the BOSU balance trainer. The basic strength, plyometric, and neuromuscular exercises included in the program are presented in APPENDIX A. As a specific neuromuscular enhancement, a sequence of 10 sessions with perturbation training was included in the program. Perturbation training included balance and stability exercises on custom-made roller board, rocker board, and platform, and involved perturbation of the support surface that allowed altered forces and torques to be applied to the injured limb in multiple directions in a controlled manner.⁸ Progression of the perturbation training sessions was based on the guidelines from the University of Delaware²⁰ and is presented in APPENDIX B and instructional videos recently published online.²⁶ Rehabilitation programs including

perturbation training have previously been shown to enhance coordinated muscle activity and thus improve the dynamic stability of the knee early after injury.^{8,20,25}

All patients were supervised at least twice a week throughout the program to assure that the intended quality of performance and correct level of difficulty was achieved, as well as to perform the perturbation sessions. Because patients were not supervised continuously during each session, compliance was additionally monitored through exercise diaries and medical records. Each training session was intended not to exceed 75 minutes, including a 10- to 15-minute warm-up on a stationary ergometer cycle, treadmill, or ellipse walker. Complications and adverse events were reported to the 2 supervising physical therapists (I.E. or H.M.) and noted in the medical records of each subject.

After completion of the progressive 5-week exercise therapy program, patients went through posttesting and the final decision for reconstructive surgery or further nonoperative management was addressed. The majority of the patients in our cohort had a preference for surgery, based on their desire to return to pivoting sports. The posttest results were incorporated when treatment options were discussed with the patients, but not used as cut-off criteria in the final decision making for surgery or further nonoperative management. Patients who were not referred to surgery continued rehabilitation in phase 3, whereas patients awaiting ACLR continued progressive rehabilitation in phase 2 with restrictions against participation in pivoting sports. Of the 100 included patients, 64 went through ACLR within the first 6 months after the posttest, and 36 continued nonoperative management.

Data Analysis

Descriptive data characterizing the cohort was calculated from frequencies and mean values with standard deviations. Changes in muscle strength and hop performance limb symmetry index (LSI) from pretest to posttest were compared using a 2-way mixed-model analysis of variance (ANOVA). LSI was expressed as the side-to-side difference in percent using the uninjured limb as control. The ANOVA was also utilized for calculation of changes in score from pretest to posttest for the KOS-ADLS, IKDC2000, and VAS. The main effect evaluated changes over time from pretest to posttest. Further, potential interaction effects between groups (potential copers/noncopers) and time, as well as potential differences in the observed changes between potential copers and noncopers, were calculated. Additionally, we calculated the percentage changes from pretest to posttest using the mean absolute values of the isokinetic muscle strength tests and the single-leg hop tests. To evaluate whether percentage changes could be regarded as clinically relevant, the standardized response mean (SRM) was calculated for changes in absolute torque values, hop lengths (one-leg hop for distance, crossover hop for distance, triple-hop for distance), and time (6-meter timed hop test) from pretest to posttest. The SRM was computed by dividing the mean change (posttest score minus pretest score) by the SD of the change.¹⁰ SRMs were regarded as moderate between 0.5 and 0.8, and large above 0.8.^{4,10} The number of adverse events was registered in the medical records for all patients.

RESULTS

Characteristics of the Cohort

A flow chart of the study is presented in FIGURE 1. To include 100 patients, 211 were considered eligible for inclusion, and 111 were excluded. Reasons for exclusion are given in FIGURE 1. There were no significant differences in age, gender, body mass index, or preinjury activity level between the included and excluded patients. The mean number of days from injury to the baseline pretest screening examination for the included patients was 60.4 (range, 23–96) days, while the mean number of days from the baseline pretest

screening examination to posttest was 34.9 (range, 15–58) days. The exercise therapy program incorporated 10 sessions, and the mean number of completed sessions of the 98 patients that were included at follow-up was 9.7 (range, 8–10) sessions. The sessions were completed within a mean time frame of 5 weeks. Subject characteristics are presented in TABLE 2. There were no significant baseline differences on age, gender, preinjury activity level, KT-1000 static knee laxity, body mass index, which side was injured, activity while injured, days from injury to pretest screening, or days from pretest to posttest between patients classified as potential copers or noncopers. Further, there were no significant baseline differences between those who later opted to have ACLR (64%) and those who continued nonoperative management (36%), except for age ($P = .005$) and activity level ($P = .003$). Those who opted for surgery were younger, with a mean age of 24.5 years, compared to 29.0 years for those who elected not to have surgery. Among those who were surgically treated, 81% were active at level I and 19% at level II; whereas the activity level was equally distributed, with 50% at both level I and II among those who continued nonoperative management.

Two patients were lost to follow-up at posttest (FIGURE 1). One subject did not show for his appointments week 2 after pretest screening, then came back 6 weeks later, after he had reconstructive surgery at another clinic. The other subject was involved in a traffic accident and consequently did not complete the posttest. Both these patients were classified as potential copers at the pretest screening examination. Five additional patients have incomplete data from the hop tests at posttest. Four of these experienced adverse events with swelling and pain during the 5-week exercise therapy program. The fifth had an episode of giving way during the crossover hop for distance at posttest. However, this subject had completed the exercise therapy program without problems.

Quadriceps and Hamstrings Muscle Strength

Changes from pretest to posttest for quadriceps and hamstrings muscle strength are shown in TABLE 3. There were no significant interaction effects between groups (potential copers and noncopers) and time. The main effect for time was significant for quadriceps muscle peak torque, torque at 30° knee flexion, and total work, as well as hamstrings muscle peak torque and total work ($P < .05$). The between-group main effect was significant for all 3 quadriceps muscle strength outcome measurements ($P \leq .01$) (FIGURE 2) but nonsignificant for hamstrings muscle strength peak torque ($P = .50$) and total work ($P = .43$) (FIGURE 3).

Changes in percent of absolute torque values for quadriceps strength for the injured limb from pretest to posttest were between 8.2% and 11.1% for the 3 outcome measures, with moderate corresponding SRM values (TABLE 4).

Single-Leg Hop Tests

There were no significant interaction effects between groups (potential copers and noncopers) and time for the single-leg hop tests (TABLE 3). Further, no significant main effect for time was found for either of the single-leg hops. For the triple-hop for distance and the 6-meter timed hop test, significant main effects for groups were present ($P < .05$) (FIGURE 4).

Changes in percent of absolute hop length for the injured limb for the 4 hop tests were between 5.5% and 9.5%. The calculated SRM values were moderate for the one-leg hop for distance, triple-hop for distance, and 6-meter timed hop test, and large for the crossover hop for distance (TABLE 5).

Self-Assessment Questionnaires

A significant interaction effect between groups (potential copers and noncopers) and time was evident for the KOS-ADLS ($P<.01$) (TABLE 6 and FIGURE 5), but not for the IKDC2000 or the VAS. Both the main effects for time and groups were significant ($P<.001$) for the IKDC2000 and the VAS (TABLE 6 and FIGURE 5).

Tolerance for the Exercise Therapy Program

Two patients were lost to follow-up at posttest. Four of the remaining 98 patients (3.9%) experienced progressively more swelling and pain during the second or third week of the program, and had to reduce exercise intensity to the extent that they could not be considered compliant with the program. Swelling and pain occurred following the performance of plyometric exercises for all 4 patients. None of the patients reported pain during muscle strength exercises, balance and stability exercises, or perturbation sessions. Two of the 4 patients that had complications during the plyometric exercises were noncopers and 2 were potential copers. These 4 individuals all later opted to have ACLR and also required a meniscus repair.

Discussion

The purpose of this study was to investigate whether a progressive 5-week exercise therapy program in the early stage after injury before decision making for either ACLR or further nonoperative management could improve knee function and was tolerated by patients with ACL injury. The overall results confirmed our first hypothesis: that a progressive exercise therapy program conducted within a mean time frame of 5 weeks would lead to significantly improved knee function in patients with ACL injury. This was evident both for subjects initially classified as potential copers and noncopers. The second hypothesis, that noncopers would improve significantly more than potential copers, was not confirmed. An interaction effect implying larger improvement in noncopers compared to potential copers was only found for KOS-ADLS. Our third hypothesis, suggesting that there would be no adverse events among patients conducting the program, was partially confirmed, with only 3.9% of the patients attending the posttest having progressive swelling and pain that required curtailing compliance with the 5-week program.

Currently, a clear consensus does not exist for the selection of exercises and exact dose-response in rehabilitation programs in the early stage after ACL injury. Our 5-week progressive program combines strength training, plyometric exercises, general exercises for balance and stability, and perturbation training. The strength training regimen is based on principles for heavy resistance strength training for healthy individuals with few repetitions in each series, to increase the cross-sectional area of the muscle and promote neuromuscular adaptation.⁴⁰ Both closed and open kinetic chain exercises were included, as recent publications have shown that open kinetic chain exercises are important to regain quadriceps muscle strength^{41,44} and also that open kinetic chain exercises can be conducted safely in patients with ACL injury.^{44,46,49} The neuromuscular exercises in the program are intended to be of the utmost challenge to the patient. Over the past few years, our exercise therapy program has evolved in the direction of higher loads, fewer repetitions, and less restrictions with regard to open kinetic chain exercises, as well as more challenging neuromuscular exercises.

LSI is commonly used to express both isokinetic muscle strength⁶¹ and single-leg hop performance,² and a LSI of greater than or equal to 90% is often considered to indicate normal limb symmetry.^{2,24,25,61} However, the use of LSI alone may be ambiguous if the main purpose is to evaluate the response to exercise and improvement of knee function

primarily in the injured limb. Using the uninjured limb as control has the methodological advantage that biological differences between patients are avoided. But the potential disadvantage is that the status of the uninjured side may lead to misinterpretation of results^{4,7,30} due to possible bilateral neuromuscular changes after injury.^{1,48} In addition to evaluation of the LSI, we performed supplementary evaluations of the absolute values for the uninjured and injured side and examined changes in percent from pretest to posttest for both isokinetic muscle strength torques and single-leg hop lengths (one-leg hop for distance, crossover hop for distance, and triple-hop for distance) and time (6-meter timed hop test). These analyses revealed changes in both quadriceps and hamstrings muscle strength for the injured side (range, 8.2%–12.9%) (TABLE 4), entailing a strength increase of 1.6% to 2.2% per week. The corresponding SRM values for the injured limb reflected changes of moderate clinical relevance (0.49–0.60), whereas the corresponding SRM values for the uninjured limb were low (0.13–0.40). Evaluation of absolute values (TABLE 5) for single-leg hop performance showed changes in percent in the injured limb from 5.5% to 9.5%. The SRM values were moderate to strong (0.50–0.84) for all tests. Thus, analyses of the absolute values and corresponding SRMs for the injured lower extremity revealed clinically interesting improvements that were concealed when evaluating only LSI. Without a control group, calculation of SRM values for pretest to posttest changes in the injured limb may be of particular clinical interest. While *P* values reflect whether an observed change is statistically significant, SRM values express the magnitude of the observed changes.⁴ Our SRM values emphasize that patients with ACL tears in the early stage after injury have potential for clinically relevant functional improvements, even from a short-term exercise therapy program consisting of only 10 training sessions.

When comparing our muscle strength data to normative values presented by Phillips et al,⁵¹ the mean posttest absolute peak torque values on the injured limb were equivalent to normative values from the dominant limb of healthy subjects (183.8 versus 180.3 Nm, respectively). However, the mean age of the subjects included in the normative study was higher than for our cohort (44.2 versus 26.1 years, respectively). However, Danneskiold-Samsøe et al¹² presented normative values for a cohort with patients age-matched to ours at 169.0 Nm, which further suggests that the patients in our cohort regained adequate muscle strength after the exercise therapy program. The limited amount of normative data for isokinetic knee muscle strength should, nevertheless, be addressed in future studies.

Previous studies from our group¹⁶ and Shirakura et al⁶⁰ showed that there were larger differences in quadriceps strength at knee flexion angles of less than 40°. Thus, quadriceps torque values at 30° knee flexion angle were included in the analyses. The results confirm previous findings that LSI differences were larger at angles closer to full knee extension (TABLE 3). This may have important clinical implications when using quadriceps strength LSI in the evaluation of treatment outcome. However, when evaluating changes in absolute values and SRM values from pretest to posttest, the deficits at 30° demonstrated the highest percentage improvement (11.1%) and the highest SRM value (0.58) of the included strength measures. This indicates that even though larger at pretest, quadriceps muscle strength weakness in the injured limb at angles closer to full extension have good potential for improvement. As a consequence, knee extension exercises targeting strength deficits throughout the whole knee extension ROM should be included in early stage rehabilitation programs.

All self-assessments of knee function significantly improved from pretest to posttest ($P < .001$). The KOS-ADLS showed a significant interaction effect, implying that noncopers improved significantly more than potential copers (FIGURE 5). Significant main effects for time and group were found for both the VAS and the IKDC2000 ($P < .001$), revealing that

both potential copers and noncopers improved but noncopers still had lower scores at posttest ($P < .001$).

The IKDC2000 is used for assessment of knee function with regard to symptoms, function, and sports activity,³ and may thus be considered to be of particular relevance for our cohort of young, active individuals. The mean IKDC2000 score for our cohort at pretest and posttest was 69.7 and 77.8 points, respectively. According to the normative data for IKDC2000 published by Anderson et al,³ scores for subjects age-matched to our cohort indicate a mean score of approximately 89 points for men and 86 points for women. Previous studies have shown that ACL injury may lead to low self-efficacy⁶⁴ and that self-efficacy and mental preparedness before ACLR may influence the final outcome.^{5,63} The improvements in the IKDC2000 may suggest the potential importance of increased self-evaluation scores in the early stage after injury, before scheduled ACLR. This is of particular interest for noncopers, who from the original screening examination algorithm were not regarded as candidates for rehabilitation.¹⁹ However, the IKDC2000 does not assess self-efficacy as such, and future studies investigating preoperative self-reported outcomes as predictors for postoperative outcome are needed to verify this suggestion.

Preoperative quadriceps muscle strength deficits have previously been assessed from isokinetic measurements to be between 7% and 21%,^{13,36–38,55} and have also been shown to be persistent after ACLR.^{17,37,68} As a consequence, there has been growing attention towards the importance of more aggressive strength training of the quadriceps muscle after ACL injury.^{6,25,41} Ingersoll et al³⁰ suggested that strength deficits after ACL injury are the result of alterations to muscle activation patterns. The almost immediate development of weakness and the often observed persistency of the deficit despite rehabilitation suggest that arthrogenic muscle inhibition may play a major role in quadriceps atrophy after ACL injury.⁴⁸ Furthermore, individuals with ACL injury who have muscle strength deficits often have overall poor function.^{62,68} However, to what extent altered neuromuscular strategies^{1,6,30,48,68} and proprioceptive deficits^{22,57} contributing to reduced function after ACL injury may be restored through rehabilitation is not well documented. Most systematic reviews and randomized controlled trials on ACL-injuries focus on individuals post ACLR. In 2 systematic reviews, Cooper et al¹¹ and Risberg et al⁵⁶ identified only a few high-quality studies on the effect of neuromuscular training programs for individuals with ACL-deficient knees, with variations both in exercises included and the duration of the programs. Still, it is concluded that exercises for proprioception and balance may improve dynamic knee stability and thus the functional ability of the patients. Further, there is some evidence suggesting that plyometric exercises will enhance muscular strength and athletic performance,^{9,59} and that rehabilitation programs, including specific perturbation training, may lead to beneficial neuromuscular adaptations.^{20,25,42} Without a comparison group, we cannot state that our findings document that combined approaches of both neuromuscular exercises and strength training are superior to other exercise programs emphasizing separate elements. However, we can from our findings state that it is possible to achieve significant and clinically important improvements in both muscle strength and knee function even with a short-term exercise program, and that this is true both for subjects initially classified as potential copers and noncopers. Future studies, including randomized controlled trials with groups that perform different exercise therapy programs, are needed to verify the potential effectiveness of our program.

A crucial issue when introducing progressive exercise therapy programs is the tolerance for the training load. In this study, 3.9% of the patients experienced adverse events during the period of conducting the program that prevented compliance with regard to progression of the plyometric exercises. Lack of tolerance was demonstrated by progressively increasing symptoms of swelling and pain during or after training sessions. We attribute these

complications to the performance of the plyometric exercises. Recent studies have emphasized the challenges related to the correct diagnosis of meniscus injuries.^{39,58,67} We included both magnetic resonance imaging and a clinical examination when evaluating individuals eligible for inclusion in the study. Our definition of a symptomatic meniscus injury implied that patients should reveal symptoms during hopping exercises, and/or have evident knee joint effusion, and/or ROM deficits that were not resolved within 3 months after the date of injury. The 4 patients that experienced adverse events all later opted to have ACLR and were found to require a concomitant meniscus repair. All patients in the study were advised not to participate in any pivoting activities during phase 2. Further, they were monitored at least twice a week and any complications and adverse events were registered. No episodes of giving way were reported. Thus, it is unlikely that any of the 4 patients had new injuries within the 5-week period, and their symptoms were most probably related to the increased demands posed on the knee during phase 2 of the rehabilitation program. The remaining 94 patients were compliant with the demands for progression and exercises in the program. Our results indicate that the majority of patients with isolated ACL-injuries are able to comply with progressive exercise therapy programs. However, our results suggest that adverse events can be expected to occur in 1 out of 25 patients. Thus, the responsible physical therapist must monitor eventual adverse events closely on an individual basis and never hesitate to adjust the program if undesired symptoms appear. Based on our findings, symptoms of pain and swelling during the rehabilitation program may be an indicator of other intra-articular pathology like a meniscus tear.

Limitations

Due to the inherent limitations of a study design without comparison groups, we cannot document superior effects of our program compared to other rehabilitation programs but are restricted to report the observed changes in outcome measures from pretest to posttest, and to discuss the outcome in comparison to other studies.

Patients were instructed and regularly reminded to update a personal written exercise diary during the 5-week exercise therapy program. However, the compliance of the patients to fill in these self-reported data was not satisfactory. We did not register this information systematically when monitoring the patients, and, as a consequence, data showing exact progression during each session throughout the exercise period cannot be provided. Future studies should include closer monitoring of dose-response and progress for each separate exercise that is included in the exercise therapy program, both for muscle strength and neuromuscular exercises. From our experience, this should be registered as part of the patient monitoring at each session and not be based on self-reporting.

Our cohort consisted of patients with isolated ACL-tears, including asymptomatic meniscus lesions. A considerable amount of patients with ACL injury have additional injuries to the menisci and/or collateral ligaments and related symptoms,⁶⁶ which is also reflected in the number of individuals excluded from our cohort. Our results can, therefore, not be generalized to patients with symptomatic concomitant injuries. Our high tolerance rate for the progressive exercise therapy program must be interpreted within this context.

Finally, the patients included in this study were young, active individuals who might have had higher motivation for exercise and rehabilitation than other subgroups of patients with ACL injury. Our results are thus dependent on high compliance to, and low drop-out rates from, the exercise therapy program.

CONCLUSION

This study showed that a progressive rehabilitation program conducted within a mean time frame of 5 weeks, with emphasis on heavy resistance strength training and challenging neuromuscular exercises, led to significantly improved knee function in the early stage after ACL injury. It is, therefore, suggested to incorporate a short-term period of intensive exercise in ACL injury management, either before scheduled ACLR, or as a preparation for further nonoperative management before returning to preinjury activity without surgery.

Acknowledgments

This study was financed by RO1 HD 037985-04, RO1 HD 037985-05, and RO1 HD 037985-06 from The National Institutes of Health. The study protocol was approved by The Regional Ethical Committee, Health Region South-East, Norway (Institutional Review Board).

We would like to acknowledge the physical therapists Ida Svege, Espen Selboskar, and Karin Rydevik for assistance in data collection, and Line Hagen in Exercise Organizer for providing illustrations for APPENDIX A.

References

1. Ageberg E. Consequences of a ligament injury on neuromuscular function and relevance to rehabilitation: using the anterior cruciate ligament-injured knee as model. *J Electromyogr Kinesiol.* 2002; 12:205–212. [PubMed: 12086815]
2. Ageberg, E.; Thomee, R.; Neeter, C.; Silbernagel, KG.; Roos, EM. Muscle strength and functional performance in patients with anterior cruciate ligament injury treated with training and surgical reconstruction or training only: a two to five-year followup; *Arthritis Rheum.* 2008. p. 1773-1779.<http://dx.doi.org/10.1002/art.24066>
3. Anderson, AF.; Irrgang, JJ.; Kocher, MS.; Mann, BJ.; Harrast, JJ. The International Knee Documentation Committee Subjective Knee Evaluation Form: normative data; *Am J Sports Med.* 2006. p. 128-135.<http://dx.doi.org/10.1177/0363546505280214>
4. Bent, NP.; Wright, CC.; Rushton, AB.; Batt, ME. Selecting outcome measures in sports medicine: a guide for practitioners using the example of anterior cruciate ligament rehabilitation; *Br J Sports Med.* 2009. p. 1006-1012.<http://dx.doi.org/10.1136/bjsm.2009.057356>
5. Beynnon, BD.; Johnson, RJ.; Abate, JA.; Fleming, BC.; Nichols, CE. Treatment of anterior cruciate ligament injuries, part I; *Am J Sports Med.* 2005. p. 1579-1602.<http://dx.doi.org/10.1177/0363546505279913>
6. Bruhn S, Kullmann N, Gollhofer A. Combinatory effects of high-intensity strength training and sensorimotor training on muscle strength. *Int J Sports Med.* 2006; 27:401–406. [PubMed: 16729384]
7. Bryant, AL.; Creaby, MW.; Newton, RU.; Steele, JR. Dynamic restraint capacity of the hamstring muscles has important functional implications after anterior cruciate ligament injury and anterior cruciate ligament reconstruction; *Arch Phys Med Rehabil.* 2008. p. 2324-2331.<http://dx.doi.org/10.1016/j.apmr.2008.04.027>
8. Chmielewski TL, Hurd WJ, Rudolph KS, Axe MJ, Snyder-Mackler L. Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral anterior cruciate ligament rupture. *Phys Ther.* 2005; 85:740–749. discussion 750–744. [PubMed: 16048422]
9. Chmielewski, TL.; Myer, GD.; Kauffman, D.; Tillman, SM. Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application; *J Orthop Sports Phys Ther.* 2006. p. 308-319.<http://dx.doi.org/10.2519/jospt.2006.2013>
10. Cohen, J. *Statistical Power Analysis for the Behavioural Sciences.* 2. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc; 1988.
11. Cooper RL, Taylor NF, Feller JA. A systematic review of the effect of proprioceptive and balance exercises on people with an injured or reconstructed anterior cruciate ligament. *Res Sports Med.* 2005; 13:163–178. [PubMed: 16392446]

12. Danneskiold-Samsoe, B.; Bartels, EM.; Bulow, PM., et al. Isokinetic and isometric muscle strength in a healthy population with special reference to age and gender; *Acta Physiol (Oxf)*. 2009. p. 1-68.<http://dx.doi.org/10.1111/j.1748-1716.2009.02022.x>
13. de Jong, SN.; van Caspel, DR.; van Haeff, MJ.; Saris, DB. Functional assessment and muscle strength before and after reconstruction of chronic anterior cruciate ligament lesions; *Arthroscopy*. 2007. p. 28p. e21-23.<http://dx.doi.org/10.1016/j.arthro.2006.08.024>
14. Dvir, Z. *Isokinetics: Muscle Testing, Interpretation and Clinical Applications*. 2. London, UK: Churchill Livingstone; 2004.
15. Eastlack ME, Axe MJ, Snyder-Mackler L. Laxity, instability, and functional outcome after ACL injury: copers versus noncopers. *Med Sci Sports Exerc*. 1999; 31:210–215. [PubMed: 10063808]
16. Eitzen, I.; Eitzen, TJ.; Holm, I.; Snyder-Mackler, L.; Risberg, MA. Anterior cruciate ligament-deficient potential copers and noncopers reveal different isokinetic quadriceps strength profiles in the early stage after injury; *Am J Sports Med*. 2010. p. 586-593.<http://dx.doi.org/10.1177/0363546509349492>
17. Eitzen, I.; Holm, I.; Risberg, MA. Preoperative quadriceps strength is a significant predictor of knee function two years after anterior cruciate ligament reconstruction; *Br J Sports Med*. 2009. p. 371-376.<http://dx.doi.org/10.1136/bjsm.2008.057059>
18. Eitzen I, Moksnes H, Snyder-Mackler L, Engebretsen L, Risberg MA. Functional tests should be accentuated more in the decision for ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2010 Apr 22. Epub ahead of print.
19. Fitzgerald GK, Axe MJ, Snyder-Mackler L. A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. *Knee Surg Sports Traumatol Arthrosc*. 2000; 8:76–82. [PubMed: 10795668]
20. Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. *Phys Ther*. 2000; 80:128–140. [PubMed: 10654060]
21. Flandry F, Hunt JP, Terry GC, Hughston JC. Analysis of subjective knee complaints using visual analog scales. *Am J Sports Med*. 1991; 19:112–118. [PubMed: 2039061]
22. Friden T, Roberts D, Ageberg E, Walden M, Zatterstrom R. Review of knee proprioception and the relation to extremity function after an anterior cruciate ligament rupture. *J Orthop Sports Phys Ther*. 2001; 31:567–576. [PubMed: 11665744]
23. Granan, LP.; Bahr, R.; Lie, SA.; Engebretsen, L. Timing of anterior cruciate ligament reconstructive surgery and risk of cartilage lesions and meniscal tears: a cohort study based on the Norwegian National Knee Ligament Registry; *Am J Sports Med*. 2009. p. 955-961.<http://dx.doi.org/10.1177/0363546508330136>
24. Gustavsson, A.; Neeter, C.; Thomee, P., et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction; *Knee Surg Sports Traumatol Arthrosc*. 2006. p. 778-788.<http://dx.doi.org/10.1007/s00167-006-0045-6>
25. Hartigan, E.; Axe, MJ.; Snyder-Mackler, L. Perturbation training prior to ACL reconstruction improves gait asymmetries in noncopers; *J Orthop Res*. 2009. p. 724-729.<http://dx.doi.org/10.1002/jor.20754>
26. Hartigan, EH.; Axe, MJ.; Snyder-Mackler, L. Time line for noncopers to pass return-to-sports criteria after anterior cruciate ligament reconstruction; *J Orthop Sports Phys Ther*. 2010. p. 141-154.<http://dx.doi.org/10.2519/jospt.2010.3168>
27. Hefti F, Muller W, Jakob RP, Staubli HU. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc*. 1993; 1:226–234. [PubMed: 8536037]
28. Hislop HJ, Perrine JJ. The isokinetic concept of exercise. *Phys Ther*. 1967; 47:114–117. [PubMed: 6045281]
29. Hole CD, Smit GH, Hammond J, Kumar A, Saxton J, Cochrane T. Dynamic control and conventional strength ratios of the quadriceps and hamstrings in subjects with anterior cruciate ligament deficiency. *Ergonomics*. 2000; 43:1603–1609. [PubMed: 11083140]
30. Ingersoll, CD.; Grindstaff, TL.; Pietrosimone, BG.; Hart, JM. Neuromuscular consequences of anterior cruciate ligament injury; *Clin Sports Med*. 2008. p. 383-404.p. [viihttp://dx.doi.org/10.1016/j.csm.2008.03.004](http://dx.doi.org/10.1016/j.csm.2008.03.004)

31. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the international knee documentation committee subjective knee form. *Am J Sports Med.* 2001; 29:600–613. [PubMed: 11573919]
32. Irrgang, JJ.; Anderson, AF.; Boland, AL., et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form; *Am J Sports Med.* 2006. p. 1567-1573.<http://dx.doi.org/10.1177/0363546506288855>
33. Irrgang JJ, Ho H, Harner CD, Fu FH. Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 1998; 6:107–114. [PubMed: 9604196]
34. Irrgang JJ, Snyder-Mackler L, Wainner RS, Fu FH, Harner CD. Development of a patient-reported measure of function of the knee. *J Bone Joint Surg Am.* 1998; 80:1132–1145. [PubMed: 9730122]
35. Kannus P, Jarvinen M, Johnson R, et al. Function of the quadriceps and hamstrings muscles in knees with chronic partial deficiency of the anterior cruciate ligament. Isometric and isokinetic evaluation. *Am J Sports Med.* 1992; 20:162–168. [PubMed: 1558244]
36. Keays SL, Bullock-Saxton J, Keays AC. Strength and function before and after anterior cruciate ligament reconstruction. *Clin Orthop Relat Res.* 2000:174–183. [PubMed: 10810475]
37. Keays, SL.; Bullock-Saxton, JE.; Keays, AC.; Newcombe, PA.; Bullock, MI. A 6-year follow-up of the effect of graft site on strength, stability, range of motion, function, and joint degeneration after anterior cruciate ligament reconstruction: patellar tendon versus semitendinosus and gracilis tendon graft; *Am J Sports Med.* 2007. p. 729-739.<http://dx.doi.org/10.1177/0363546506298277>
38. Keays, SL.; Bullock-Saxton, JE.; Newcombe, P.; Keays, AC. The relationship between knee strength and functional stability before and after anterior cruciate ligament reconstruction; *J Orthop Res.* 2003. p. 231-237.[http://dx.doi.org/10.1016/S0736-0266\(02\)00160-2](http://dx.doi.org/10.1016/S0736-0266(02)00160-2)
39. Konan, S.; Rayan, F.; Haddad, FS. Do physical diagnostic tests accurately detect meniscal tears?; *Knee Surg Sports Traumatol Arthrosc.* 2009. p. 806-811.<http://dx.doi.org/10.1007/s00167-009-0803-3>
40. Kraemer, WJ.; Adams, K.; Cafarelli, E., et al. American College of Sports Medicine position stand Progression models in resistance training for healthy adults; *Med Sci Sports Exerc.* 2009. p. 687-708.<http://dx.doi.org/10.1249/MSS.0b013e3181915670>
41. Kvist J. Rehabilitation following anterior cruciate ligament injury: current recommendations for sports participation. *Sports Med.* 2004; 34:269–280. [PubMed: 15049718]
42. Lewek MD, Chmielewski TL, Risberg MA, Snyder-Mackler L. Dynamic knee stability after anterior cruciate ligament rupture. *Exerc Sport Sci Rev.* 2003; 31:195–200. [PubMed: 14571959]
43. Magnussen, RA.; Granan, LP.; Dunn, WR., et al. Cross-cultural comparison of patients undergoing ACL reconstruction in the United States and Norway; *Knee Surg Sports Traumatol Arthrosc.* 2010. p. 98-105.<http://dx.doi.org/10.1007/s00167-009-0919-5>
44. Mikkelsen C, Werner S, Eriksson E. Closed kinetic chain alone compared to combined open and closed kinetic chain exercises for quadriceps strengthening after anterior cruciate ligament reconstruction with respect to return to sports: a prospective matched follow-up study. *Knee Surg Sports Traumatol Arthrosc.* 2000; 8:337–342. [PubMed: 11147151]
45. Moksnes, H.; Snyder-Mackler, L.; Risberg, MA. Individuals with an anterior cruciate ligament-deficient knee classified as noncopers may be candidates for nonsurgical rehabilitation; *J Orthop Sports Phys Ther.* 2008. p. 586-595.<http://dx.doi.org/10.2519/jospt.2008.2750>
46. Morrissey, MC.; Perry, MC.; King, JB. Is knee laxity change after ACL injury and surgery related to open kinetic chain knee extensor training load?; *Am J Phys Med Rehabil.* 2009. p. 369-375.<http://dx.doi.org/10.1097/PHM.0b013e3181a0d7ed>
47. Noyes FR, Matthews DS, Mooar PA, Grood ES. The symptomatic anterior cruciate-deficient knee. Part II: the results of rehabilitation, activity modification, and counseling on functional disability. *J Bone Joint Surg Am.* 1983; 65:163–174. [PubMed: 6822580]
48. Palmieri-Smith, RM.; Thomas, AC. A neuromuscular mechanism of posttraumatic osteoarthritis associated with ACL injury; *Exerc Sport Sci Rev.* 2009. p. 147-153.<http://dx.doi.org/10.1097/JES.0b013e3181aa6669>

49. Perry, MC.; Morrissey, MC.; Morrissey, D.; Knight, PR.; McAuliffe, TB.; King, JB. Knee extensors kinetic chain training in anterior cruciate ligament deficiency; *Knee Surg Sports Traumatol Arthrosc.* 2005. p. 638-648.<http://dx.doi.org/10.1007/s00167-004-0603-8>
50. Peterson, MD.; Rhea, MR.; Alvar, BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription; *J Strength Cond Res.* 2005. p. 950-958.<http://dx.doi.org/10.1519/R-16874.1>
51. Phillips BA, Lo SK, Mastaglia FL. Isokinetic and isometric torque values using a Kin-Com dynamometer in normal subjects aged 20 to 69 years. *Isokinetics Exer Sci.* 2000; 8:147-159.
52. Pincivero DM, Heller BM, Hou SI. The effects of ACL injury on quadriceps and hamstring torque, work and power. *J Sports Sci.* 2002; 20:689-696. [PubMed: 12200920]
53. Reid, A.; Birmingham, TB.; Stratford, PW.; Alcock, GK.; Giffin, JR. Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction; *Phys Ther.* 2007. p. 337-349.<http://dx.doi.org/10.2522/ptj.20060143>
54. Rhea, MR.; Alvar, BA.; Burkett, LN.; Ball, SD. A meta-analysis to determine the dose response for strength development; *Med Sci Sports Exerc.* 2003. p. 456-464.<http://dx.doi.org/10.1249/01.MSS.0000053727.63505.D4>
55. Risberg MA, Holm I, Steen H, Eriksson J, Ekeland A. The effect of knee bracing after anterior cruciate ligament reconstruction. A prospective, randomized study with two years' follow-up. *Am J Sports Med.* 1999; 27:76-83. [PubMed: 9934423]
56. Risberg, MA.; Lewek, MD.; Snyder-Mackler, L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type?; *Arthroscopy.* 2004. p. 125-145.<http://dx.doi.org/10.1016/j.jptsp.2004.02.003>
57. Roberts D, Friden T, Zatterstrom R, Lindstrand A, Moritz U. Proprioception in people with anterior cruciate ligament-deficient knees: comparison of symptomatic and asymptomatic patients. *J Orthop Sports Phys Ther.* 1999; 29:587-594. [PubMed: 10560067]
58. Ryzewicz, M.; Peterson, B.; Siparsky, PN.; Bartz, RL. The diagnosis of meniscus tears: the role of MRI and clinical examination; *Clin Orthop Relat Res.* 2007. p. 123-133.<http://dx.doi.org/10.1097/BLO.0b013e31802fb9f3>
59. Sáez-Sáez de Villarreal, E.; Requena, B.; Newton, RU. Does plyometric training improve strength performance? A meta-analysis. *J Sci Med Sport.* 2009 Nov 09. Epub ahead of print. <http://dx.doi.org/10.1016/j.jsams.2009.08.005>
60. Shirakura K, Kato K, Udagawa E. Characteristics of the isokinetic performance of patients with injured cruciate ligaments. *Am J Sports Med.* 1992; 20:754-760. [PubMed: 1456372]
61. Siqueira CM, Pelegrini FR, Fontana MF, Greve JM. Isokinetic dynamometry of knee flexors and extensors: comparative study among non-athletes, jumper athletes and runner athletes. *Rev Hosp Clin Fac Med Sao Paulo.* 2002; 57:19-24. [PubMed: 12170345]
62. Tagesson, S.; Oberg, B.; Good, L.; Kvist, J. A comprehensive rehabilitation program with quadriceps strengthening in closed versus open kinetic chain exercise in patients with anterior cruciate ligament deficiency: a randomized clinical trial evaluating dynamic tibial translation and muscle function; *Am J Sports Med.* 2008. p. 298-307.<http://dx.doi.org/10.1177/0363546507307867>
63. Thomee, P.; Wahrborg, P.; Borjesson, M.; Thomee, R.; Eriksson, BI.; Karlsson, J. Self-efficacy of knee function as a pre-operative predictor of outcome 1 year after anterior cruciate ligament reconstruction; *Knee Surg Sports Traumatol Arthrosc.* 2008. p. 118-127.<http://dx.doi.org/10.1007/s00167-007-0433-6>
64. Thomee, P.; Wahrborg, P.; Borjesson, M.; Thomee, R.; Eriksson, BI.; Karlsson, J. Self-efficacy, symptoms and physical activity in patients with an anterior cruciate ligament injury: a prospective study; *Scand J Med Sci Sports.* 2007. p. 238-245.<http://dx.doi.org/10.1111/j.1600-0838.2006.00557.x>
65. Trees, AH.; Howe, TE.; Dixon, J.; White, L. Exercise for treating isolated anterior cruciate ligament injuries in adults; *Cochrane Database Syst Rev.* 2005. p. CD005316<http://dx.doi.org/10.1002/14651858.CD005316.pub2>
66. Trees, AH.; Howe, TE.; Grant, M.; Gray, HG. Exercise for treating anterior cruciate ligament injuries in combination with collateral ligament and meniscal damage of the knee in adults;

Cochrane Database Syst Rev. 2007. p.
CD005961 <http://dx.doi.org/10.1002/14651858.CD005961.pub2>

67. Van Dyck, P.; Vanhoenacker, FM.; Gielen, JL.; Dossche, L.; Weyler, J.; Parizel, PM. Three-Tesla magnetic resonance imaging of the meniscus of the knee: What about equivocal errors?; *Acta Radiol.* 2010. p. 296-301. <http://dx.doi.org/10.3109/02841850903515403>
68. Williams GN, Buchanan TS, Barrance PJ, Axe MJ, Snyder-Mackler L. Quadriceps weakness, atrophy, and activation failure in predicted noncopers after anterior cruciate ligament injury. *Am J Sports Med.* 2005; 33:402–407. [PubMed: 15716256]
69. Wolfe BL, LeMura LM, Cole PJ. Quantitative analysis of single- vs. multiple-set programs in resistance training. *J Strength Cond Res.* 2004; 18:35–47. [PubMed: 14971985]
70. Wroble RR, Van Ginkel LA, Grood ES, Noyes FR, Shaffer BL. Repeatability of the KT-1000 arthrometer in a normal population. *Am J Sports Med.* 1990; 18:396–399. [PubMed: 2403189]

KEY POINTS**FINDINGS**

A 5-week progressive exercise therapy program in the early stage after ACL injury led to significantly improved knee function before the decision making for reconstructive surgery or further nonoperative management. The compliance to and tolerance for the program was high, with few adverse events.

IMPLICATION

Short-term progressive exercise therapy programs should be incorporated in the early stage after ACL injury, to optimize knee function before ACLR or as a first step in the preparation to return to previous activity without surgery.

CAUTION

The participants in this study had an ACL tear with no symptomatic concomitant injuries; therefore, results cannot be generalized to all patients with ACL injury. The results of this study are further dependent on motivated patients with high compliance to the exercise therapy program.

FIGURE 1.

Flow chart of the study. Abbreviations: ACL, anterior cruciate ligament; IKDC2000, The International Knee Documentation Committee Subjective Knee Form; KOS-ADLS, Knee Outcome Survey activities of daily living scale; MRI, magnetic resonance imaging; VAS, visual analog scale.

FIGURE 2.
Main group and interaction effects between copers and noncopers, quadriceps strength.

FIGURE 3.
Main group and interaction effects between copers and noncopers, hamstrings strength.

FIGURE 4.
Main group and interaction effects between copers and noncopers, single-leg hop tests.

FIGURE 5.

Main group and interaction effects between copers and noncopers, self-reported knee function. Abbreviations: IKDC2000, The International Knee Documentation Committee Subjective Knee Form; KOS-ADLS, Knee Outcome Survey activities of daily living scale; VAS, visual analog scale.

TABLE 1

Classification of Activity Level*

Level	Sports Activity	Occupational Activity
I	Jumping, cutting, pivoting (soccer, basketball, American football)	Demands comparable to level I sports activities
II	Lateral movements (skiing, tennis)	Heavy manual labor, working on uneven surfaces
III	Light activity (running, weight-lifting)	Light manual labor
IV	Sedentary activity (housework, activities of daily living)	Comparable to activities of daily living

* In accordance with Hefti et al.²⁷

TABLE 2**Characteristics of the Cohort**

Subject characteristics	
Gender, males/females (%)	44/56
Age (y) *	26.1 (14–47)
Body mass index females (kg/m ²) *	23 (20–27)
Body mass index males (kg/m ²) *	24 (20–36)
Classification, potential copers/noncopers (%)	52/48
KT-1000 static laxity †	5.6 ± 2.3
Injured side, left/right (%)	53/47
Activity level prior to injury, I/II (%)	70/30
Activity when injured (n subjects)	
Soccer	33
Team handball	22
Alpine skiing	22
Basketball	5
Martial arts	4
Other	14

* Data presented as mean (range).

† Data presented as mean ± SD.

TABLE 3

Changes from Pretest to Posttest for Limb Symmetry Indexes, Isokinetic Muscle Strength, and Single-Leg Hop Tests*

	Lsi Pretest	Lsi Posttest	difference Pretest-Posttest
Quadriceps PT [†]	88.6% ± 9.7%	92.6% ± 9.8%	4.0% ± 9.4%
Quadriceps torque 30° flex [†]	84.4% ± 15.7%	92.5% ± 17.8%	8.1% ± 15.4%
Quadriceps TW [†]	88.4% ± 11.7%	92.0% ± 11.6%	3.6% ± 10.7%
Hamstrings PT [†]	94.0% ± 9.7%	96.9% ± 9.8%	2.9% ± 12.8%
Hamstrings TW [†]	92.8% ± 14.6%	96.0% ± 9.8%	3.2% ± 15.3%
OLH [‡]	90.4% ± 9.4%	90.0% ± 18.6%	-0.4% ± 18.6%
TCH [‡]	90.5% ± 13.3%	90.6% ± 17.9%	0.1% ± 16.5%
TH [‡]	89.5% ± 12.6%	90.9% ± 18.3%	1.4% ± 14.8%
6MTH [‡]	90.5% ± 15.6%	92.2% ± 17.9%	1.7% ± 18.4%

Abbreviations: 6MTH, 6-meter timed hop test; LSI, limb symmetry index (side-to-side percentage differences, injured versus uninjured limb); NC, noncopers; OLH, one-leg hop test for distance; PC, potential copers; PT, peak torque; TCH, triple crossover hop test for distance; TH, triple-hop test for distance; TW, total work.

* Data are mean ± SD. There was no significant time-by-group interaction effect for any of the variables.

[†] Significant main effect for time was found for all strength outcomes ($P \leq .001-.04$), with large effect sizes for quadriceps strength outcomes (0.15–0.22). Between-group (PC/NC) effects were significant for quadriceps strength outcomes ($P < .01$) and for the TH and 6MTH ($P = .02$), with moderate to large effect sizes (0.06–0.16).

[‡] No main effect for time was found for the single-leg hop tests ($P > .05$).

TABLE 4

Muscle Strength Torque Improvement (%) From Pretest to Posttest*

	Pretest [†]	Posttest [‡]	change (%)	srM
Uninjured limb				
Quadriceps PT (Nm)	192.5 ± 51.6	200.1 ± 56.8	3.9%	0.27
Quadriceps 30° flex (Nm)	118.8 ± 30.9	121.2 ± 32.7	0.2%	0.13
Quadriceps TW (J)	887.8 ± 237.2	934.3 ± 266.6	5.2%	0.35
Hamstrings PT (Nm)	96.8 ± 27.1	103.2 ± 29.8	6.6%	0.37
Hamstrings TW (J)	545.1 ± 165.8	591.8 ± 182.3	8.6%	0.40
Injured limb				
Quadriceps PT (Nm)	169.8 ± 45.8	183.8 ± 52.5	8.2%	0.49
Quadriceps 30° flex (Nm)	100.9 ± 34.7	112.1 ± 36.2	11.1%	0.58
Quadriceps TW (J)	784.1 ± 225.8	856.4 ± 264.0	9.3%	0.53
Hamstrings PT (Nm)	90.4 ± 25.6	99.7 ± 29.3	10.2%	0.53
Hamstrings TW (J)	499.8 ± 148.9	564.7 ± 170.5	12.9%	0.60

Abbreviations: PT, peak torque; SRM, standardized response mean; TW, total work.

* Torque values and percentage changes are presented as mean ± SD.

[†] n = 100.[‡] n = 98.

TABLE 5

Hop Performance Improvement (%) From Pretest to Posttest*

	Pretest [†]	Posttest [‡]	change (%)	srM
Uninjured limb				
OLH (cm)	139.8 ± 26.6	145.1 ± 31.5	3.8%	0.27
TCH (cm)	416.5 ± 92.7	451.8 ± 86.2	8.5%	0.51
TH (cm)	460.3 ± 100.9	481.9 ± 84.6	4.7%	0.32
6MTH (s)	1.84 ± 0.29	1.79 ± 0.27	2.7%	0.29
Injured limb				
OLH (cm)	126.9 ± 25.0	136.0 ± 28.2	7.2%	0.71
TCH (cm)	387.1 ± 78.5	423.9 ± 86.9	9.5%	0.84
TH (cm)	423.5 ± 82.9	449.3 ± 87.7	6.1%	0.69
6MTH (s)	2.00 ± 0.38	1.89 ± 0.32	5.5%	0.50

Abbreviations: 6MTH, 6-meter timed hop test; OLH, one-leg hop test for distance; SRM, standardized response mean; TCH, triple crossover hop test for distance; TH, triple-hop test for distance.

* Hop lengths, time in seconds and percentage changes are reported as mean ± SD.

[†] n = 100.

[‡] n = 93.

TABLE 6

Changes from Pretest to Posttest for Self-Assessment Questionnaires*

	Pretest score	Posttest score	difference Pretest-Posttest
KOS-ADLS [†]	81.4 ± 10.7	86.4 ± 8.8	5.0 ± 9.0
IKDC2000 [‡]	69.7 ± 11.7	77.2 ± 10.2	7.5 ± 11.0
VAS (global rating) [‡]	78.3 ± 12.9	83.7 ± 12.5	5.4 ± 12.5

Abbreviations: IKDC2000, The International Knee Documentation Committee Subjective Knee Form; KOS-ADLS, Knee Outcome Survey activities of daily living scale; NC, noncopers; PC, potential copers; VAS, global rating of knee function on a visual analogue scale.

* Data presented as mean ± SD.

[†] For the KOS-ADLS, a significant interaction effect ($P < .01$) was found, revealing that noncopers improved more than potential copers.

[‡] For the IKDC2000 and VAS there was no interaction effect. Significant main effects ($P < .001$) were found for time and between groups (PC/NC). The effects sizes for the main effect for time and between groups (PC/NC) were large (0.16–0.35).

APPENDIX A

Exercise	Description	Sets by Number of Repetitions	Figures
Stationary cycle	Continuous warm-up at your preferred resistance	10 min
Treadmill	Continuous warm-up at your preferred speed	10 min
Elliptical trainer	Continuous warm-up at your preferred resistance	10 min
Single-limb squat	Maintain knee-over-toe position	3 × 8
Step-up	Maintain knee-over-toe position	2 × 10
Squat on BOSU	Maintain knee alignment and core stability. Squat quickly down and up	2 × 20
Single-limb leg press	Start in 90° knee flexion	3 × 6 (+2)
Single-limb knee extension	Start in 90° knee flexion	4 × 6 (+2)

Exercise	Description	Sets by Number of Repetitions	Figures
Squats	Squat slowly down to 90° knee flexion, stop, lift quickly up again	3 × 8 (+2)
Leg curl	Lift quickly up, stop, and then slowly down to full extension	3 × 8 (+2)
Hamstring on Fitball	One foot on top of the ball, lift back and pelvis up, pull ball towards you	3 × 6
Single-leg hop	Hop up on step, stop, continue down and directly 1 hop forward with a soft controlled landing	1 × 15
Sideways single-leg hop	Start on 1 side of a board. Hop quickly sideways and stop after 3 hops. Continue and stop 5 times	3 × 15
Skating	Start on 1 leg, hop sideways, perform a soft, deep and steady landing on 1 leg, hop back to the other side	2 × 20

APPENDIX B

PERTURBATION TRAINING PROTOCOL				
Sessions 1–4. Early Phase				
Progression by adding perturbations in all directions and minimizing of verbal cues				
Activity				
Session	Rocker Board	Roller Board/Platform	Roller Board	
1	<ul style="list-style-type: none">Bilateral stance2 sets, anterior/posterior2 sets, medial/lateral	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior2 sets with uninvolved limb on roller board, anterior/posterior	<ul style="list-style-type: none">Bilateral stance2 sets anterior/posterior	
2	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior direction2 sets medial/lateral direction	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior plus medial/lateral2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior	
3	<ul style="list-style-type: none">Unilateral stance2 sets medial/lateral direction2 sets diagonal direction	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotation	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior plus medial/lateral	
4	<ul style="list-style-type: none">Unilateral stance2 sets medial/lateral direction2 sets diagonal direction	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotation	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior plus medial/lateral plus rotation	
Sessions 5–7: Middle Phase				
Progression by adding light sport-specific activity during perturbations				
Activity				
Session	Rocker Board	Roller Board/Platform	Roller Board	
5	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior direction2 sets medial/lateral direction2 sets diagonal directionBall against wall	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotationBall against wall	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior plus medial/lateral plus rotationBall against wall	
6	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior direction2 sets medial/lateral direction2 sets diagonal direction	<ul style="list-style-type: none">2 sets with injured limb on roller board, anterior/posterior plus medial/lateral2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral	<ul style="list-style-type: none">Unilateral stance2 sets anterior/posterior plus medial/lateral plus rotation	

PERTURBATION TRAINING PROTOCOL

Sessions 1–4. Early Phase

Progression by adding perturbations in all directions and minimizing of verbal cues

Activity			
Session	Rocker Board	Roller Board/Platform	Roller Board
7	<ul style="list-style-type: none"> Ball against wall/floor 	<ul style="list-style-type: none"> Ball against wall/floor 	<ul style="list-style-type: none"> Ball against wall/floor
	<ul style="list-style-type: none"> Unilateral stance 	<ul style="list-style-type: none"> 2 sets with injured limb on roller board, anterior/posterior plus medial/lateral 	<ul style="list-style-type: none"> Unilateral stance
	<ul style="list-style-type: none"> 2 sets medial/lateral direction 	<ul style="list-style-type: none"> 2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral 	<ul style="list-style-type: none"> 2 sets anterior/posterior plus medial/lateral plus rotation
	<ul style="list-style-type: none"> 2 sets diagonal direction Ball thrown by other 	<ul style="list-style-type: none"> Ball thrown by other 	<ul style="list-style-type: none"> Ball thrown by other

Sessions 8–10: Late Phase

Progression by adding sport-specific stances combined with sport-specific activity

Activity			
Session	Rocker Board	Roller Board/Platform	Roller Board
8	<ul style="list-style-type: none"> Unilateral stance 	<ul style="list-style-type: none"> 2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> Unilateral stance
	<ul style="list-style-type: none"> 2 sets anterior/posterior direction 	<ul style="list-style-type: none"> 2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> 2 sets anterior/posterior plus medial/lateral plus rotation
	<ul style="list-style-type: none"> 2 sets medial/lateral direction 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other
	<ul style="list-style-type: none"> 2 sets diagonal direction Ball against wall/floor, thrown by other Other individually adjusted relevant sport-specific activities 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities
9	<ul style="list-style-type: none"> Unilateral stance 	<ul style="list-style-type: none"> 2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> Unilateral stance
	<ul style="list-style-type: none"> 2 sets medial/lateral direction 	<ul style="list-style-type: none"> 2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> 2 sets anterior/posterior plus medial/lateral plus rotation
	<ul style="list-style-type: none"> 2 sets diagonal direction 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other
	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other Other individually adjusted relevant sport-specific activities 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities
10	<ul style="list-style-type: none"> Unilateral stance 	<ul style="list-style-type: none"> 2 sets with injured limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> Unilateral stance
	<ul style="list-style-type: none"> 2 sets medial/lateral direction 	<ul style="list-style-type: none"> 2 sets with uninvolved limb on roller board, anterior/posterior plus medial/lateral plus rotation 	<ul style="list-style-type: none"> 2 sets anterior/posterior plus medial/lateral plus rotation
	<ul style="list-style-type: none"> 2 sets diagonal direction 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other 	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other
	<ul style="list-style-type: none"> Ball against wall/floor, thrown by other Other individually adjusted relevant sport-specific activities² 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities 	<ul style="list-style-type: none"> Other individually adjusted relevant sport-specific activities