CEU

Functional and Patient-Reported Outcomes Improve Over the Course of Rehabilitation: A Secondary Analysis of the ACL-SPORTS Trial

Amelia J.H. Arundale, PT, PhD, DPT,*† Jacob J. Capin, PT, DPT, MS,†
Ryan Zarzycki, PT, PhD, DPT,† Angela Smith, PT, DPT, ATC,‡ and Lynn Snyder-Mackler, PT, ATC, ScD†‡

Background: The Anterior Cruciate Ligament–Specialized Post-Operative Return to Sports (ACL-SPORTS) randomized controlled trial was designed to address deficits in functional and patient-reported outcomes. The trial examined the effects of a secondary ACL prevention program that included progressive strengthening, agility training, plyometrics (SAP), and other components of current primary prevention protocols, with perturbation training (SAP + PERT group) and without PERT (SAP group). A secondary purpose of this study was to examine whether study outcomes differed between men and women.

Hypotheses: (1) Athletes in both the SAP and SAP + PERT groups will have improved knee function and patient-reported outcome measures from pre- to posttraining, (2) the SAP + PERT group would have higher outcome scores than the SAP group, and (3) outcomes will differ by sex.

Study Design: Randomized controlled trial (NCT01773317).

Level of Evidence: Level 2.

Methods: A total of 79 athletes (39 women) were randomized into the SAP and SAP + PERT groups. All athletes had undergone primary ACL reconstruction and achieved 80% quadriceps strength limb symmetry (QI), full range of motion, had minimal effusion, and had no pain. Additionally, all had begun running again. Prior to and after the training program, athletes' QI, hopping, and patient-reported outcomes were assessed. Repeated-measures analyses of variance were used to determine whether there were differences between groups. Subsequently, the SAP and SAP + PERT groups were collapsed to analyze differences between sexes.

Results: There were significant increases for all variables, with the exception of QI. There were no differences between the SAP and SAP + PERT groups. Both men and women made significant improvements in all knee function and patient-reported outcome measures except QI. Men made significant improvements in QI, whereas women did not.

Conclusion: The common elements of the training program that all athletes received (10 sessions of progressive strengthening, agility training, plyometrics, and secondary prevention) may be a beneficial addition to the return-to-sport phase of ACL reconstruction rehabilitation. The results suggest that women may require further quadriceps strengthening to maintain and improve QI, an important focus given the relationship between QI and risk for reinjury.

Clinical Relevance: During the return-to-sport phase of ACL reconstruction rehabilitation, clinicians tend to shift their focus away from strengthening toward more advanced sports-related tasks. These results indicate that women in particular need continued focus on quadriceps strengthening.

Keywords: anterior cruciate ligament; return to sport; rehabilitation; secondary prevention

From †Biomechanics and Movement Science Program, University of Delaware, Newark, Delaware, and ‡Department of Physical Therapy, University of Delaware, Newark, Delaware

*Address correspondence to Amelia J.H. Arundale, PT, PhD, DPT, Biomechanics and Movement Science Program, University of Delaware, 540 South College Avenue, Newark, DE 19713 (email: arundale@udel.edu).

The following authors declared potential conflicts of interest: Amelia J.H. Arundale and Jacob J. Capin are supported by a grant from the Foundation for Physical Therapy.
DOI: 10.1177/1941738118779023

There is a need to improve knee function and patient-reported outcomes (PROs) after anterior cruciate ligament (ACL) reconstruction. In the first 2 years after ACL reconstruction, many athletes demonstrate quadriceps or hamstring strength deficits.[12,18,44] Quadriceps strength is an important factor after ACL reconstruction in cutting, pivoting, and jumping sport athletes as there is a 3% decrease in knee reinjury rate for every 1% increase in quadriceps strength limb symmetry (QI, defined as the percentage difference between the uninvolved and involved limbs).[18] QI may influence jump-landing biomechanics/loading,[38] hopping performance,[37] and self-reported knee function.[6,45] Opportunities for improvement in PROs have also been noted in several large-scale studies.[16,39]

There is also evidence that differences in function and PROs after ACL reconstruction exist between sexes. In the first year after ACL reconstruction, women have greater deficits in knee extensor strength,[25] tend to have lower International Knee Documentation Committee (IKDC) 2000 subjective scores,[27] and are less likely to have returned to sport compared with men.[3] Women have a greater risk of second ACL injury than men,[34,35] and overall have lower odds of returning to their preinjury level of sport.[2] Six years after ACL reconstruction, women are less active than their male counterparts.[39] These results suggest that rehabilitation outcomes after ACL reconstruction should be examined separately in men and women to ensure interventions are effective for both sexes.

The vast majority of the current literature on the return-to-sport phase of rehabilitation after ACL reconstruction is of level 5 evidence or expert opinion.[1,5,31] Clinicians need higher level evidence on specific interventions during this phase. The Anterior Cruciate Ligament–Specialized Post-Operative Return to Sports (ACL-SPORTS) single-blinded randomized controlled trial examined a sport-specific secondary ACL injury prevention program and aimed to provide clinical and biomechanical outcomes. The training program at the core of the ACL-SPORTS trial was based on the primary ACL injury prevention literature, which has shown that successful programs include multiple exercise modalities, both strengthening and plyometric components,[41] performed twice per week and have a weekly duration of longer than 30 minutes.[40] Using these guidelines, the training program was also modeled after primary ACL injury prevention protocols successful in preventing ACL injuries and modifying landing mechanics in young women.[20,21] In addition, evidence from the nonoperative treatment of ACL injuries was also incorporated with the use of perturbation training (PERT).[14,15] PERT is a neuromuscular re-education technique beneficial in helping ACL-deficient athletes normalize gait patterns[8] and return to sport.[14]

The methods of the ACL-SPORTS randomized controlled trial have been published previously.[43] One group received the training program, involving secondary ACL injury prevention and strengthening, agility, and plyometrics exercises (SAP group), while the other group received the same training program with the addition of PERT (SAP + PERT group). The primary outcome measures of the ACL-SPORTS randomized controlled trial were gait biomechanics,[7] with secondary outcome measures of knee function and PROs. Results regarding the primary outcomes found no difference between the SAP and SAP + PERT groups in gait biomechanics at 1 and 2 years after ACL reconstruction.[7] The purposes of this study were to (1) examine the acute outcomes of the ACL-SPORTS randomized controlled trial with regard to knee function (quadriceps strength limb symmetry and single-leg hop test limb symmetry) and PRO scores and (2) determine whether outcomes differed between men and women. We hypothesized that both groups would improve significantly from pre- to posttraining and that the SAP + PERT group would have greater outcome scores than the SAP group. Given the tendency for women to have greater quadriceps strength deficits[25] and lower scores on PROs,[27] we also hypothesized the outcomes would differ by sex.

METHODS

The methods of the ACL-SPORTS single-blinded randomized controlled trial have been previously published in detail by White et al[43] and are briefly described here. The study was approved by the University of Delaware Institutional Review Board and registered at clinicaltrials.gov (NCT01773317). Prior to participation, all athletes gave written informed consent (or assent if younger than 18 years with parent/guardian written informed consent). A total of 80 athletes (40 women) participated in this study. Athletes were between the ages of 13 and 54 years (median, 18.7 years), participated in level I (n = 73) or II (n = 7) sports[11] (cutting, pivoting, and jumping sports) for more than 50 hours per year prior to the ACL injury, and intended to return to their preinjury levels of activity. Furthermore, athletes had no prior history of ACL injury, major lower extremity injury, or surgery. To ensure a generalizable sample, athletes were recruited from the local community via physician and physical therapist referral, newspaper advertisements, and word of mouth. ACL reconstructions were performed by 31 different experienced orthopaedic surgeons, and athletes participated in postoperative rehabilitation in a number of different community physical therapy clinics. Rehabilitation prior to enrollment was not standardized, but strict enrollment criteria were applied to ensure a homogenous entry level. Athletes were enrolled in the study at the point when they are typically discharged from physical therapy in the United States—on achieving activities of daily living goals and beginning to run. Enrollment criteria consisted of 3 to 9 months after unilateral ACL reconstruction with no grade III concomitant ligamentous injuries or chondral injuries larger than 1 cm^2 (assessed via arthroscopy or magnetic resonance imaging), minimum 80% QI, minimal effusion, no pain, full range of motion, successful completion of a running progression, and not having yet returned to level I or II sports (Figure 1).[1,43] These criteria were selected to ensure that it was safe for all athletes to perform the exercises involved in the training program. Of the 261 athletes screened for this study, only 14 were excluded because they were unable to meet these criteria within 9 months of their ACL reconstruction. The

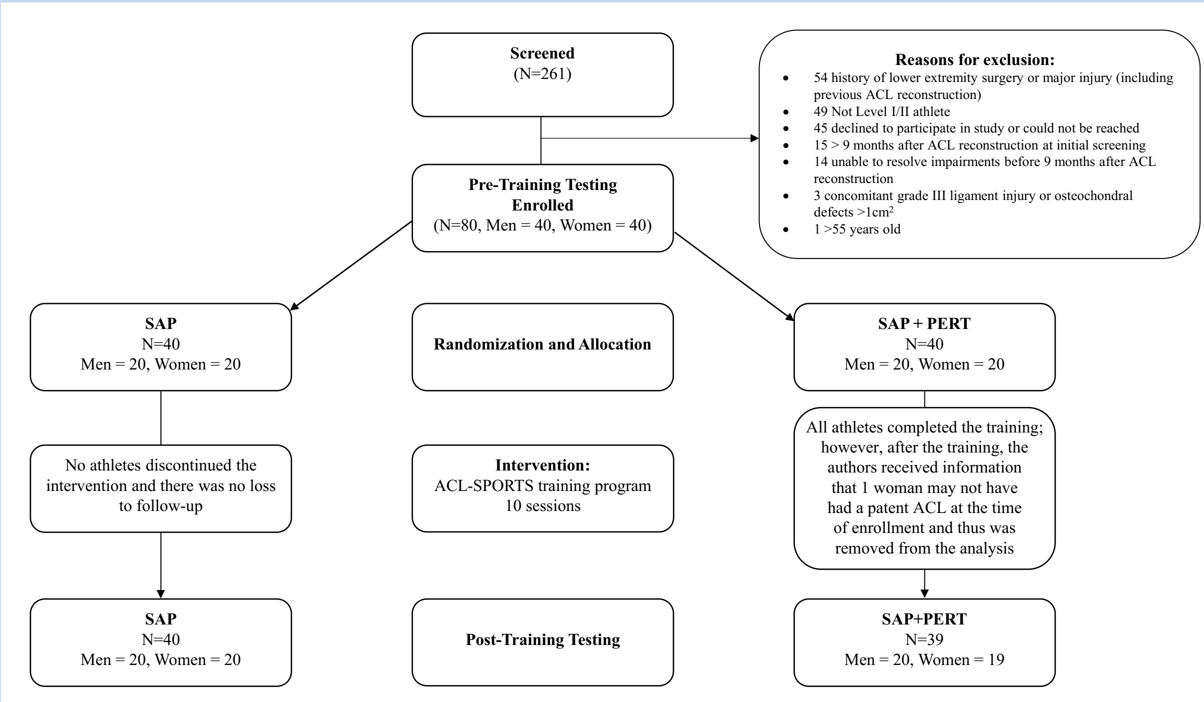


Figure 1. CONSORT (Consolidated Standards of Reporting Trials) flow diagram of athletes included in the study. SAP, secondary prevention, agilities, and plyometrics; SAP + PERT = secondary prevention, agilities, and plyometrics with the addition of perturbation training.

primary reasons for athlete exclusion were a history of a lower extremity surgery or major injury (including previous ACL reconstruction) (21%), not being a level I or II athlete prior to ACL injury (19%), or declining to participate in the study/unable to contact (17%) (Figure 1).

Athletes were enrolled from November 2011 to January 2017. On enrollment, athletes were randomized into either the SAP group (N = 40; 20 women, 20 men) or SAP + PERT group (N = 40; 20 women, 20 men) (Table 1). Randomization was stratified by sex to ensure an equal number of men and women in each group. Randomization and concealed allocation were performed using a random number generator by a research coordinator who had no contact with the athletes beyond scheduling. All researchers performing data collections were blinded to the study group. After completion of training, the researchers received information that 1 woman (SAP + PERT group) may not have had a patent ACL at the time of enrollment. As a result, the authors excluded this woman's data from analysis (Figure 1).

For clarity, the term *training program* is used to refer to the exercises that all athletes in the study performed: Nordic hamstring, standing squat, drop jump, triple single-leg hop, tuck jump exercises, and progressive agility drills (Table 1). Exercises were tailored to an athlete's sport through integrating movements, such as throwing or kicking, and equipment, such as balls or sticks.[43] Training was performed twice a week for 5 weeks, for a total of 10 sessions. Sessions progressively increased in difficulty following soreness and effusion guidelines[43] to monitor the athlete's response to treatment and ensure a safe progression through the protocol. Sessions were supervised by a physical therapist, and education was given on correct landing techniques and lower extremity alignment during exercises, particularly avoiding knee valgus collapse. Procedural reliability was performed to ensure that all athletes received all exercises in the protocol per their group assignment. Training sessions from each athlete were randomly selected, and the number of protocol exercises performed during that training session was assessed for reliability. A minimum of 85% was considered acceptable. Three training sessions from the first 10 athletes enrolled into the ACL-SPORTS randomized controlled trial and then 1 session from each of the remaining 79 athletes were included, for a total of 99 procedural reliability checks.

On enrollment (pretraining) and again on completion of the training program (posttraining), athletes participated in quadriceps strength testing, single-leg hop testing, and completed PROs. Quadriceps strength testing was assessed using an electromechanical dynamometer (Kin-com; DJO Global or System 3; Biodex) to measure maximal volitional isometric contractions.[19,28,43] Athletes were seated on the machine with their hips and knees positioned at 90° and the machine's lever arm axis of rotation aligned with the axis of rotation of the athlete's knee. Straps held the athlete's pelvis, thigh, and shank

Table 1. Exercises performed by each group[a]

Group(s) Performing		Sessions 1-3	Sessions 4-6	Sessions 7-10
Training program (SAP and SAP + PERT)[43]	Nordic hamstrings	2 × 5 (~30°-45°)	3 × 5 (~30°-45°)	3 × 5 (~60°)
	Standing squat (bilateral to 90°)	Session 1: 3 × 10 focusing on proper technique Session 2 and 3: Add theraband around knees (green or blue, per athlete ability)	3 × 10 progression to black theraband around knees	Not performed
	Drop jump	3 × 10 Taking off and landing bilaterally Step height progresses as appropriate for the athlete from 4 to 6 to 8 inches tall	3 × 10 Taking off bilaterally, landing on the involved limb Step height progresses as appropriate for the athlete from 4 to 6 to 8 inches tall	3 × 10 Taking off and landing on the involved limb Step height progresses as appropriate for the athlete from 4 to 6 to 8 inches tall
	Triple single-leg hop	Forward/backward (3 hops forward, 3 hops backward) × 10 Side to side (3 consecutive hops laterally) × 10 Overground	Forward/backward (3 hops forward, 3 hops backward) × 15 Side to side (3 consecutive hops laterally) × 15 Over a low object approximately 2 inches high (such as cup or low cone)	Forward/backward (3 hops forward, 3 hops backward) × 15 Side to side (3 consecutive hops laterally) × 15 Over an object, the height appropriate for the athlete such as 4-inch cones or 6-inch hurdles
	Tuck jumps	Not performed	Not performed	2 sets for 10-20 seconds Progressing to 3 sets for 20-30 seconds
	Agility drills	3-4 drills performed each session progressing in the first session from 50% of maximal effort to 100% effort and speed over the 10 training sessions. Drills could include, but were not limited to, forward/backward running, side shuffles, cariocas, figure eights, circles, and 90° turns. In addition to speed and effort, progression also included eliminating linear drills in favor of multidirectional drills and making the drills sport-specific.		
SAP only	Single-leg balance with hip flexor resistance	3 × 30 seconds	3 × 45 seconds	3 × 1 minute
SAP + PERT only	Perturbation training[14,43] Progressed according to athlete response, not by treatment session number –As athlete progresses, the speed of perturbations is increased –Perturbations begin in anterior/posterior and medial/lateral and are advanced to including rotations			
	Roller board	Double-limb support Single-limb support in parallel bars Single-limb support out of parallel bars		
	Roller board and stationary platform (one foot on roller board, one foot on platform)	Perturbations with feet parallel to each other in a straddle stance Add perturbations with feet in a diagonal stance Add functional task during perturbations		
	Tilt board	Double-limb support Single-limb support Add functional task during perturbation		

PERT, perturbation training; SAP, secondary prevention, agilities, and plyometrics.

[a]More detailed explanations of all exercises performed by each group can be found in White et al.[43]

in place. Maximal volitional contractions were performed on the uninvolved limb then the involved limb, with 2 submaximal contractions performed as practice prior to the recording of a maximal contraction. QI was calculated by dividing the maximum torque of the involved limb by the maximum torque of the uninvolved limb and multiplying by 100%. The single, crossover, and triple hops for distance and the 6-m timed hop tests[33] were also performed bilaterally. Athletes performed the tests on the uninvolved limb followed by the involved limb, performing 2 practice trials of each hop followed by 2 trials that were recorded. The tests were always performed in the same order: single, crossover, and triple hops for distance and then the 6-m timed hop. Limb symmetry indices were calculated for the 3 distance hops by dividing the mean of the 2 recorded trials on the involved limb by the mean of the 2 recorded trials on the uninvolved limb and multiplied by 100%. Limb symmetry indices for the 6-m timed hop were calculated by dividing the mean of the 2 recorded trials on the uninvolved limb by the mean of the 2 recorded trials on the involved limb and multiplied by 100%.

PROs included the Knee Outcome Survey Activities of Daily Living subscale (KOS-ADLs), the global rating of perceived knee function (GR), IKDC, and the Knee injury and Osteoarthritis Outcome Score (KOOS) Sport/Recreation and quality of life (QoL) subscales. The KOS-ADL is a 14-item questionnaire asking the athlete about his or her knee symptoms and function during tasks related to daily living.[24] The questionnaire is valid in an active population[30] and has been used frequently as a tool to help determine when athletes are ready to progress to more advanced tasks as well as in return-to-sport criteria.[1,18] The GR is a single question asking the athlete to rate his or her current knee function on a scale from 0 to 100 (0 being unable to perform any activity, 100 being preinjury level of activity including sports). The IKDC is a 10-item questionnaire that enquires about an athlete's symptoms, function, and activity, particularly with regard to pain, swelling, stiffness, and giving-way.[22,23] Scored on a scale from 0% to 100%, the IKDC has a minimal clinically important difference (MCID) of 11.5%.[23] The KOOS-Sport/Recreation and KOOS-QoL are 2 of the 5 subscales that make up the KOOS and are often looked at separately as they are useful in differentiating athletes at higher levels of function after ACL reconstruction.[43] The KOOS-Sport/Recreation subscale asks athletes about difficulty they have with tasks such as squatting, running, jumping, and kneeling. The KOOS-QoL enquires about the athlete's awareness of his or her knee and lifestyle modifications made as a result of the knee. Both subscales are scored as a percentage from 0% to 100% and have MCIDs of 8%.[36]

Statistical Analysis

Statistical analyses were performed using SPSS version 24 (IBM Corp). Alpha was set a priori at $P \leq 0.05$. The variables of interest were QI, limb symmetry on all 4 hop tests, KOS-ADL, GR, IKDC, KOOS-Sport/Recreation, and KOOS-QoL scores. Paired *t* tests were used to determine whether there was a change in each variable from pre- to posttraining for the entire sample. The number of athletes who achieved ≥90%[18,42,43] on each measure at pre- and posttraining was calculated, and chi-square tests were used to determine whether there were differences between pre- and posttraining.

SAP Versus SAP + PERT

Independent *t* test and chi-square tests were used to examine differences between the SAP and SAP + PERT groups in demographic and surgical variables. Repeated-measures analyses of variance (ANOVAs) (time × group) with planned least squares comparisons were used to examine changes in each variable over time in the SAP and SAP + PERT groups. Planned least squares comparisons were the change over time in each group and the differences between groups pre- and posttraining.

Men Versus Women

Previous studies examining only the men have found no difference between the SAP and SAP + PERT groups in gait biomechanics, knee function, or PROs.[4,7] Analysis in this study also found no differences between groups for any outcome measure; thus, the SAP and SAP + PERT groups were collapsed for secondary analyses. Independent *t* tests and chi-square tests were used to examine differences between men and women in demographic and surgical variables. Repeated-measures ANOVAs (time × sex) with planned least squares comparisons were used to examine the changes in each variable over time in men and women. Planned least squares comparisons were the change over time for each sex and the differences between the sexes at pre- and posttraining.

The power calculations that determined the overall sample size of the randomized controlled trial were based on sagittal plane gait biomechanics and are published.[43] To ensure adequate power for the analyses in this study, pretraining means and the IKDC MCID (11.5%)[23] were used to determine the effect size that would detect a difference in the size of the MCID, a method used in previous articles.[4] Using G*Power software v 3.1.0 (Universität Düsseldorf) calculations indicated that using a 2 × 2 (time × group) ANOVA with power = 0.95 and $\alpha = 0.05$, an effect size of $f(V) = 6.44$ could be detected with a sample of 5 in each group.

RESULTS

A total of 79 athletes (39 women) were enrolled in this study and completed all 10 sessions of the training program with no adverse events (Table 2), and 93 of the 100 procedural reliability checks showed a greater than 85% adherence to the protocol.

Entire Sample

There was a significant improvement from pre- to posttraining for all measures with the exception of QI (Table 3, Figure 2). There were improvements greater than the MCID of 8%[36] for both the KOOS-Sport/Recreation and KOOS-QoL subscales. There were also significantly more athletes who achieved ≥90%

Table 2. Demographics, injury mechanism, graft type, and time from surgery to enrollment between men and women

	SAP (N = 40)	SAP + PERT (N = 39)	*P* Value	Women (N = 39)	Men (N = 40)	*P* Value
Age, y	21.2 ± 7.7	21.1 ± 7.6	0.94	18.9 ± 7.3	23.3 ± 7.3	<0.01
Weight, kg	77.4 ± 14.7	77.3 ± 15.1	0.96	68.4 ± 12.5	86.1 ± 11.4	<0.01
Height, m	1.7 ± 0.1	1.7 ± 0.1	0.85	1.6 ± 0.1	1.8 ± 0.1	<0.01
Weeks from surgery to enrollment/ pretraining	23.3 ± 7.8	23.7 ± 8.3	0.85	25.4 ± 8.3	21.5 ± 7.3	0.03
Mechanism of injury	Noncontact: 25 Contact: 15	Noncontact: 25 Contact: 14	>0.99	Noncontact: 28 Contact: 11	Noncontact: 22 Contact: 18	0.16
Graft type	Autograft: 30 Allograft: 10	Autograft: 31 Allograft: 8	0.79	Autograft: 34 Allograft: 5	Autograft: 27 Allograft: 13	0.06
Injured limb	Right: 22 Left: 18	Right: 23 Left: 16	0.82	Right: 22 Left: 17	Right: 23 Left: 17	>0.99
Sports				Soccer: 14 Basketball: 7 Field hockey: 5 Cheerleading: 3 Softball: 2 Volleyball: 2 Flag football: 1 Ice hockey: 1 Lacrosse: 1 Track (hurdles): 1 Tennis: 1 Ultimate frisbee: 1	American football: 8 Soccer: 8 Basketball: 7 Lacrosse: 5 Flag football: 3 Ultimate frisbee: 3 Ice hockey: 2 Baseball: 1 Beach volleyball: 1 Cheerleading: 1 Rugby: 1	

PERT, perturbation training; SAP, secondary prevention, agilities, and plyometrics.

at posttraining compared with pretraining for all variables except QI (*P* = 0.31), the 6-m timed hop (*P* = 0.31), and KOOS-QoL (*P* > 0.99) (Table 3, Figure 2).

SAP Versus SAP + PERT

There were no significant differences between the SAP and SAP + PERT groups for any demographic or surgical variables (Table 2). There were no differences between the SAP and SAP + PERT groups at pre- or posttraining for any variable, and both the SAP and SAP + PERT groups had significant increases in each variable with 1 exception: Neither the SAP (*P* = 0.58) nor the SAP + PERT group (*P* = 0.11) had an increase in QI over the course of the training program (Table 4).

Men Versus Women

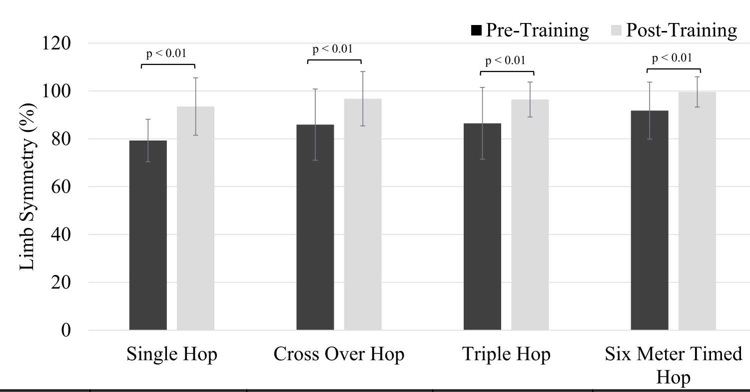
There were differences between men and women in both age (*P* < 0.01) and time from surgery to enrollment (*P* = 0.03) (Table 2). Women were younger and took longer from surgery to enrollment compared with men. American football, soccer, and basketball were the most frequently played sports by men, while soccer, basketball, and field hockey were the most frequently played sports by women.

Both men and women had significant improvements over the course of the training program in all PROs and hop tests (Table 5). Men had a significant increase in QI over the course of the training program (*P* = 0.02), while women did not (*P* = 0.86) (Table 5). Both men and women had significant improvements on all PROs, including increases in KOOS-Sport/

Table 3. Change in all variables from pre- to posttraining (N = 79)

Measure	Mean ± SD		*P* Value	No. of Athletes ≥90%		*P* Value
	Pretraining	Posttraining		Pretraining	Posttraining	
QI	91.08 ± 8.74	93.39 ± 12.00	0.13	36	54	0.33
KOS-ADL	92.89 ± 6.25	95.08 ± 5.42	<0.01	63	69	<0.01
GR	79.19 ± 9.06	86.86 ± 8.31	<0.01	16	43	0.02
IKDC	77.88 ± 9.39	85.70 ± 9.61	<0.01	6	29	<0.01
KOOS-Sport/ Recreation	79.30 ± 14.52	88.80 ± 12.12[a]	<0.01	28	53	<0.01
KOOS-QoL	58.47 ± 16.05	67.25 ± 18.78[a]	<0.01	2	9	> 0.99

GR, global rating of perceived knee function; IKDC, International Knee Documentation Committee; KOS-ADL, Knee Outcome Survey Activities of Daily Living subscale; KOOS, Knee injury and Osteoarthritis Outcome Score; QI, quadriceps strength limb symmetry; QoL, quality of life.
[a]Improvement greater than minimal clinically important difference of 8%.[36]



Number of Athletes ≥ 90%		Single Hop	Cross Over Hop	Triple Hop	Six Meter Timed Hop
	Pre-Training	16	30	30	36
	Post-Training	46	50	55	60
	p-value	0.01	0.01	0.01	0.31

Figure 2. Change in single-leg hop limb symmetry from pre- to posttraining.

Recreation that exceeded the MCID of 8% (Table 5).[36] Although both men and women had increases in KOOS-QoL scores, only men had improvements in scores greater than the MCID.

DISCUSSION

This study found that 10 sessions of a secondary ACL injury prevention training program led to improvements in hop test limb symmetry and PRO scores, regardless of group or sex. The cohort of predominantly level I[11] athletes all performed a secondary ACL injury prevention training program that seemed to positively affect knee function during the return-to-sport phase of ACL reconstruction rehabilitation. When analyzing the cohort as a whole, QI was the only variable that did not significantly improve. However, when examining the cohort by sex, men had a significant increase in QI with the training program; women did not. The results of this study have implications on return-to-sport rehabilitation planning and decision making.

Entire Sample

Regardless of group, athletes had improvements in hop test limb symmetry and PRO scores. Outcome scores 6 to 9 months after

Table 4. Results of repeated-measures ANOVAs comparing the outcomes of the SAP and SAP + PERT groups

Measure	Interaction *P* Value (p^2)	Main Effect of Time *P* Value (η_p^2)[a]	Main Effect of Group *P* Value (η_p^2)[a]	Group	Pretraining, Mean ± SD	Posttraining, Mean ± SD	Change Over Time *P* Value	Difference at Pretraining *P* Value	Difference at Posttraining *P* Value
QI, %	0.46 (0.01)	0.13 (0.03)	0.97 (<0.01)	SAP	91.7 ± 9.0	92.9 ± 13.6	0.58	0.54	0.70
				SAP + PERT	90.5 ± 8.6	93.9 ± 10.4	0.11		
Single hop for distance, %	0.36 (0.01)	<0.01 (0.54)	0.87 (<0.01)	SAP	79.7 ± 15.8	92.4 ± 12.1	<0.01	0.79	0.48
				SAP + PERT	78.7 ± 15.2	94.4 ± 10.9	<0.01		
Crossover distance, %	0.44 (0.01)	<0.01 (0.37)	0.21 (0.03)	SAP	88.7 ± 12.9	97.7 ± 7.0	<0.01	0.25	0.35
				SAP + PERT	84.4 ± 16.8	95.9 ± 7.7	<0.01		
Triple hop for distance, %	0.54 (0.01)	<0.01 (0.48)	0.62 (<0.01)	SAP	87.6 ± 10.6	96.5 ± 6.4	<0.01	0.56	0.87
				SAP + PERT	85.8 ± 13.8	96.2 ± 6.5	<0.01		
Six-meter timed hop, %	0.94 (<0.01)	<0.01 (0.41)	0.92 (<0.01)	SAP	91.7 ± 9.1	99.5 ± 6.9	<0.01	0.97	0.89
				SAP + PERT	91.8 ± 9.5	99.7 ± 7.5	<0.01		
KOS-ADL	0.59 (<0.01)	<0.01 (0.19)	0.90 (<0.01)	SAP	92.7 ± 6.5	95.1 ± 5.8	<0.01	0.76	0.92
				SAP + PERT	93.1 ± 6.1	95.0 ± 5.1	<0.01		
GR	0.47 (0.01)	<0.01 (0.39)	0.29 (0.01)	SAP	78.0 ± 10.1	86.4 ± 7.5	<0.01	0.22	0.62
				SAP + PERT	80.5 ± 7.8	87.3 ± 9.1	<0.01		
IKDC	0.33 (0.01)	<0.01 (0.44)	0.33 (0.01)	SAP	79.3 ± 8.2	86.1 ± 9.5	<0.01	0.18	0.70
				SAP + PERT	76.5 ± 10.4	85.3 ± 9.8	<0.01		
KOOS-Sport/ Recreation	0.13 (0.030	<0.01 (0.37)	0.99 (<0.01)	SAP	78.3 ± 15.0	89.9 ± 11.4	<0.01	0.52	0.43
				SAP + PERT	80.4 ± 14.2	88.0 ± 12.9	<0.01		
KOOS-QoL	0.63 (<0.01)	<0.01 (0.20)	0.83 (<0.01)	SAP	58.6 ± 16.5	66.4 ± 15.7	<0.01	0.94	0.69
				SAP + PERT	58.3 ± 15.7	68.1 ± 21.7	<0.01		

ANOVA, analysis of variance; GR, global rating of perceived knee function; IKDC, International Knee Documentation Committee; KOS-ADL, Knee Outcome Survey Activities of Daily Living subscale; KOOS, Knee injury and Osteoarthritis Outcome Score; PERT, perturbation training; QI, quadriceps strength limb symmetry; QoL, quality of life; SAP, secondary prevention, agilities, and plyometrics.

[a]η_p^2 indicates partial eta square (small $\eta_p^2 = 0.01$, medium $\eta_p^2 = 0.06$, large $\eta_p^2 = 0.14$).[9]

Table 5. Results of repeated-measures ANOVA comparing the outcomes of men and women

Measure	Interaction *P* Value (η_p^2)[a]	Main Effect of Time *P* Value (η_p^2)[a]	Main Effect of Group *P* Value (η_p^2)[a]	Group	Pretraining, Mean ± SD	Posttraining, Mean ± SD	Change Over Time *P* Value	Difference at Pretraining *P* Value	Difference at Posttraining *P* Value
QI, %	0.08 (0.04)	0.13 (0.03)	0.18 (0.02)	Women	91.2 ± 9.4	90.8 ± 11.5	0.86	0.92	0.06
				Men	91.0 ± 8.2	95.9 ± 12.3	0.02		
Single hop for distance, %	0.74 (<0.01)	<0.01 (0.54)	0.86 (<0.01)	Women	79.2 ± 16.0	92.9 ± 10.0	<0.01	0.99	0.71
				Men	79.2 ± 15.0	94.0 ± 12.8	<0.01		
Crossover hop for distance, %	0.74 (< 0.01)	<0.01 (0.37)	0.83 (<0.01)	Women	87.1 ± 16.1	96.8 ± 6.7	<0.01	0.77	0.97
				Men	86.0 ± 14.0	96.8 ± 8.1	<0.01		
Triple hop for distance, %	0.49 (0.01)	<0.01 (0.48)	0.88 (<0.01)	Women	87.0 ± 12.5	95.8 ± 5.5	<0.01	0.86	0.45
				Men	86.4 ± 12.1	97.0 ± 7.2	<0.01		
Six-meter timed hop, %	0.73 (<0.01)	<0.01 (0.41)	0.62 (<0.01)	Women	92.3 ± 7.7	99.8 ± 7.8	<0.01	0.59	0.82
				Men	91.1 ± 10.6	99.4 ± 6.5	<0.01		
KOS-ADL	0.45 (0.01)	<0.01 (0.19)	0.74 (<0.01)	Women	93.3 ± 5.8	95.1 ± 5.1	0.02	0.58	0.99
				Men	92.5 ± 6.7	95.1 ± 5.8	<0.01		
GR	0.28 (0.02)	<0.01 (0.40)	0.77 (<0.01)	Women	80 ± 8	87 ± 9	<0.01	0.42	0.72
				Men	78 ± 10	87 ± 8	<0.01		
IKDC	0.17 (0.02)	<0.01 (0.45)	0.93 (<0.01)	Women	78.7 ± 9.9	85.1 ± 9.9	<0.01	0.47	0.58
				Men	77.1 ± 8.9	86.3 ± 9.5	<0.01		
KOOS-Sport/ Recreation	0.60 (<0.01)	<0.01 (0.36)	0.68 (<0.01)	Women	79.5 ± 14.7	89.7 ± 10.6[b]	<0.01	0.91	0.50
				Men	79.1 ± 14.5	87.9 ± 10.6[b]	<0.01		
KOOS-QoL	0.59 (<0.01)	<0.01 (0.20)	0.70 (<0.01)	Women	58.3 ± 16.1	66.0 ± 19.3	<0.01	0.94	0.57
				Men	58.6 ± 16.2	68.4 ± 18.4[b]	<0.01		

ANOVA, analysis of variance; GR, global rating of perceived knee function; IKDC, International Knee Documentation Committee; KOS-ADL, Knee Outcome Survey Activities of Daily Living subscale; KOOS, Knee injury and Osteoarthritis Outcome Score; QI, quadriceps strength limb symmetry; QoL, quality of life.

[a] η_p^2 indicates partial eta square (small η_p^2 = 0.01, medium η_p^2 = 0.06, large η_p^2 = 0.14).[9]

[b] Change greater than KOOS minimal clinically important difference of 8%.[36]

ACL reconstruction are important as they are related to functional and return-to-sport measures at 1 and 2 years[29,32,42] and may also influence osteoarthritis development.[10] Achieving ≥90% limb symmetry on the 6-m timed hop test as well as ≥90% on the GR is related to returning to a preinjury level of sport by 1 year, and ≥90% on the 6-m timed hop and single hop are related to returning to preinjury level at 2 years.[32] In the current study, the mean 6-m timed hop test limb symmetry posttraining was 99.6%, with 60 of 79 athletes achieving ≥90% limb symmetry. Further, in previous studies, athletes who met strength criteria (≥90% quadriceps and hamstring strength) were more likely to maintain or increase their activity level between 8 and 12 months after ACL reconstruction compared with athletes who did not.[42] Thus, regardless of group, the improvements that were seen in athletes after the training program in this study are clinically relevant and important as they have implications for the athletes' future function and sports participation.

SAP Versus SAP + PERT

PERT has been successfully used in nonoperative management of ACL injuries to assist athletes in safely returning to sport.[14] Cohorts in Norway[17] and the United States[13] have shown that preoperative rehabilitation involving PERT coupled with progressive postoperative physical therapy results in higher PRO scores compared with standard-of-care treatment. Given this evidence, the authors hypothesized that athletes in the SAP + PERT group would have higher functional and PRO scores. This hypothesis was not supported, as there were no differences between the SAP and SAP + PERT groups. It is possible the SAP + PERT group experienced changes in neuromuscular control that were not detected in QI, hop testing, or PROs. However, the results seem to indicate that the training program itself drives improvements in limb symmetry and self-report.

Examining only the men in the ACL-SPORTS randomized controlled trial, previous studies have found no difference between the SAP and SAP + PERT groups in QI, hop test limb symmetry, PRO scores,[4] or gait symmetry at 1 and 2 years.[7] These previous studies, combined with the results of this study, indicate that it is appropriate to combine the SAP and SAP + PERT groups for secondary analyses.

Men Versus Women

Men and women had similar QIs at pretraining; however, the men's QI increased after the training program, while the women's did not. Although men and women were not significantly different at posttraining, the nonsignificant decrease in QI for women led the researchers to scrutinize the data. Examining the sample as individuals, 20 women (50%) had decreases in QI (7 had bilateral decreases in quadriceps strength, 4 had decreased in quadriceps strength on their involved limb but increased on their uninvolved limb, and 9 had increases in strength bilaterally but greater on the uninvolved side) over the course of training. In contrast, only 11 men (27.5%) had QI decreases (3 had bilateral decreases in quadriceps strength, 3 had decreased strength on their involved limb and increased strength on their uninvolved limb, and the remaining 5 had increases in strength bilaterally but greater on the uninvolved limb).

All athletes were encouraged to continue performing the home strengthening programs they were prescribed prior to the training program, and athletes who were between 80% and 90% QI at enrollment were given additional quadriceps strengthening exercises within the program for the first 6 sessions.[43] However, even with these additional exercises, it seems that women may require additional focus and continued quadriceps strengthening. Kim and Park[25] found that women had greater quadriceps deficits than men 1 year after ACL reconstruction, and given the importance of quadriceps strengthening in ACL reconstruction rehabilitation[27,37,38] and the implications of QI on risk of reinjury,[18,26] the results of this study have significant clinical meaning. Even a QI difference of 1% affects an athlete's reinjury risk.[18] During the return-to-sport phase of rehabilitation, clinicians tend to shift their focus away from strengthening and toward sport-specific movements, higher level athletic tasks, and gradual return to sport. The results of this study indicate that, especially in women, quadriceps strengthening needs to remain expressly part of an athlete's prescribed and monitored training program to prevent decreases in quadriceps strength, avoid continued strength asymmetries, and achieve return-to-sport criteria.

This study did not have a control group that met the enrollment criteria but did not perform any intervention; thus, to gauge the program's benefit, the results must be compared with the literature. The PROs of this study are most easily compared with the Scandinavian ACL registries at 1 year.[16] In this study, both sexes had increases greater than the MCID of 8%[36] on the KOOS-Sport/Recreation subscale, and men had clinically meaningful increases in the KOOS-QoL subscale. Both the men and the women had posttraining KOOS-Sport/Recreation scores that were greater than those in the Scandinavian ACL registry (KOOS-Sport/Recreation, 63-64; KOOS-QoL, 60) by almost 3 times the MCID.[16] It is important to acknowledge that not all of the individuals in the Scandinavian ACL registries were athletes. The KOOS-QoL, however, may be more easily compared between athletes and nonathletes, as it indicates an individual's view of lifestyle modifications and his or her general awareness of the knee during everyday activities. The mean KOOS-QoL score for the men in this study was 8% greater than the Scandinavian ACL registries at 1 year, the same value as the MCID for the measure.[36] The men reached the posttraining time point at a mean of 28.9 ± 7.9 weeks (about 7 months) after ACL reconstruction, indicating the men in this study reached a point where their knee made less of an impact on their lives earlier after surgery compared with those in the Scandinavian ACL registry at 1 year. The women in this cohort made a significant improvement in KOOS-QoL score; however, the 7.2% change in score the women experienced did not quite reach the MCID of 8%. Although there are differences between Denmark, Norway, Sweden, and the United States regarding the course of physical therapy that athletes receive after ACL reconstruction, the results of this study point toward a potential benefit of the training program in the return-to-sport phase of rehabilitation.

A strength of this study was the generalizability of the sample. ACL reconstructions were performed by a number of different orthopaedic surgeons, and athletes received their postoperative rehabilitation in many community-based physical therapy clinics. This variation prior to enrollment strengthened the generalizability, while strict enrollment criteria meant all athletes started the study at a standardized place in their rehabilitation.[1,43] The enrollment criteria standaradized the starting point of the study, but they did not make the cohort exclusive. Pain, effusion, and range of motion were used as indicators that the athlete's knee was quiet and not aggravated, and the ≥80% QI criteria ensured that athletes were strong enough to safely participate in the higher level athletic tasks introduced in the training program.[43] As only 14 of the 261 athletes (5%) screened for this study were excluded because they could not resolve their impairments within 9 months of their ACL reconstruction, these criteria were not too difficult achieve. Furthermore, athletes in the study took differing amounts of time to meet the enrollment criteria. Again, such variation is also a reflection of a typical ACL reconstruction rehabilitation population, as not all athletes are discharged from physical therapy or return to sport at the same time after surgery.

One potential limitation of this study was the use of QI as both an inclusion criteria and outcome variable. The inclusion criteria were necessary for safety and to standardize the starting point of the study but may have limited the amount of change in QI the study was able to observe. However, the fact that differences between men and women in QI were observed makes these findings all the more important. The authors neither collected data on the rehabilitation programs each athlete performed prior to the training program nor collected details on whether athletes performed exercises outside the training program. Athletes were advised to avoid other athletic activities on the days they performed the training program. Athletes were also encouraged to continue any home exercise programs they had been given prior to enrollment on non–training program days. As the training program is a rigorous 60-90 minute program performed twice a week, the authors believe it is unlikely that the results of this study are because of outside home exercise programs, but future studies should record details of any such activities outside the training program. Another potential limitation of this study was the potential effect of multiple comparisons. Planned comparisons within the repeated-measures ANOVAs were used to reduce the number of post hoc comparisons, and given the results, the clinical impact of this study may remain the same even if a more conservative alpha were used.

CONCLUSION

This study found that performance of a secondary ACL injury prevention training program during the return-to-sport phase of rehabilitation resulted in significant increases in hop test limb symmetry and PRO scores. The training program seemed to improve knee function in this cohort of predominantly level I[11] athletes, regardless of whether an athlete received PERT or not. This study also found that men had a significant increase in QI with performance of the training program while women did not, potentially indicating that women may require more quadriceps strengthening even during the return-to-sport phase of ACL reconstruction rehabilitation. The PRO scores of this study were greater than those of the Scandinavian ACL registries, potentially indicating the program may be a valuable return-to-sport phase intervention after ACL reconstruction.

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy Grade

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
The training program that all athletes received as part of the ACL-SPORTS randomized controlled trial shows potential benefit as a sport-specific intervention during the return-to-sport phase of ACL reconstruction rehabilitation, improving limb symmetry and patient-reported outcome scores.	A
Often clinicians shift their focus away from strengthening to more advanced sport-related tasks during the return-to-sport phase of ACL reconstruction rehabilitation. This study would recommend that, particularly for women, quadriceps strengthening may still be necessary.	A

REFERENCES

1. Adams D, Logerstedt D, Hunter-Giordano A, Axe M, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: a criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42:601-614.
2. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. 2014;48:1543-1552.
3. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med*. 2011;39:538-543.
4. Arundale A, Cummer K, Capin J, Zarzycki R, Snyder-Mackler L. Report of the clinical and functional primary outcomes in men of the ACL-SPORTS trial:

similar outcomes in men receiving secondary prevention with and without perturbation training 1 and 2 years after ACL reconstruction. *Clin Orthop Relat Res.* 2017;43:2523-2534.
5. Bizzini M, Hancock D, Impellizzeri F. Suggestions from the field for return to sports participation following anterior cruciate ligament reconstruction: soccer. *J Orthop Sports Phys Ther.* 2012;42:304-312.
6. Bodkin S, Goetschius J, Hertel J, Hart J. Relationships of muscle function and subjective knee function in patients after ACL reconstruction. *Orthop J Sports Med.* 2017;5:2325967117719041.
7. Capin JJ, Zarzycki R, Arundale A, Cummer K, Snyder-Mackler L. Report of the primary outcomes for gait mechanics in men of the ACL-SPORTS trial: secondary prevention with and without perturbation training does not restore gait symmetry in men 1 or 2 years after ACL reconstruction. *Clin Orthop Relat Res.* 2017;43:2513-2522.
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.
9. Cohen J. A power primer. *Psychol Bull.* 1992;112:155-159.
10. Culvenor AG, Patterson BE, Guermazi A, Morris HG, Whitehead TS, Crossley KM. Accelerated return to sport after anterior cruciate ligament reconstruction and early knee osteoarthritis features at 1 year: an exploratory study. *PM R.* 2018;10:349-356.
11. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med.* 1994;22:632-644.
12. Ebert JR, Edwards P, Yi L, et al. Strength and functional symmetry is associated with post-operative rehabilitation in patients following anterior cruciate ligament reconstruction [published online September 15, 2017]. *Knee Surg Sport Traumatol Arthrosc.* doi:10.1007/s00167-017-4712-6.
13. Failla MJ, Logerstedt DS, Grindem H, et al. Does extended preoperative rehabilitation influence outcomes 2 years after ACL reconstruction? A comparative effectiveness study between the MOON and Delaware-Oslo ACL cohorts. *Am J Sports Med.* 2016;44:2608-2614.
14. Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physically active individuals. *Phys Ther.* 2000;80:128-140.
15. Fitzgerald GK, Axe MJ, Snyder-Mackler L. Proposed practice guidelines for nonoperative anterior cruciate ligament rehabilitation of physically active individuals. *J Orthop Sports Phys Ther.* 2000;30:194-203.
16. Granan L-P, Forssblad M, Lind M, Engebretsen L. The Scandinavian ACL registries 2004-2007: baseline epidemiology. *Acta Orthop.* 2009;80:563-567.
17. Grindem H, Granan LP, Risberg MA, Engebretsen L, Snyder-Mackler L, Eitzen I. How does a combined preoperative and postoperative rehabilitation programme influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL cohort and the Norwegian National Knee Ligament Registry. *Br J Sports Med.* 2015;49:385-389.
18. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med.* 2016;50:804-808.
19. 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;40:141-154.
20. Hewett T, Lindenfeld T, Riccobene J, Noyes F. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med.* 1999;27:699-706.
21. Hewett T, Stroupe A, Nance T, Noyes F. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24:765-773.
22. 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.
23. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form. *Am J Sports Med.* 2006;34:1567-1573.
24. 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.
25. Kim DK, Park WH. Sex differences in knee strength deficit 1 year after anterior cruciate ligament reconstruction. *J Phys Ther Sci.* 2015;27:3847-3849.
26. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med.* 2016;50:946-951.
27. Lentz TA, Tillman SM, Indelicato PA, Moser MW, George SZ, Chmielewski TL. Factors associated with function after anterior cruciate ligament reconstruction. *Sports Health.* 2009;1:47-53.
28. Logerstedt D, Di Stasi S, Grindem H, et al. Self-reported knee function can identify athletes who fail return-to-activity criteria up to 1 year after anterior cruciate ligament reconstruction: a Delaware-Oslo ACL cohort study. *J Orthop Sports Phys Ther.* 2014;44:914-923.
29. Logerstedt D, Grindem H, Lynch A, et al. Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. *Am J Sports Med.* 2012;40:2348-2356.
30. Marx RG, Jones EC, Allen AA, et al. Reliability, validity, and responsiveness of four knee outcome scales for athletic patients. *J Bone Joint Surg Am.* 2001;83:1459-1469.
31. Myer GD, Schmitt LC, Brent JL, et al. Utilization of modified NFL Combine testing to identify functional deficits in athletes following ACL reconstruction. *J Orthop Sports Phys Ther.* 2011;41:377-387.
32. Nawasreh Z, Logerstedt D, Cummer K, Axe M, Risberg MA, Snyder-Mackler L. Functional performance 6 months after ACL reconstruction can predict return to participation in the same preinjury activity level 12 and 24 months after surgery. *Br J Sports Med.* 2017;52:375.
33. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med.* 1991;19:513-518.
34. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sports Med.* 2012;22:116-121.
35. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med.* 2014;42:1567-1573.
36. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. *J Orthop Sports Phys Ther.* 1998;28:88-96.
37. Schmitt L, Paterno MV, Hewett T. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2012;42:750-759.
38. Schmitt LC, Paterno MV, Ford KR, Myer GD, Hewett TE. Strength asymmetry and landing mechanics at return to sport after ACL reconstruction. *Med Sci Sport Exer.* 2014;47:1426-1434.
39. Spindler KP, Huston LJ, Wright RW, et al. The prognosis and predictors of sports function and activity at minimum 6 years after anterior cruciate ligament reconstruction: a population cohort study. *Am J Sports Med.* 2011;39:348-359.
40. Sugimoto D, Myer GD, Foss KD, Hewett TE. Dosage effects of neuromuscular training intervention to reduce anterior cruciate ligament injuries in female athletes: meta- and sub-group analyses. *Sports Med.* 2014;44:551-562.
41. Sugimoto D, Myer GD, Foss KD, Hewett TE. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis. *Br J Sports Med.* 2015;49:282-289.
42. Toole AR, Ithurburn MP, Rauh MJ, Hewett TE, Paterno MV, Schmitt LC. Young athletes after anterior cruciate ligament reconstruction cleared for sports participation: how many actually meet recommended return-to-sport criteria cutoffs? *J Orthop Sports Phys Ther.* 2017;47:825-833.
43. White K, Di Stasi S, Smith A, Snyder-Mackler L. Anterior Cruciate Ligament–Specialized Post-Operative Return-to-Sports (ACL-SPORTS) training: a randomized control trial. *BMC Musculoskelet Disord.* 2013;14:108.
44. Xergia S, McClelland J, Kvist J, Vasiliadis H, Georgoulis A. The influence of graft choice on isokinetic muscle strength 4-24 months after anterior cruciate ligament reconstruction. *Knee Surg Sport Traumatol Arthrosc.* 2011;19:768-780.
45. Zwolski C, Schmitt LC, Quatman-Yates C, Thomas S, Hewett TE, Paterno MV. The influence of quadriceps strength asymmetry on patient-reported function at time of return to sport after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2015;43:2242-2249.