Research Report

The Efficacy of Perturbation Training in Nonoperative Anterior Cruciate Ligament Rehabilitation Programs for Physically Active Individuals

Background and Purpose. Treatment techniques involving perturbations of support surfaces may induce compensatory muscle activity that could improve knee stability and increase the likelihood of returning patients to high-level physical activity. The purpose of this study was to determine the efficacy of augmenting standard nonoperative anterior cruciate ligament (ACL) rehabilitation programs with a perturbation training program. Subjects. Twenty-six patients with an acute ACL injury or ruptures of ACL grafts participated in the study. Subjects had to have a unilateral ACL injury, be free of concomitant multiple ligament or meniscal damage requiring surgical repair, and pass a screening examination designed to identify patients who had the potential to return to high-level physical activity with nonoperative treatments. Subjects also had to be regular participants in level I activities (eg, soccer, football, basketball) or level II activities (eg, racquet sports, skiing, construction work). Methods. Subjects were randomly assigned to either a group that received a standard rehabilitation program (standard group) or a group that received the standard program augmented with a perturbation training program (perturbation group). Treatment outcome was determined from scores on the Knee Outcome Survey's Activities of Daily Living Scale (ADLS) and Sports Activity Scale, a global rating of knee function, scores on a series of single-limb hop tests, measurements of maximum isometric quadriceps femoris muscle force output, and the group frequency of unsuccessful rehabilitation. Unsuccessful rehabilitation was defined as the occurrence of an episode of giving way of the knee or failure to maintain the functional status of a rehabilitation candidate on retesting. Results. More subjects had unsuccessful rehabilitation in the standard group compared with the perturbation group. There was a within-group × time interaction for the ADLS, global rating of knee function, and crossover hop test scores. These scores decreased from posttraining to the 6-month follow-up for the standard group. Conclusion and Discussion. Although both the standard program and the perturbation training program may allow subjects to return to high-level physical activity, the perturbation training program appears to reduce the risk of continued episodes of giving way of the knee during athletic participation, and it allows subjects to maintain their functional status for longer periods. [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.]

Key Words: *Anterior cruciate ligament, Knee, Rehabilitation.*

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Nonoperative treatment for anterior cruciate ligament (ACL) injury usually consists of rehabilitation that emphasizes joint mobility, increasing thigh muscle force production, endurance, agility training, functional activity modifications, and protective bracing.[1–5] These appear to be successful only for those patients who are more sedentary or who are willing to modify their physical activities.[1,2,6] Recent studies[7–13] suggest that patients who achieve higher levels of functional recovery after ACL rupture alter their muscle activity in a manner that improves the stability of the knee. The success of rehabilitation programs for patients who want to participate in high-level activity, such as sports activities requiring cutting, jumping, and pivoting maneuvers of the lower extremity, should improve if treatment techniques that induce appropriate compensatory alterations in muscle activity are incorporated into treatment programs.

The challenge in designing treatments that induce compensatory muscle activity is that there appears to be no single proven compensatory pattern. Individuals who successfully compensate for a ruptured ACL appear to adopt idiosyncratic compensation patterns in several muscle groups of the lower extremities. Although there is consistency across studies with respect to the muscles that are altered to improve knee stability (eg, hamstring, gastrocnemius, quadriceps femoris muscles), the patterns of altered activity are remarkably varied.[10,11] Successful training strategies, in our opinion, have to provide the opportunity for development of *individualized* compensatory alterations in activity of several lower-extremity muscles.

Although there is limited understanding of the neuromuscular control mechanisms that play a role in maintaining knee stability, current theories regarding these mechanisms should be considered in the design of treatment. Johansson and Sjölander[14] have suggested that stimulation of mechanoreceptors in joint structures increases gamma motor activity in a manner that may increase the sensitivity of muscle spindles in muscles associated with the joint. This increased sensitivity of the muscle spindles may result in a higher state of "readiness" of muscles to respond to perturbing forces applied to the joint, which may, in turn, improve joint stability.[14]

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The afferent mechanism in this response appears to respond to moderate levels of force and theoretically could be activated during perturbations that occur during functional activity.[14] The implication for treatment may be that applying potentially destabilizing forces to the knee during treatment may enhance neuromuscular responses to destabilizing forces that may be encountered during function.

Nichols[15] proposed a "force-feedback" hypothesis, based on a series of experiments in the decerebrate cat, that may also explain the coordinated response from muscles to perturbing forces applied to a joint. When a perturbing force is applied to a joint, muscles that would resist the perturbation are stretched and become activated to resist the perturbation.[15] Simultaneously, there is a reflex inhibitory influence on muscles that would have a tendency to pull in the same direction as the perturbation.[15] The inhibitory influence reduces, but does not entirely eliminate, the unwanted stretch reflex from muscles antagonistic to those that would resist the perturbing force.[15] The net result is a coordinated coactivation of extremity muscles affected by the perturbation to stiffen the joint and maintain stability.[15]

The proposed mechanisms for neuromuscular control of joint stability described by Johansson and Sjölander[14] and Nichols[15] have several implications for design of treatment programs. The force-dependent nature of the mechanisms suggests that exposing the joint to potentially destabilizing loads during training may be the necessary stimulus to encourage the development of effective neuromuscular compensatory patterns. Treatment techniques that attempt to promote the development of these protective compensatory patterns could be designed to encourage involuntary muscular responses to destabilizing forces.

Treatments that involve perturbing support surfaces (perturbation training) allow altered forces and torques to be applied to the lower extremity in multiple directions and in a controlled manner. These techniques may induce compensatory muscle activation patterns in patients with ACL deficiencies.[16–18] The results of a randomized clinical trial indicated that subjects who received perturbation training combined with a standard nonoperative ACL rehabilitation program reported a greater increase in Lysholm Knee Rating Scale scores after training than subjects who received only the standard program.[16] Although augmenting nonoperative ACL rehabilitation programs with perturbation training techniques appears to be a favorable treatment option, this approach has not been tested on highly active individuals who want to return to preinjury levels of function.

The purpose of our study was to compare treatment effectiveness between a standard nonoperative ACL rehabilitation program and one that is augmented with perturbation training techniques in returning physically active individuals to high levels of activity. We hypothesized that subjects receiving the perturbation training would be more successful in returning to high-level physical activities following rehabilitation than subjects who did not receive this treatment.

Method

Subjects

Patients referred by their physicians to the University of Delaware Physical Therapy Clinic (Newark, Del) with a diagnosis of ACL rupture or rupture of an ACL graft were potential subjects for the study. Individuals were excluded from the study if: (1) the onset of injury was longer than 6 months prior to referral, (2) there was concurrent multiple ligament injury or repairable meniscal damage associated with the ACL injury, (3) they did not participate in greater than 50 hours per year of level I physical activities (eg, football, basketball, soccer) or level II physical activities (eg, racquet sports, skiing, manual labor occupations),[2] or (4) they exhibited less than 3 mm of side-to-side difference in passive anterior knee laxity, measured with maximum manual Lachman testing using a KT-2000 arthrometer.*[19]

A screening examination, which we had developed and tested in a previous study,[20] was used in an effort to differentiate patients who had good potential to succeed with nonoperative treatment (rehabilitation candidates) from those who may be at high risk for reinjury. This screening examination consisted of a series of single-limb hop tests described by Noyes et al,[21] the Knee Outcome Survey's Activities of Daily Living Scale,[22] a global rating of knee function, and the patient's report of the frequency of episodes of the knee giving way from the time of injury to the time of the screening examination. The screening examination was administered when patients were free of knee pain and effusion, exhibited full knee joint range of motion, were able to perform a synchronous (smooth and sustained) isometric contraction of the quadriceps femoris muscles as determined by palpation and visual inspection, were able to perform a straight leg raise without the presence of a knee extension lag, and were able to tolerate hopping on the involved limb. In order to participate in the training study, patients had to meet all of the following criteria: (1) timed hop test score of ≥80%, (2) Activities of Daily Living Scale score of ≥80%, (3) global rating of knee function of ≥60%, and (4) no more than one episode of

* MEDmetric Corp, 7542 Trade St, San Diego, CA 92121.

Table 1.
Group Characteristics for Age, Height, Weight, Anterior Knee Laxity, and Sex

	Standard Group			Perturbation Group		
	$\bar{X}$	SD	Range	$\bar{X}$	SD	Range
Age (y)	27.6	11.8	15–34	29.2	11.5	18–57
Height (cm)	175.0	9.1	154.9–185.4	178.3	7.1	167.6–190.5
Weight (kg)	78.9	13.4	56.8–102.3	83.6	16.1	61.4–115.9
Laxity[a] (mm)	5.5	2.0	3–10	5.1	1.5	3–6
Sex	3 female, 11 male			3 female, 9 male		

[a] Laxity measurement is the difference in passive anterior knee laxity between the involved and uninvolved knees.

the knee giving way from the time of injury to the time of the screening examination.

Twenty-eight subjects qualified for the training study. These subjects were randomly assigned to either a group that received a standard rehabilitation program (standard group) or a group that received the standard program combined with a perturbation training program (perturbation group). A computer-generated random number list was used to randomly assign subjects to groups (SYSTAT Design module, version 2.0†). All subjects signed an informed consent form, approved by the University of Delaware Human Subjects Review Board, prior to participating in the study. One subject in the standard group was dropped from the study because he was unable to maintain a regular treatment schedule. One subject in the perturbation group did not complete the study because she decided that time constraints made surgical treatment more convenient than undergoing nonoperative treatment. A total of 26 subjects (14 subjects in the standard group and 12 subjects in the perturbation group) completed the training. Group characteristics for age, height, weight, anterior knee laxity, and sex are shown in Table 1. Subject participation in level I and II activities is summarized in Table 2.

Table 2.
Group Characteristics for Activity Level

Activity	Standard Group	Perturbation Group
Collegiate football	1	2
Semiprofessional football		1
Collegiate lacrosse	1	
Collegiate field hockey		1
Collegiate track/soccer	1	
High school basketball	1	
High school softball		1
High school field hockey	1	
Semiprofessional baseball		1
Senior Olympic volleyball		1
Basketball	6[a]	
Hockey	1	1
Tennis	1	1
Softball	1[b]	2
Volleyball		1

[a] Two subjects also worked as construction workers (level II occupation).
[b] Subject was also a candidate for the local police academy (level II occupation).

Training Programs

Standard program. The standard rehabilitation program consisted of resistive exercises for the quadriceps femoris and hamstring muscle groups, cardiovascular endurance training, agility skill training, and sport-specific skill training. The resistive exercises consisted of leg extensions, leg curls, and leg press progressive resistance exercises on a hydraulic resistance exercise device. A 1-repetition maximum was established at the beginning of the resistance exercise. The subject was instructed to perform 2 sets of 10 repetitions at 50% of the 1-repetition maximum, 2 sets of 8 repetitions at 75% of the 1-repetition maximum, and 2 sets of 5 repetitions using maximum effort. These guidelines were used for all 3 resistive exercises. The leg extension exercise was performed through a joint excursion from 90 to 45 degrees of flexion to minimize anterior tibial shearing during the exercise. Subjects whose maximum voluntary quadriceps femoris muscle isometric force for the involved limb was less than 80% of the uninvolved quadriceps femoris muscle force received a high-intensity electrical stimulation training protocol.[23] The protocol consisted of 10 electrically stimulated isometric contractions of the quadriceps femoris muscles, 10 seconds on and 50 seconds off, with a 2,500-Hz stimulus delivered at 75 bursts per second and an amplitude equivalent to the current needed to produce 50% of maximum voluntary isometric torque of the injured limb's quadriceps femoris muscle. The electrical stimulation protocol was continued until the maximum voluntary isometric force of the injured limb's quadriceps femoris muscle was 80% of that of the uninvolved limb's quadriceps femoris muscle.

Cardiovascular training techniques were selected based on each subject's sports activities. A graded running program was used for subjects involved in running

† SYSTAT Inc, 1800 Sherman Ave, Evanston, IL 60201.

sports. The running program began with treadmill running and progressed to level surface running, then hill running, and finally sprinting and figure-eight running. A graded skating program was used for subjects involved in skating sports. This training began with sliding-board skating simulation and progressed to straight ice skating and then quick stops and starts, cutting, and changing directions.

Running activities were progressed based on subject tolerance for the activity. Tolerance was determined by monitoring complaints of pain during or following the activity or an increase in swelling after the activity. When subjects tolerated treadmill running for 10 to 15 minutes without inducing pain or swelling, they were progressed to level-surface running on a track or road. Subjects were instructed to add hill running when they were able to tolerate 20 to 30 minutes of level-surface running without pain or swelling. Sprinting and figure-eight running was added to the program when the subjects were able to perform the agility training techniques at maximum effort without pain or swelling.

The skating program was progressed in a manner similar to the running program. Tolerance was determined by monitoring complaints of pain during or following the activity or an increase in swelling after the activity. When subjects tolerated 10 to 15 minutes of the sliding board simulation, they were progressed to straight skating by doing laps around the rink. When they could tolerate 20 to 30 minutes of lap skating and they were able to tolerate maximum-effort agility training, quick stops and starts, cutting, and changing directions were added to the skating program.

For subjects who were not involved in running or skating, stationary cycling was used. The subjects were instructed to cycle 20 to 30 minutes per day at a cycling rate of 60 to 80 rpm, with moderate resistance, as determined by the subjects.

Agility training techniques were used to improve lower-extremity coordination and the ability to quickly change movement direction. The techniques included side sliding (moving laterally in right and left directions, emphasizing quick change in direction every 4.5 m [5 yd]), cariocas (forward and backward leg crossovers while moving laterally in right and left directions, emphasizing quick change in direction every 9 m [10 yd]), forward and backward quick start-and-stop shuttle runs, multidirectional quick start-and-stop running, figure-eight running, and a 45-degree cutting-and-spinning drill. Agility training was initiated at approximately one half of their maximum effort and progressed to full-effort activity when they tolerated one half-effort agility training without pain or swelling.

Sport-specific skills were initiated when subjects tolerated full-effort agility training without pain or swelling. Sport-specific tasks, such as ball catching, passing, and kicking, were added during the agility training phase. Sport-specific skills were also practiced in the context of playing situations. For example, basketball players would begin practicing dribbling skills, jump shots, and layups. Hockey players would perform stick handling, passing, and shooting drills during their skating workouts. These activities were initiated without an opponent and then progressed to practice with an opponent. All subjects wore a custom-made knee brace during the running, agility training, and sport-specific skill training activities.

Perturbation training program. The perturbation training techniques were: (1) anteroposterior and mediolateral perturbations on a Balance Master motorized force platform,[‡] (2) anteroposterior and mediolateral rotary perturbations on a tiltboard, (3) multidirectional perturbations while the subjects were standing with one lower extremity on a roller board and the contralateral lower extremity on a stationary platform, and (4) multidirectional perturbations while the subjects were standing in single-limb support on a roller board.

The motorized force platform was used for the first few training sessions to deliver the perturbations in a consistent manner with respect to speed and displacement, allowing the therapist to focus on each subject's response rather than the stimulus. The platform, according to the manufacturer, delivered a 6.35-cm (2.5-in) translational displacement in approximately 0.5 second. The subject stood on the platform, and the therapist programmed the platform to be perturbed in anterior and posterior translations in a random manner. Medial and lateral translations were performed by having the subject stand on the platform, facing the lateral edge of the platform. The subject initially stood on the platform with bilateral lower-extremity support, with his or her hands supported on the crossbar for balance. The therapist informed the subject of the direction that the perturbation would occur so that the subject would be allowed to become familiar with the perturbations. As the subject became comfortable with the perturbations, arm support was eliminated and finally only single-limb support was used. This progression occurred within the first session. Once the subject could maintain balance during single-limb support, the translations were applied unannounced and in a random order with respect to direction and timing. Approximately 15 to 20 translations occurred per session.

When the subjects were able to maintain balance without difficulty during the motorized force platform transla-

[‡] Neurocom International Inc, 9570 SE Lawnfield Rd, Clackamas, OR 97015.

Figure 1.
Roller board perturbation technique. Reprinted with permission of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association from 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.* In press.

Figure 2.
Tiltboard perturbation technique. Reprinted with permission of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association from 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.* In press.

tions (usually in 4 or 5 sessions), the motorized force platform was replaced with a roller board. The roller board was a 35- × 38-cm platform supported by 4 swivel rollers, with a roller placed on each corner of the platform's underside. Each subject stood on the roller board in single-limb support while the therapist manually perturbed the roller board randomly in multiple directions, at varying speeds (Fig. 1). The displacement of the board during the perturbations varied between approximately 2.5 to 5 cm (1–2 in). The speed of the perturbations varied from quick displacements to slow, gradual displacements. A training bout lasted approximately 1 to 1.5 minutes. The activity was initially performed in parallel bars so that the subject would have arm support, if needed. When balance improved, the training was performed outside the parallel bars.

During the tiltboard perturbations, the subjects stood on the tiltboard with bilateral lower-extremity support and were asked to maintain a balanced position on the board (Fig. 2). Once a subject gained a balanced position on the board, the therapist manually applied anterior and posterior tilting perturbations at random to disturb the subject's balanced position. The surface of the tiltboard was approximately 7.5 cm (3 in) in height from the surface of the floor. The amount of tilting during the perturbations varied from approximately 2.5 to 7.5 cm (1–3 in). The timing and speed of the perturbations were also randomly varied by the therapist. The timing between perturbations varied from approximately 1 to 5 seconds. The speed of tilting perturbations varied from a quick application to a slow, gradual application of tilting. Subjects were instructed to respond by regaining the balanced position on the board. The therapist provided standby assistance in the event that the subjects

Figure 3.
Roller board and stationary platform perturbation technique. Reprinted with permission of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association from 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.* In press.

stepped off the board. The same process was repeated for medial and lateral tilting perturbations. Each bout lasted approximately 1 to 1.5 minutes. When subjects were able to perform this activity with minimal difficulty in double-limb support, the treatment was progressed to single-limb support.

During the roller board/stationary platform exercise, each subject stood with one limb on the roller board and the other limb on a box that was approximately the same height as the roller board (Fig. 3). The subject was instructed to maintain a steady position of the roller board when the therapist attempted to move the board. The subject attempted to resist the therapist's force on the board by pushing the lower extremity on the roller board in the opposite direction while matching the speed and magnitude of the therapist's perturbation force. The therapist perturbed the roller board in varying directions, amplitudes, and speed. The subject's ability to match the therapist's perturbations was monitored by the therapist by observing the movement of the roller board. If the subject matched the therapist's perturbations correctly, there should have been minimal movement of the roller board as the therapist applied and released forces or changed the direction and speed of forces on the roller board. This technique is similar to a proprioceptive neuromuscular facilitation–rhythmic stabilization technique.[24] A training bout consisted of approximately 1 to 1.5 minutes of perturbations. Subjects performed one training bout with the involved limb on the roller board and a second bout with the involved limb on the stationary box. Training bouts were conducted with the subject assuming a straddle stance, a forward diagonal stance, and a backward diagonal stance. These stances were used because we believed they simulate stance positions used during many athletic activities. In addition, the diagonal stances increased the level of difficulty for the subject in controlling the roller board perturbations. The total treatment time was approximately 6 to 9 minutes for this activity.

The level of difficulty of the tiltboard, roller board with stationary platform, and single-limb roller board perturbation techniques was progressed by adding sport-specific tasks during the perturbations. These tasks were added to encourage carryover of possible learned compensatory responses to functional activity. Schmidt[25] has suggested that practicing an acquired skill in the context of a functional task could enhance the carryover of the skill to functional performance. The sport-specific tasks were added during tiltboard perturbations when subjects were able to withstand the perturbations with minimal disturbance in their balance. Sport-specific activities were added to the roller board/stationary platform technique when subjects were exhibiting minimal co-contraction responses to the perturbations (determined by the therapist via visual inspection).

All subjects were treated for 10 sessions, at a frequency of 2 to 3 sessions per week, depending on scheduling constraints. All subjects completed the training program within 5 weeks. Subjects in both groups were encouraged to begin a partial return to their sport at the eighth treatment. Full return to athletic competition was allowed at the completion of the training program.

Determination of Treatment Outcome

Unsuccessful rehabilitation was operationally defined as either the occurrence of an episode of the knee giving way or a subject's reduction in status from being a candidate for rehabilitation to being at high risk for reinjury on retesting, based on the criterion measures of the screening examination. Recurrent episodes of the knee giving way have been associated with increased potential for doing further damage to knee structures.[26,27] We believed, therefore, that the occurrence of an episode of the knee giving way would be a strong indicator that the subject would be unable to safely continue participation in high-level physical activity. Clinical tests of treatment outcome were: (1) measurement of maximum voluntary isometric force output of the quadriceps femoris muscles, (2) the ability to do a series of single-limb hop tests,[21] and (3) measurement of passive anterior knee laxity using a KT-2000 knee arthrometer.[19] Quadriceps femoris muscle maximum isometric force output was measured using a burst-superimposition method.[28] The subject was seated on a Kin-Com II isokinetic dynamometer,[§] and the dynamometer force arm was secured to the subject's ankle. The knee was held in 90 degrees of flexion. Self-adhesive electrodes were applied to the quadriceps femoris muscle so that an electrical stimulus could be applied during muscle contraction. The subject was asked to exert as much force as possible while extending the knee against the force arm of the dynamometer. An electrical stimulus (amplitude=130 V, pulse duration=600 microseconds, pulse interval=10 microseconds, train duration=1 second) was applied during the contraction to ensure that the muscle was maximally activated during the test. The force test score was expressed as an index representing the injured limb's quadriceps femoris muscle force divided by the uninjured limb's quadriceps femoris muscle force and multiplied by 100.

The hop tests used in this study have been described by Noyes et al[21] as performance-based measures of knee function, although they appear to reflect impairment. The tests are all single-limb hop tests and include: (1) a single hop for distance, (2) a triple crossover hop for distance in which the subject must cross over a 15.2-cm-wide (6-in-wide) tape with each consecutive hop, (3) a straight triple hop for distance, and (4) a timed hop in which the subject hops a distance of 6 m as fast as possible (Fig. 4). Subjects did 2 practice trials followed by 2 measurement trials of each hop test on both limbs. The hop test score for each limb was reported as the average of the 2 measurement trials. The single hop, crossover hop, and triple hop scores were expressed as a percentage of the injured extremity score divided by the uninjured extremity score and multiplied by 100. The timed hop score was expressed as a percentage of the uninjured extremity score divided by the injured extremity score and multiplied by 100.

[§] Chattanooga Group Inc, 4717 Adams Rd, Hixson, TN 37343.

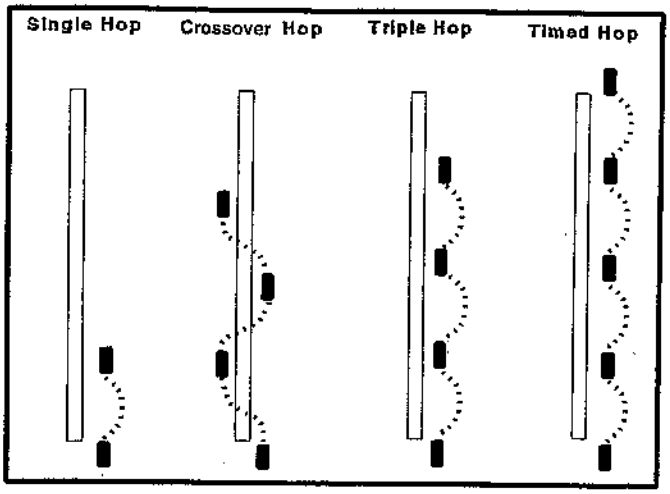

Figure 4.
Diagram of single-limb hop test series. Redrawn with permission from Noyes et al.[21]

Passive anterior knee laxity measurements were taken to determine whether there was a change in laxity with participation in nonoperative management of the injury. The KT-2000 is an instrumented arthrometer that measures the degree of anterior tibial displacement (in millimeters) with respect to the femur when the examiner applies an anterior translational force to the posterior aspect of the subject's leg. The instrument was strapped to the anterior aspect of the subject's leg while the subject was positioned supine. The examiner pulled on the handle of the arthrometer with maximum manual force, creating an anterior translational force on the posterior aspect of the leg. The passive anterior knee laxity measurement is expressed as the difference in anterior displacements between the involved and uninvolved knees. Results from a previous study performed at the University of Delaware involving 10 subjects with ACL injury indicated that measurements obtained with the KT 2000 were reliable.[29]

Self-report measures of knee function were: (1) the Knee Outcome Survey's Activities of Daily Living Scale,[22] (2) the Knee Outcome Survey's Sports Activity Scale,[22] and (3) a global rating of knee function. The Activities of Daily Living Scale of the Knee Outcome Survey assesses how a person's knee condition affects daily activities such as ambulation, stair climbing, kneeling, sitting, and squatting. The Sports Activity Scale of the Knee Outcome Survey assesses how a person's knee condition affects participation in sports activities and sports-related tasks such as running, jumping, cutting, and quick starting and stopping. Scores for both the Activities of Daily Living Scale and the Sports Activity Scale are reported as percentage scores, determined by dividing the subject's score by the total possible score and multiplying by 100 for each scale. A global rating of knee function was used to assess the subjects' overall knee function. Subjects rated knee function on a scale of 0% to 100%, with 100% representing preinjury function.

Table 3.
Contingency Table of Frequency Data for Successful and Unsuccessful Rehabilitation Between Groups

	Successful Rehabilitation	Unsuccessful Rehabilitation	Total
Pertubation group	11	1	12
Standard group	7	7	14
Total	18	8	26

Data Management and Analysis

The number of subjects from each group classified as having unsuccessful rehabilitation was recorded. A chi-square analysis was used to determine whether there was a difference between groups in the number of subjects who were classified as having unsuccessful rehabilitation at the 6-month follow-up test session. Likelihood ratios[30] were also calculated on these data to determine the probability of a successful outcome when receiving perturbation training or the standard treatment. The formula for a positive likelihood ratio is: (sensitivity/1−specificity).[30] The formula was applied to the frequency data in this study in the following manner. Based on the results of the chi-square analysis, we expected that subjects in the perturbation group would be more likely to have successful rehabilitation and subjects in the standard group would be more likely to have unsuccessful rehabilitation. Therefore, sensitivity would equal the number of subjects in the perturbation group who successfully completed the study divided by the number of subjects in both groups who successfully completed the study. Specificity would equal the number of subjects in the standard group who had unsuccessful rehabilitation divided by the number of subjects in both groups who had unsuccessful rehabilitation.

Group means and standard deviations were calculated for each of the clinical tests and for self-report scores for pretraining, immediately posttraining, and 6-month postinjury testing sessions. A 2-way, group × time, repeated-measures multivariate analysis of variance was used to determine whether there were group differences in the test variables. The level of statistical significance for all analyses was $P<.05$.

Results

Frequency of Success Versus Failure

Table 3 is a contingency table of the frequency of success or failure of rehabilitation in each group at the time of the 6-month postinjury follow-up test session. One subject in the perturbation group had an episode of the knee giving way while playing football prior to the end of

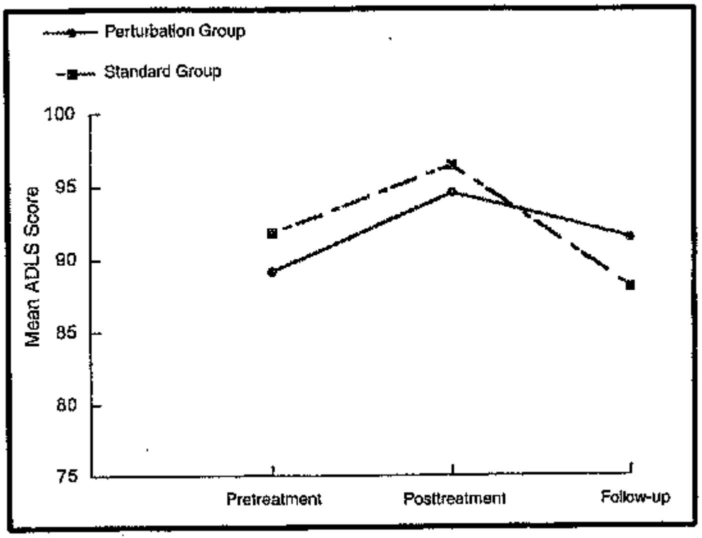

Figure 5.
Plot of Activities of Daily Living Scale (ADLS) interaction. Significant interaction ($P<.05$).

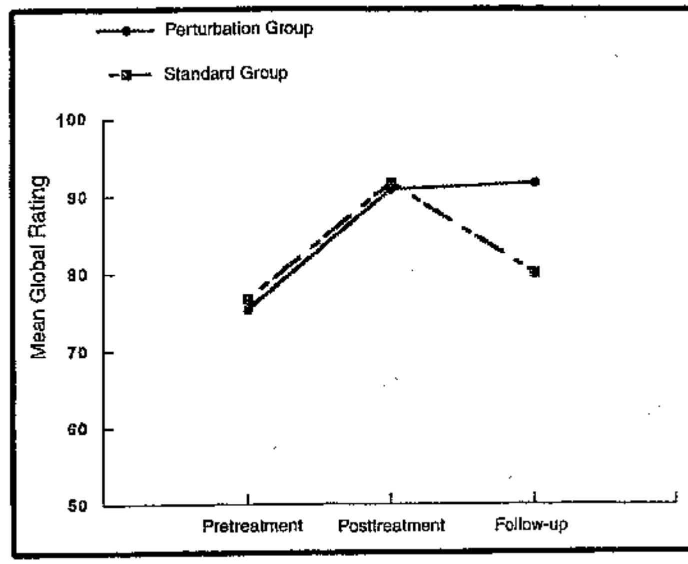

Figure 6.
Plot of global rating of knee function interaction. Significant interaction ($P<.05$).

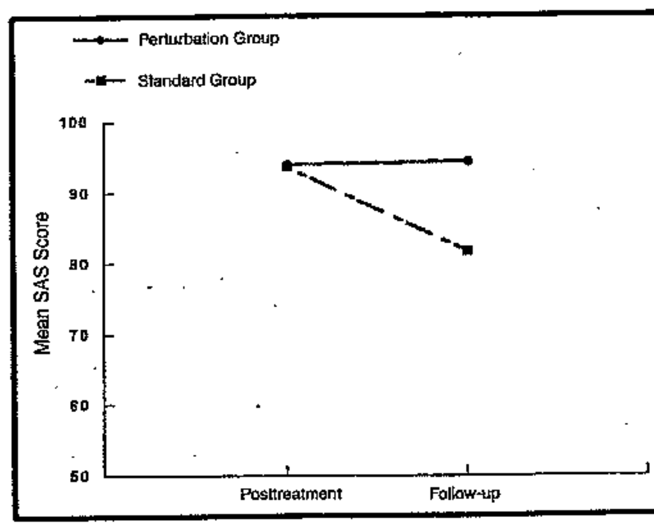

Figure 7.
Plot of Sports Activity Scale (SAS) interaction. Interaction was not significant ($P=.12$).

the training period. All other subjects in this group had not experienced an episode of the knee giving way on return to full activity. Seven subjects in the standard group were classified as having unsuccessful rehabilitation. One of these subjects experienced an episode of the knee giving way during training. Five subjects reported an episode of the knee giving way on return to full activity, and 1 subject regressed to being at high risk for reinjury based on test scores at the 6-month postinjury follow-up test session. The chi-square analysis indicated that a greater number of subjects in the standard group had unsuccessful rehabilitation ($\chi^2=5.27$, critical value=3.84, $P<.05$). The positive likelihood ratio was 4.88 ([11/18]/1−[7/8]). This finding indicates that subjects who received the perturbation training were 4.88 times more likely to succeed have a successful outcome with nonoperative treatment than subjects who did not receive the perturbation training.

Self-Report Surveys

The scores of 3 subjects were not included in the analysis. One subject from the standard group was lost to follow-up because he received surgery prior to the follow-up test session. Two subjects, one from each group, had an unsuccessful outcome before the end of the training program and did not receive a posttreatment examination, resulting in incomplete data for this analysis. The analyses, therefore, were based on data for 11 subjects from the perturbation group and 12 subjects from the standard group. There were no differences in group means for pretreatment, posttreatment, and follow-up test sessions ($P>.05$). Interactions were present for the Activities of Daily Living Scale and global rating of knee function scores ($P<.03$) (Figs. 5 and 6). There was a reduction in the Activities of Daily Living Scale and global rating of knee function score means from the posttreatment test session to the follow-up test session in the standard group, whereas no change in these means occurred during this time frame for the perturbation group. A similar trend was observed in posttreatment and follow-up Sports Activity Scale scores; however, the interaction was not statistically significant (Fig. 7).

Hop Tests

The 2 subjects who had an unsuccessful outcome prior to the end of training did not have a posttreatment examination. One subject in the standard group was lost to follow-up because he had surgery prior to the follow-up examination. A second subject in the standard group was unable to perform the hop tests at the time of follow-up due to a back injury. A third subject was unable

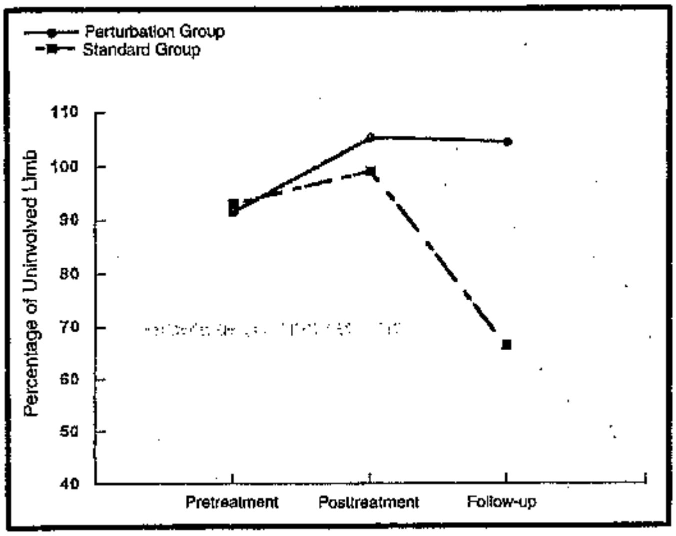

Figure 8.
Plot of single-limb crossover hop test interaction. Significant interaction ($P<.05$).

to perform the hop tests at the time of follow-up due to leg cramps. The analysis was performed on data from the remaining subjects (11 subjects in the perturbation group and 10 subjects in the standard group). Subjects who refused to perform the hop tests on retesting because of pain or fear of reinjury were given a score of 0 for the hop tests (4 subjects in the standard group refused to hop). There were no differences between groups for pretreatment and posttreatment hop test scores. The perturbation group scored higher on the follow-up single and triple hop for distance tests (single hop test: $\overline{X}$=101%, SD=14%; triple hop test: $\overline{X}$=99%, SD=12%) than did the standard group (single hop test: $\overline{X}$=68%, SD=48%; triple hop test: $\overline{X}$=59%, SD=51%) ($P<.05$). There were no differences in group means for follow-up crossover test (P=.07) and timed hop test (P=.09). There was an interaction for the crossover hop test scores ($P<.05$). Standard group crossover scores decreased from the posttreatment test session ($\overline{X}$=100%, SD=15%) to the follow-up test session ($\overline{X}$=64%, SD=55%), whereas perturbation group scores were maintained during this time period (posttreatment test session: $\overline{X}$=105%, SD=13%; follow-up test session: $\overline{X}$=104%, SD=16%) (Fig. 8).

Quadriceps Femoris Muscle Force Index and Anterior Knee Laxity

Data were not obtained for 4 subjects (1 subject in the standard group and 3 subjects in the perturbation group) at the posttreatment test session. One subject from each group had an unsuccessful outcome before the end of training and did not receive a posttreatment examination. The Kin-Com II dynamometer was in repair at the time of posttreatment examination for 2 other subjects from the perturbation group, and the examinations were not rescheduled. Data were not obtained for 5 subjects (3 subjects in the standard group and 2 subjects in the perturbation group) at the follow-up test session. Three subjects in the standard group and 1 subject in the perturbation group could not be scheduled for force testing prior to their surgeries. One subject in the perturbation group had a scheduling conflict for the follow-up testing session and was never rescheduled. Therefore, a meaningful group × time repeated-measures analysis could not be conducted. Standard t tests were used to compare group mean differences at each testing session for the available data. There were no differences between groups for quadriceps femoris muscle isometric force indexes at the pretreatment testing session (perturbation group: $\overline{X}$=91%, SD=17%; standard group: $\overline{X}$=86%, SD=8%), the posttreatment testing session (perturbation group: $\overline{X}$=94%, SD=15%; standard group: $\overline{X}$=90%, SD=13%), or the follow-up testing session (perturbation group: $\overline{X}$=96%, SD=15%; standard group: $\overline{X}$=92%, SD=10%).

Pretraining group means for anterior knee laxity (reported as differences between involved and uninvolved knees) are provided in Table 1. Follow-up examination mean anterior knee laxity was 4.9 mm (SD=1.7) the perturbation group and 5.4 mm (SD=2.3) for the standard group. There were no differences between groups in anterior knee laxity, and there was no change in laxity from the pretreatment test session to the follow-up test session within either group ($P>.05$).

Discussion

The results of the chi-square analysis indicate that more subjects in the standard group had unsuccessful rehabilitation compared with the perturbation group. The subjects either experienced an episode of the knee giving way or regressed to being at high risk for reinjury during the follow-up period. The likelihood ratio calculated for the frequency data for success or failure of rehabilitation suggests that patients would be almost 5 times more likely to successfully return to high-level physical activity if they receive the perturbation training than if they receive only the standard training program. Adding the perturbation training to current standard nonoperative ACL rehabilitation programs more predictably returns patients to level I and II activities. The higher scores for the perturbation group for follow-up single and triple hop tests further support this finding.

Interactions were found for the Activities of Daily Living Scale, global rating of knee function, and crossover hop test scores. Subjects in both groups improved their scores from the pretreatment test session to the posttreatment test session. Subjects in the perturbation group maintained their scores on these measures from the posttreatment test session to the follow-up test session, whereas the scores of the subjects in the standard group fell. Both treatment programs were capable of returning subjects to level I and II activities; however, the perturbation program allowed for longer-term success of rehabilitation.

There were no differences in passive anterior knee laxity between groups prior to training and at the follow-up examination. There was also no change in mean laxity measurements from the pretraining test session to the follow-up test session for either group. It should be noted, however, that follow-up laxity measurements were not obtained for 1 subject in the perturbation group and 4 subjects in the standard group. All 5 subjects had had an episode of the knee giving way between the pretraining and follow-up examination periods. It is possible that anterior knee laxity measurements could have increased in these subjects as a result of the episode of the knee giving way. However, of the remaining 2 subjects in the study who had an episode of the knee giving way, passive anterior knee laxity was unchanged in 1 subject and was reduced in the other subject from the pretreatment test session to the follow-up test session. Several studies[27,31–34] have indicated that passive anterior knee laxity is not correlated with functional outcome following ACL injury. Therefore, we believe that even if a difference in passive anterior knee laxity existed between groups, it would probably not explain differences in treatment outcomes between groups.

The perturbation training may provide some protective effect for continued participation in high-level physical activities following nonoperative ACL rehabilitation. Although the mechanism for this protective effect cannot be determined from the results of this study, it could be related to adaptations in neuromuscular control of knee stability. Subjects in the perturbation program were given additional exposure to potentially destabilizing forces about the knee in a controlled, yet progressive, manner. This additional exposure may have provided an additional opportunity for the neuromuscular system to adapt to these forces by developing successful compensatory muscle activity patterns. Future studies are needed to compare pretraining and posttraining changes in muscle activity during functional activities. These studies may be useful in describing the underlying mechanisms for the success of the perturbation training program.

The method of application of the perturbation training techniques may also have contributed to the success of the perturbation training program. As individuals acquire new motor skills, muscle activity responses will progress from strong co-contraction patterns to more selective muscle activity and movement patterns.[35] During the roller board and stationary platform perturbation, most subjects appeared to respond with strong co-contractions of lower-extremity muscles during early treatment sessions (based on visual inspection and palpation). Subjects were asked not to overcome the forces applied by the therapist, but rather to match the forces as they were applied and released. This method of instruction resulted in more selective lower-extremity muscle contractions in response to the applied loads. This method of instruction during the roller board and platform technique may have better prepared the subjects for higher-skilled muscular responses to destabilizing forces when they returned to full athletic competition.

Applying the perturbation techniques during performance of sport-specific tasks may have added to the success of this treatment. If the perturbation techniques allowed subjects to acquire protective compensatory neuromuscular adaptations, application of these techniques during sport-specific tasks may have provided for carryover of the protective responses to functional situations. Practicing learned motor skills in the context of functional tasks has been suggested to ensure carryover during functional activities.[25]

Subjects were treated for 10 sessions, at a frequency of 2 to 3 times per week. Although this treatment dosage seemed to be adequate over a 6-month period from the time of injury, the optimal dosage for extended participation in level I and II activities cannot be determined from the results of this study. Future investigations that use varied numbers and frequencies of training sessions may be useful in identifying an optimal dose-response relationship for the perturbation training program.

We were the first researchers to use a screening examination to select patients with good potential to succeed with nonoperative management for participation in a study of this type. In previous studies,[1,2,6,27,31,36] subjects self-elected nonoperative management for their injuries. Many subjects in these studies experienced continued episodes of instability and had reduced their activity levels as a result of their knee condition, even after undergoing rehabilitation. Engström et al[31] reported that only 23% of their subjects were able to return to preinjury activity levels with nonoperative management. Andersson[36] reported that only 30% of subjects electing nonoperative management were able to return to preinjury activity levels within 1 year of injury.

The best success rate for returning patients to high-level physical activity was reported by Shelton et al.[27] Subjects in their study self-elected nonoperative treatment and were excluded only if multiple ligament or repairable meniscal damage was associated with the ACL injury. Thirty-one of the 43 subjects in Shelton and colleagues' study returned to athletic competition. Only 12 (39%) of the 31 subjects who returned to athletic competition were able to do so without experiencing an episode of giving way at the knee. Comparing this result with ours, 69% (18/26) of all subjects in our study returned to full activity and did not report an episode of giving way at the knee at the time of the follow-up examination. The success rate was 92% (11/12) in the perturbation group and 50% (7/14) in the standard group. The success rates for subjects in our study were superior to that of the study by Shelton et al, regardless of treatment group assignment. The evidence suggests that use of the screening examination to select appropriate patients for nonoperative management of ACL rupture improves the probability of successful return to high-level activity in this patient population.

Conclusions

Augmenting nonoperative ACL rehabilitation programs with the perturbation training techniques described in this report enhances the probability of successful return to high-level physical activity. Although both training programs used in this study allowed subjects with isolated ACL ruptures to return to high-level physical activities, subjects who received the perturbation training demonstrated greater long-term success than subjects who did not receive this training. The greater proportion of successful return to activity in both treatment groups compared with previously reported success rates indicates the screening examination enhanced treatment outcome by identifying patients with good potential to succeed with nonoperative management.

References

1 Ciccotti MG, Lombardo SJ, Nonweiler B, Pink M. Non-operative treatment of ruptures of the anterior cruciate ligament in middle-aged patients: results after long-term follow-up. *J Bone Joint Surg Am.* 1994; 76:1315–1321.

2 Daniel DM, Stone ML, Dobson BE, et al. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med.* 1994;22:632–644.

3 Friden T, Zatterstrom R, Lindstrand A, Moritz U. Anterior-cruciate-insufficient knees treated with physiotherapy: a three-year follow-up study of patients with late diagnosis. *Clin Orthop.* 1991;263:190–199.

4 Irrgang JJ. Modern trends in anterior cruciate ligament rehabilitation: nonoperative and postoperative management. *Clin Sports Med.* 1993;12:797–813.

5 Wilk KE, Andrews JR. Current concepts in the treatment of anterior cruciate ligament disruption. *J Orthop Sports Phys Ther.* 1992;15:279–293.

6 Buss DD, Min R, Skyhar M, et al. Nonoperative treatment of acute anterior cruciate ligament injuries in a selected group of patients. *Am J Sports Med.* 1995;23:160–165.

7 Ciccotti MG, Kerlan RK, Perry J, Pink M. An electromyographic analysis of the knee during functional activities, II: the anterior cruciate ligament-deficient and -reconstructed profiles. *Am J Sports Med.* 1994;22:651–658.

8 Gauffin H, Tropp H. Altered movement and muscular-activation patterns during the one-legged jump in patients with an old anterior cruciate ligament rupture. *Am J Sports Med.* 1992;20:182–192.

9 Kalund S, Sinkjaer T, Arendt-Nielsen L, Simonsen O. Altered timing of hamstring muscle action in anterior cruciate deficient patients. *Am J Sports Med.* 1990;18:245–248.

10 Rudolph KS, Eastlack ME, Axe MJ, Snyder-Mackler L. 1998 Basmajian Student Award Paper: Movement patterns after anterior cruciate ligament injury: a comparison of patients who compensate well for the injury and those who require operative stabilization. *J Electromyogr Kinesiol.* 1998;8:349–362.

11 Shiavi R, Zhang LQ, Limbird T, Edmondstone MA. Pattern analysis of electromyographic linear envelopes exhibited by subjects with uninjured and injured knees during free and fast speed walking. *J Orthop Res.* 1992;10:226–236.

12 Sinkjaer T, Arendt-Nielsen L. Knee stability and muscle coordination in patients with anterior cruciate ligament injuries: an electromyographic approach. *J Electromyogr Kinesiol.* 1991;1:209–217.

13 Solomonow M, Baratta R, Zhou BH, et al. The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. *Am J Sports Med.* 1987;15:207–213.

14 Johansson H, Sjölander P. Neurophysiology of joints. In: Wright V, Radin EL, eds. *Mechanics of Human Joints: Physiology, Pathophysiology, and Treatment.* New York, NY: Marcel Dekker Inc; 1993:243–289.

15 Nichols TR. A biomechanical perspective on spinal mechanisms of coordinated muscular action: an architecture principle. *Acta Anat (Basel).* 1994;151:1–13.

16 Beard DJ, Dodd CAF, Trundle HR, Simpson AHRW. Proprioception enhancement for anterior cruciate ligament deficiency: a prospective randomised trial of two physiotherapy regimes. *J Bone Joint Surg Br.* 1994;76:654–659.

17 Di Fabio RP, Graf B, Badke MB, et al. Effect of knee joint laxity on long-loop postural reflexes: evidence for a human capsular-hamstring reflex. *Exp Brain Res.* 1992;90:189–200.

18 Ihara H, Nakayama A. Dynamic joint control training for knee ligament injuries. *Am J Sports Med.* 1986;14:309–315.

19 Daniel DM, Stone ML, Sachs R, Malcolm L. Instrumented measurement of anterior laxity in patients with acute ligament disruption. *Am J Sports Med.* 1985;13:401–407.

20 Fitzgerald GK. *Non-operative Management of Anterior Cruciate Ligament Injury in Physically Active Individuals.* Philadelphia, Pa: MCP Hahnemann University; 1998. Doctoral dissertation.

21 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.

22 Irrgang JJ, Snyder-Mackler L, Wainner RS, et al. Development of a patient-reported measure of function of the knee. *J Bone Joint Surg Am.* 1998;80:1132–1145.

23 Snyder-Mackler L, Delitto A, Bailey SL, Stralka SW. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament: a prospective, randomized clinical trial of electrical stimulation. *J Bone Joint Surg Am.* 1995;77:1166–1173.

24 Knott M, Voss DE. Techniques for facilitation. In: Knott M, Voss DE, eds. *Proprioceptive Neuromuscular Facilitation: Patterns and Techniques.* 2nd ed. Hagerstown, Md: Harper & Row; 1968:83–110.

25 Schmidt RA. Organizing and scheduling practice. In: Schmidt RA, ed. *Motor Learning and Practice: From Principles to Practice.* Champaign, Ill: Human Kinetics Inc; 1991:199–225.

26 Noyes FR, Mooar PA, Matthews DS, Butler DL. The symptomatic anterior cruciate-deficient knee, part I: the long-term functional disability in athletically active individuals. *J Bone Joint Surg Am.* 1983; 65:154–162.

27 Shelton WR, Barrett GR, Dukes A. Early season anterior cruciate ligament tears: a treatment dilemma. *Am J Sports Med.* 1997;25:656–658.

28 Snyder-Mackler L, Binder-Macleod SA, Williams PR. Fatigability of human quadriceps femoris muscle following anterior cruciate ligament reconstruction. *Med Sci Sports Exerc.* 1993;25:783–789.

29 Queale WS, Snyder-Mackler L, Handling KA, Richards JG. Instrumented examination of knee laxity in patients with anterior cruciate deficiency: a comparison of the KT-2000, Knee Signature System, and Genucom. *J Orthop Sports Phys Ther.* 1994;19:345–351.

30 Dujardin B, Van den Ende J, Van Gompel A, et al. Likelihood ratios: a real improvement for clinical decision making? *Eur J Epidemiol.* 1994;10:29–36.

31 Engström B, Gornitzka J, Johansson C, Wredmark T. Knee function after anterior cruciate ligament ruptures treated conservatively. *Int Orthop.* 1993;17:208–213.

32 Harilainen A, Alaranta H, Sandelin J, Vanhanen I. Good muscle performance does not compensate instability symptoms in chronic anterior cruciate ligament deficiency. *Knee Surg Sports Traumatol Arthrosc.* 1995;3:135–137.

33 Lephart SM, Perrin DH, Fu FH. Relationship between selected physical characteristics and functional capacity in the anterior cruciate ligament-insufficient athlete. *J Orthop Sports Phys Ther.* 1992;16:174–181.

34 Snyder-Mackler L, Fitzgerald GK, Bartolozzi AR 3rd, Ciccotti MG. The relationship between passive joint laxity and functional outcome after anterior cruciate ligament injury. *Am J Sports Med.* 1997;25:191–195.

35 Vereijkin B, van Emmerik REA, Whiting HTA, Newell KM. Freezing degrees of freedom in skill acquisition. *Journal of Motor Behavior.* 1992;24:133–142.

36 Andersson AC. Knee laxity and function after conservative treatment of anterior cruciate ligament injuries: a prospective study. *Int J Sports Med.* 1993;14:150–153.

Invited clinicians and researchers discuss a research report's implications for practice, research, education, and administration.

Research reports answer questions—and often raise new ones. Mark DeCarlo, James Irrgang, and Kevin Wilk join Editor Jules Rothstein in a discussion about the clinical and research implications of "The Efficacy of Perturbation Training in Nonoperative Anterior Cruciate Ligament Rehabilitation Programs for Physically Active Individuals."

Rothstein: Fitzgerald, Axe, and Snyder-Mackler make a strong case that people with anterior cruciate ligament [ACL] injuries can be classified as belonging to one of two groups. One group is described as being relatively sedentary and as having success with rehabilitation. The other group is described as being far more active and as having less success with rehabilitation. Is that what *you* find, both in your practice and in your reading of the literature?

Wilk: Noyes et al[1] proposed the "rule of thirds." They found that one third of their patients with ACL tears compensated and did well, one third modified their participation in sports and did not do very well, and one third could not return to sports at all. When I see a patient with an ACL injury, I always ask, "What level of function is the patient returning to? Is the patient returning to a sport that requires a lot of hard pivoting or cutting, or is the patient returning to straight-ahead running or jogging?" I attempt to assess the patient's level of functional activity, such as work and sports. And I find that, for people who have torn their ACL and are involved in hard running and cutting, the likelihood of returning to the previous level of function is diminished as compared with the likelihood for those returning to a lower level of function.

Rothstein: Are there any data on this rule of thirds, or was it based only on a general clinical impression?

DeCarlo: I don't know of any study that substantiates the rule. In my own practice, the rule of thirds doesn't apply.

Rothstein: What are *your* fractions?

DeCarlo: First, what types of patients with ACL injuries are we talking about? Are some patients sedentary individuals who want to maintain that lifestyle? Are some very active individuals who want to maintain that level of activity? Are some fairly active but want a nonoperative approach and, because of their injuries, *become* sedentary? In my clinical experience, not every person is a candidate for ACL reconstruction; however, more than a third of my patients with torn ACLs—perhaps as many as two thirds—ultimately have ACL reconstruction.

Irrgang: Patients who are referred to my facility have already determined that they want surgery; therefore, a very high proportion of my patients have surgery! Daniel et al[2] provided some data suggesting that the rule of thirds may not be accurate. Individuals who are returning to high levels of activity probably have a greater need for ACL reconstruction than those who aren't returning to high levels of activity.

Rothstein: All three of you manage patients who are of a homogeneous type. That is, regardless of whether they're coming for surgery, they—and you—have high expectations for function. We don't know the "rule" for the "average orthopedic setting." An orthopedic physical therapist in a hospital setting, for example, may not see the proportion of ACL reconstructions that you see. A physical therapist's expectations regarding reconstruction therefore may depend on the nature of his or her practice.

Irrgang: We also have to remember who is at risk for ACL injury. Most ACL injuries happen as a result of physical activity. If these physically active patients return to their previous levels of activity, they're going to be at greater risk for reinjury than patients who don't return to previous levels.

Wilk: Helping a patient decide whether to have ACL reconstruction poses a real dilemma, whether the patient is a high school athlete or a 40-year-old skier who was injured on the slopes. Both types of patients ask, "Should I have the surgery, or can I cope with this problem? What are my chances of full recovery with and without surgery?" As a physical therapist, I look at age and level of activity. For the 40-year-old skier with a torn ACL who is never going to ski again but who wants to be able to participate in workout sessions, an ACL reconstruction may not be necessary. For someone younger who is involved in a more aggressive sport or work activity—such as a college student—I'd probably recommend reconstruction. I would base that recommendation on my clinical experience, which tells me that, without surgery, a person involved in strenuous sports is likely to have knee instability, such as "giving way" episodes, and may develop meniscal pathologies.

Irrgang: The decision on surgery also has to do the with the patient's willingness to make lifestyle modifications. Let's reconsider that 40-year-old skier. If he is *not* going to give up the activity that caused his knee to give out in the first place, he probably needs to have ACL reconstruction.

DeCarlo: A patient may have experienced other knee trauma at the time of the ACL tear. What is the status of the menisci and the articular surface of the femoral condyles? Even if the patient isn't very active, what would be the long-term ramifications of a well-done ACL reconstruction for a person with articular surface damage? Would surgery prevent major problems down the road in terms of degenerative changes in the knee? There are other factors to consider, such as whether the patient is likely to adhere to rehabilitation in the preoperative phase.

Wilk: Do orthopedic surgeons who perform a high volume of ACL reconstructions even *think* about trying nonoperative intervention first? In my experience, they think about nonoperative intervention only if the patient is adamant about pursuing it. I think that most surgeons believe, rightly or wrongly, that the majority of people will experience problems or cause further damage and that therefore the best intervention is reconstruction.

Rothstein: One of the founders of sports medicine, an orthopedist, used to say that there were only two types of patients in his waiting room—pre-op and post-op. Apparently there are still settings where that philosophy exists.

Wilk: Years ago, reconstructive surgery typically was performed *only* if nonoperative interventions failed—which may or may not have been the best approach.

Rothstein: There also were many failed operations in those days, more so than today.

DeCarlo: In some areas of the country, physical therapists still may not have access to orthopedic surgeons who can reconstruct the knee with a predictably high success rate; in those areas, trying a nonoperative program first may be indicated. Over the past 15 years, there has been an increase in the number of fellowship-trained orthopedic surgeons with high-level surgical skills as

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related to performing ACL reconstruction. With this increase, and with the greater competition, I think it's rare to not be able to find a technically proficient surgeon. . . . There also is a timing issue. A nonoperative program may be appropriate for an athlete if the injury occurs in the beginning of the sport season.

Irrgang: Many of the subjects in this study are focusing on what they can do to get through the season. For the high school senior who has a scholarship on the line, what's the probability of completing the high school season without a reinjury after undergoing this nonoperative program? In all likelihood, after the season ends, that student athlete will end up getting a reconstruction. I believe the authors are proposing a program that may provide a *temporary* solution that will allow the athlete to return to play without surgery.

Measuring Performance

Rothstein: The program described by Fitzgerald and colleagues may restore patient function and reduce vulnerability to new injuries. If it worked for one season, why *wouldn't* it work for the next season?

DeCarlo: The training was described as consisting of 10 visits. Would the patients need to continue with this kind of training in order to maintain the same high level of performance they had before they were injured? The authors posed that question at the end of the article when they talked about the need for further study. Another question involves the wearing of a brace by patients who are ACL deficient. What is the level of satisfaction with wearing a brace? And how successful were they as far as their athletic skills and participation in their sport during the season? All of these questions are related.

Rothstein: We're asking about the long-term future and a qualitative measurement—which is problematic. Even for surgery, we don't have very good *qualitative* measures. Our discussion reminds me of the expiration dates that are stamped on consumer goods: "If you really want to be safe, use before this date." But often, the item is perfectly good for 2 more years after the use-by date. . . . It's as though this article is reporting on an intervention that offers successful rehabilitation that *may or may not* expire over time, at which point the patient may need some other treatment.

Wilk: Fitzgerald and colleagues used "giving way" episodes, clinical tests, and knee scores as the criteria for determining success. But what is the best ultimate measure? *Did these subjects participate at their preinjury level or something less?* Just "getting through the season" isn't good enough if you're looking for a program that will reestablish a higher level of knee function.

Rothstein: Obviously, time is one measure. The patient may still be on the football team but may not have played a minute since the injury, whereas before the injury he might have been playing 40 minutes per game.

Wilk: Effectiveness in the sport is another measure.

Rothstein: How do we measure *quality* of sports performance as part of our patient management?

Wilk: With a basketball player, we might measure performance in terms of points per game. What was the player's average points per game or number of assists preinjury versus postinjury? Using the Cincinnati Knee Rating System,[3] we can compare the average preinjury and postinjury knee scores. If a player's knee score was 100 points prior to injury, what is the postinjury knee score at 6 months into the nonoperative program?

DeCarlo: With all sports, I look at specific performance. My facility uses the Cincinnati knee score extensively. I believe it gives a good indication of overall level of function because of the 100-point scale and the many different questions that it asks.

Irrgang: When measuring performance, I also routinely ask patients how the knee was doing prior to the injury. How does the patient *feel* it's doing now?

Individualized Muscle-Firing Patterns?

Rothstein: Early in this article, the authors talk about designing treatments that induce compensatory muscle action, but they say that the compensation for the ruptured ACL is idiosyncratic. Even though the authors recommend a protocol of rehabilitation, they suggest that, when all is said and done, the specific compensations vary from patient to patient. Do you agree?

Wilk: Research has shown that once the ACL is torn, proprioception is diminished,[4] and a "quadriceps avoidance gait" develops—people walk with a slightly flexed knee and use the hamstrings more than they use the quadriceps femoris muscles.[5–7] Even though there may be some individualized muscle-firing patterns, the literature shows that people who injure their ACL tend to "turn off" their quadriceps femoris muscles and use their hamstrings more, particularly the lateral hamstrings. Walla et al[7] reported that people who learn to use primarily the lateral hamstrings to control the knee achieve dynamic stability of the knee joint more effectively.

Irrgang: When Rudolph et al[8] looked at "copers" and "non-copers" among people with torn ACLs, they found that the non-copers had greater co-contraction stiffness of the joint, whereas the copers could more selectively activate the hamstrings or other muscles to stabilize the knee. People with an ACL-deficient knee may have different ways of reacting to that condition from a neuromuscular control point of view. Maybe that explains why some people can cope, and some people can't.

Wilk: Several research papers published in peer-reviewed journals show that patients with torn ACLs use their hamstrings more than their quadriceps femoris muscles.[4,6,9,10] For the perturbation training that Fitzgerald and colleagues described—we've conducted the same training in my facility using surface EMG [electromyography] as well as in-dwelling EMG—patients assume a flexed position, otherwise they can't stabilize the knee. Having 25 to 30 degrees of knee flexion definitely gives the hamstrings a big advantage. So I'm surprised by this study's emphasis on *individualized* patterns. In my clinical experience, most patients exhibit a consistent pattern.

DeCarlo: If the three of us were able to look at a high volume of patients with ACL injuries who opt for a nonoperative program—we don't have that high volume, because most of our patients have surgery—I suspect that we would find a consistent compensatory gait pattern. There may be individual variables, however. Several researchers[11–14] have reported that if patients hyperpronate, they may be more apt to having an ACL tear. And if someone hyperpronates *and* has an ACL deficiency, there may be variations. By "hyperpronation," I mean significant subtalar pronatory motion resulting in internal tibial rotation beyond contact or heel-strike phase.[15] But I believe that, in general, the quadriceps avoidance gait is consistent.

Rothstein: Perturbation training presents a stimulus and asks for a response. These authors basically report that they instructed patients to "do this" and that the result was greater function.

Wilk: I'm sure the authors gave more detailed patient instructions than "do this," however! When a patient is on a tilt board, the physical therapist creates perturbations by either tapping the board or having the patient throw a ball. In the clinic, I explicitly instruct the patient to "stay in a flexed position, hold the platform as horizontal as you can, and, when I rock it, bring it back to the horizontal as fast as you can." My instruction is to "keep your knee flexed to about 25 to 30 degrees"—because that's usually where the patient is the most comfortable—"but keep your chest over your knees, so you have hip flexion." That's the only way the patient can stay on the board if I'm really "thumping" it. If I'm only lightly tapping the board, the patient can stabilize in any position he or she wants, including completely upright. But once you start rocking that board and creating strong perturbations, the patient should be in the hip flexion or knee flexion position, otherwise the patient is never going to stay upright to do a scaled activity.

Irrgang: But the key to this activity is what's happening at the level of muscle, and patient instructions don't tell us how patients are using their muscles. Do they use a co-contraction of the quadriceps femoris muscles and the hamstrings, a selective activation of the hamstrings, or a selective activation of other involved muscles? Fitzgerald and colleagues are saying that individuals may use different strategies to stabilize the knee.

Rothstein: Wilk's description of patient instruction suggests that there may be a continuum in how physical therapists instruct patients. That is, we provide a stimulus—in the case of this study, on a nonmechanized basis—with which we can shape patient behavior. The therapist has two options: give only enough guidance so that patients don't hurt themselves, or give patients detailed guidance. This implies that there can be different ways of using a similar approach in managing patients. To what extent is it better to guide patients or to let patients find their own methods?

Wilk: You can utilize perturbation training in one of these two ways—using instruction or allowing patients to seek their own method—and perhaps still end up at the same point. We've conducted EMG studies using the Balance Master* system, similar to what Fitzgerald and colleagues used, and we've found very high levels of hamstring activity, particularly of lateral hamstring activity, which confirms the studies by Berchuck et al[16] and others[6,7,9] on quadriceps avoidance gait. We see this in the clinic all the time: People often walk with a flexed-knee gait.

Not Your Average Patient?

Rothstein: The authors believe they found a unique patient group for the nonoperative program. They used the hop test[17] to differentiate patients. Do you use this test, and, if so, do you think it makes that differentiation?

Wilk: I believe that the heart of this study is patien[t] selection. In these subjects, the single-leg hop test sco[re] was 80% or greater than that of the unaffected leg, [and] the knee scores were 60% or greater than those o[f the] unaffected leg. These results tell me that the patie[nt]

* NeuroCom International Inc, 9570 SE Lawnfield Rd, Clackam

special. My speculation is that they had good functional stability and excellent muscle co-contractions and that they basically had recovered from their initial injury. This is very good information for screening purposes. That is, if patients with a torn ACL can do a hop test at 80% of the unaffected leg, maybe they can deal with ACL deficiency at least for a month or two, enough to play out a season. I wonder how much time transpired in this study from the time of injury to the screening test?

Irrgang: Based on my personal knowledge of the authors' program, by the time the hop test was conducted, these patients had recovered from the acute episode, had started rehabilitation, had regained their range of motion, and had started some strengthening exercises. That would be approximately 3 or 4 weeks postinjury.

DeCarlo: We use the hop test as part of postoperative rather than preoperative screening. Our patients who do not have reconstruction but who want to return to activity typically have made a choice to modify their activity level. We therefore don't use this test in making decisions on return to sports.

Rothstein: According to our discussion, the patients in this study are not representative of the "typical patient" with a torn ACL. The screening protocol used by Fitzgerald and colleagues apparently did a good job of identifying those who could be helped by the nonoperative program. This study is a wonderful example of the difference between an outcome study—for a select group of patients there was a positive outcome—and a study that clinicians can use for evidence-based practice. Based on the use of the hop test, this study appears to have limited generalizability. Many therapists wouldn't find "their" specific patients among these subjects. But for those physical therapists who do treat this type of patient, there is strong evidence about the benefit of the intervention.

Wilk: That's why the study is valuable. But if a physician sees a patient with a torn ACL—for example, a high school or college athlete, recreational or scholastic—and the patient wants to know whether surgery is necessary, I seriously doubt that a physician would say, "I don't know. Go to physical therapy for a series of tests to determine whether you need it."

Irrgang: This also applies to the question, "Can I play out the season?" There may be a reason why the patient needs to play out that season. Maybe it's his or her last season of eligibility. Fitzgerald and colleagues are saying, "Let's give it a little bit of time. Let's see whether the patient qualifies for the nonoperative program, and then, if the patient can successfully complete the program, let's see what happens."

Wilk: After a patient tears the ACL, the physical therapist might take 2 or 3 weeks to reduce the swelling and restore some range of motion. Next, the therapist might do the screening test, which may take a day or two. Then, the patient may undergo rehabilitation—according to this study, three times per week for 5 weeks. This brings us to 7 or 8 weeks postinjury. Given this scenario, the patient may ask, "Why don't I just have the surgery first? It would be 8 weeks before I could go back to play anyway." In most sports, the season essentially would be over by then. That's where the treatment dilemma lies. Most athletes, and maybe even the general population, do not want to spend the time in nonoperative treatment if they're only going to need surgery anyway. As we've already noted, that's the mindset of many surgeons today.

Rothstein: How long it would take to get an avid skier—not a professional skier—back to skiing post-ACL reconstruction?

Wilk: Scholastic and professional athletes are somewhat more predictable than recreational athletes. We can't be sure about the recreational athlete's level of motivation or conditioning, both of which factor into how long the rehabilitation is going to take. Skiing is one of the sports for which it takes longer, just because of the nature of the sport and the type of person the skier tends to be. The ultimate answer is that these patients return to skiing when they're ready—but I would estimate at least 5 or 6 months.

Rothstein: What about for simpler activities, such as pick-up football?

Wilk: Again, I would always add the caveat, "Patients return when they're ready." But I would estimate 4 or 5 months.

Rothstein: That's a little less than twice as long as the protocol used in this study.

Irrgang: At my facility, the approach is not as aggressive as the one used in this study. Our time frame is probably closer to 6 months. The athletes *start* returning at 4 or 5 months, but full participation takes at least 6 months.

DeCarlo: As a general rule, I find that recreational skiers won't be able to return to the slopes until the following winter. But as I think about recreational and professional athletes in other sports and about our clinical experience during the past 3 or 4 years—using the patellar tendon graft from the opposite knee for primary ACL reconstruction—I can say that football players who are injured in the preseason are playing that same season, and basketball players begin their agility training within 6 weeks postsurgery. We're aggressive even with the recreational athlete who may not have a defined season, because within 6 weeks or so of the operation, they are doing the agility program, and within 3 months or so they are reasonably competitive.

What's "Standard"?

Rothstein: Here's a question that relates not only to this study but to any situation when we want to compare interventions. The authors say that they used a "standard program" for comparison. In conducting research, I've found it difficult to determine what a "standard program" is, and I usually have to depend on colleagues for an expert opinion. Is the program described in this study a "standard program"?

DeCarlo: The authors addressed such issues as motion, swelling, and gait early in the article. As far as the training program, however, they didn't give a tremendous amount of detail, probably because it would have been too lengthy. There could be a lot of discussion regarding quadriceps femoris muscle and hamstring strengthening. Did they use open and closed chain exercise or isolated functional strengthening? As a general rule, strengthening of the lower extremity, endurance training, agility training, and sports-specific work would constitute a "standard program." In terms of the specifics of the exercises, however, there could be quite a bit of variation. The electrical stimulation protocol used in this article was described in the literature by Snyder-Mackler,[18] but there is no expert consensus on that protocol as part of the standard program.

Rothstein: Is it even practical to consider electrical stimulation as part of the standard program?

DeCarlo: Under managed care, and with restrictions on patient access to physical therapy, that's a very real question. My patients live 60 miles away on average. It wouldn't be realistic to expect them to visit the clinic three times a week for electrical stimulation.

Irrgang: If a patient starts functioning well with activities of daily living, the physical therapist would have a hard time justifying this higher level of intervention to payers.

Wilk: "Standard program" means different things to different people. And sometimes what we write for publication is different from what we do in the clinic. Since 1995, at my facility, we have made a conscious effort with all patients who have ACL injuries—both reconstructed and unreconstructed—to work on proprioception, neuromuscular training, perturbation training, and improvement of limb confidence. Anecdotally, I've noticed tremendous improvements at a faster rate. So, although our standardized program would include all of the things described in this article—strength, cardiovascular, agility, and sports-specific training—in between the lines we are using a great deal of neuromuscular and motor control training. In my opinion, that's the key with all patients with ACL injuries, whether they have surgery or not.

Rothstein: Is "standard" different for your facility from what's reported in this paper?

Wilk: I'm not sure. When the authors talk about "agility skill training," for instance, they do not include details, probably because the description would be too cumbersome. But I would speculate that it included some proprioceptive training. In my facility, our program consists of approximately 50% or 60% strength and cardiovascular training and 40% or 50% proprioceptive training. That's how important proprioceptive training has become to our "standard program."

Rothstein: It could be argued that using the limbs inherently involves proprioception. What does "proprioceptive training" mean to you?[1]

Wilk: One day post-ACL reconstruction, we may ask patients to do weight bearing activities such as putting equal weight on both legs, using a force platform to determine weight distribution. When they do closed chain squats, we may have them look at a screen so that they maintain equal weight on both sides. I believe that this is a proprioceptive activity, because it involves awareness of how much weight the leg is bearing and the location of the knee joint in space. Within 7 days, patients begin standing on foam half circles, doing lunges and weight bearing, and then move on to the Biodex Balance System,† doing squats on an uneven or unsteady surface, finally working toward the tilt board. This is the "standard program" for our clinic. Every patient receives it.

Irrgang: In this study, however, the control group did not use tilt boards.

Rothstein: By virtue of these particular patients and their need to get back to sports within a brief period of time, the study represents a "special niche." Our discus-

† Biodex Medical Systems Inc, Brookhaven R&D Plaza, 20 Ramsey Rd, Box 702, Shirley, NY, 11967-0702.

sion now suggests that there may another niche—the niche of having enough time! Not only must there be enough visits but enough *time per visit* for electrical stimulation, which can be very time consuming.

Wilk: The perturbation training also is time consuming—and labor intensive. First, the therapist has to train patients in this type of activity to reduce the risk of injury. Even if patients are just balancing on a platform while throwing a ball into a bounce-back system, they should be supervised to ensure their safety. In perturbation training, the therapist creates a stimulus by tapping the platform, which means that the therapist must observe the patient while creating the perturbation stimulus.

DeCarlo: At my facility, about 40% of our caseload is covered by managed care plans, but we still are different from the norm because patients can come in whenever they need to. Many travel a great distance. But that's not just a time issue. It's a resource issue. Particularly for high school students, considerable family resources are involved; for instance, parents may have to take time off work to bring their kids to therapy.

Rothstein: Exercises are modified in this study on the basis of complaints of pain and swelling. Are these the general guidelines that your clinics use?

Irrgang: In addition to pain and swelling, I look at the quality and correctness of movement. I evaluate patient performance qualitatively.

DeCarlo: From a therapist's standpoint, it is important to know whether there is pain and swelling, because these symptoms relate to meniscal trauma and articular surface damage. In my experience, figure eight running and agility training are easier for patients to resume than traditional running activities. The sports-specific and agility programs are more challenging, so I focus on those.

Wilk: In modifying the exercises, I ask the patient, "How did your knee *feel*? Did you have any episodes in which you felt like your knee was going to give way? Did you feel any instability or shifting in the knee?"

Multiple Outcome Measures: Which Ones Determine Success?

Rothstein: Fitzgerald and colleagues gave operational definitions of "unsuccessful rehabilitation," and the first one is "knee giving way." Do you consider this to be a reasonable outcome? What about arthrometer scores? Why would they change when nothing is being done to the ligament?

DeCarlo: In the long term, the arthrometer score certainly could change, but not in the short term. . . . "Giving way" is important in determining outcomes. In this study, if the patient's knee gave way at any time during rehab or return to activity, the patient was excluded from further nonoperative treatment. Every time the knee gives way, the patient risks further intra-articular damage that could become a long-term problem,[19–21] such as arthritic changes—which is why I disagree with recommending nonoperative treatment to the high-level athlete. I believe that therapists can return athletes to activity within a reasonable time frame, even within a season, following a well-performed ACL reconstruction, and that the surgery decreases the potential for greater intra-articular problems.

Wilk: Again, another big factor is whether the athlete is satisfied with the level at which he or she is able to compete. Is the athlete functioning near the preinjury level? If the knee is stable but the athlete still isn't competing at the desired level because of lack of confidence in the limb or because of some other performance problem that has compromised strength, I view that as a failure. "Knee giving way" and arthrometer scores shouldn't be the only criteria. Some people in this study did fail, both with the standardized treatment and with the perturbation training. Of those individuals who failed, I want to know which ones were participating in sports—and what type and level of sports. Was there a correlation between a certain sport or level of participation and ultimate failure?

Rothstein: When we have so many measures, as in this study, how do we decide when we've succeeded and when we've failed?

Irrgang: "Knee giving way" is a good definition of poor outcome, at least for the purposes of this study. Wilk added the outcome of whether patients are feeling apprehensive or having other symptoms, pain, and swelling with an attempt to return to activity. These measures could be put into some type of a cluster. If patients have two out of the three, for instance, that could be the criterion for failure.

Rothstein: Is there a hierarchy of outcomes criteria?

Wilk: Giving way and the performance would have to be close to the top and would have to go hand in hand.

Rothstein: But aren't there measures that would be "nice to know" versus indicative of success or failure?

DeCarlo: If strength isn't good, for instance, none of the other variables is going to be good either.

Rothstein: There are no data to support that supposition, however.

Wilk: One of my patients, a National Football League lineman with an ACL reconstruction, has a 43% deficit compared with the opposite leg. He's been practicing, and he knows he can play; he's just waiting for *clearance* to play. He has a big strength deficit, but functionally he has no giving way. His knee is stable, his quadriceps femoris circumference measurements have decreased, he has no effusion, and he's been running and doing one-on-one drills for 4 weeks.

Rothstein: What, then, is the relationship between impairment—in this case, weakness—and disability?

DeCarlo: If strength isn't at a certain level, patients generally are more predisposed to knee ache and to increased swelling in the joint. As a result, they may not be able to perform effectively. So, those variables are somewhat interrelated.

Irrgang: They are interrelated, but I don't know how *strong* those relationships are. Performance is what ultimately determines success or failure. If athletes are not performing up to *their* expectations—if they're having instability or other symptoms—I'd define that as failure, as opposed to inadequate quadriceps femoris muscle strength or a poor arthrometer test score. Again, we should look at how patients are doing from a functional point of view.

Wilk: Using giving way as the criterion for success or as the ultimate outcome doesn't tell you the patient's status in terms of activity level. A patient might not have an episode of giving way, and she might have returned to skiing; but perhaps she can handle only the "bunny hill" or is able to ski only once every 2 weeks as opposed to twice per week. In the case of a football player, perhaps he's playing, but only for a few minutes per game. In other words, the athletes may still be participating at the same sport, but not at the same level or frequency.

Rothstein: When patients take preemptive action to decrease their risk for reinjury, it's harder for the physical therapist to do an evaluation. But that's their right. They're the ones who feel the pain. So, when some patients have fewer problems than others, maybe it's because they're doing less. That's why a thorough history and discussion are critical. When a patient says, "I'm 100% successful at everything I did this week," you may find out that all he did was go to the store twice. We need more descriptive information from the patient interview; otherwise, the context in which we make our clinical judgments is weak.

Irrgang: Again, for me the big question is whether the patient is participating at the preinjury level. If not, the outcome may not be adequate.

Wilk: In judging these two groups—the standard treatment group and the perturbation training group—I see some disparity. The standard group seemed to have a higher level of sport participation than the perturbation group did. The standard group included one person who played lacrosse, which is a high-level activity; one who played soccer; one who played field hockey; six who played collegiate basketball; and one who played high school basketball. The perturbation group included one field hockey player and one volleyball player—no basketball players. That has implications. Basketball is probably one of the toughest sports because of the jumping, the frequency of cutting and pivoting, and the coefficient of friction between the gym floor and the sneakers. At what level and how often are these subjects playing? Are the six basketball players in the standard group recreational or scholastic athletes? Are they playing once per week or 7 days per week? Noyes[22] proposed grading functional activities—at level one, level two, or level three—based not only on the type of sport, but on the frequency of the sport. If patients are returning to basketball at a college level, which involves playing 7 days per week, they're going to have different needs from those of patients who play recreational basketball once or twice per week.

Patient Motivation

Rothstein: All of you have made it clear that you don't believe you succeed with this type of patient unless you meet the patient's unique needs. This philosophy isn't necessarily limited to patients who play sports. But should a therapist be held responsible because a patient with a low back problem doesn't go back to work—especially when the patient didn't like his job to begin with?

Irrgang: Sports patients are very motivated to get back to what they were doing. We don't usually have the psychological or other variables that may affect the outcome in other types of patients.

DeCarlo: The principle that drives sports physical therapists, both from a clinical standpoint and a research standpoint, is getting these individuals back to their previous level of activity.

Rothstein: Given those expectations, are you surprised by the results of this study?

Wilk: I was surprised, but I was also delighted. I firmly believe in neuromuscular training, and the results of this study help support what I do clinically.

Rothstein: What about the fact that the groups may not be quite equal in terms of sport and participation level?

Wilk: Even the standard group had a 50% success rate, according to the criteria. Compare that with the results of most other studies. According to the literature review conducted by the authors, the success rate ranges between 23% and 39%. We'd probably all agree that about 20% of our patients cope or adapt to their ACL deficiency. In that context, a 50% success rate using conventional treatment without perturbation training seems very high. And the perturbation group had a 92% success rate at the 6-month mark. These results are amazing. They are almost triple the rates reported in previous studies.

Rothstein: Would the difference in the sample account for that?

Irrgang: The way they selected patients for this program might account for some of the success. The selection method has to be taken into account when generalizing results to practice.

Is It Evidence for *Your* Patients?

Rothstein: We might like a study's results because they reinforce our opinion or because we like the way the study was done, but if our own patients don't meet the eligibility criteria that the study uses for its subjects, we are not treating the same type of patients. In the case of this article, the results do not necessarily constitute evidence for what a given therapist is doing. They may provide inspiration, but not evidence. What about this study best indicates that the subjects were special?

Wilk: The fact that the authors were able to conduct the hop test with patients who were only 3 or 4 weeks postinjury is surprising. I assume that the patients had no meniscal pathology or significant bone bruises. Even with magnetic resonance imaging, however, meniscal lesions are not always obvious. At 3 weeks, most patients with ACL deficiency may have normal gait, but they may still feel uncomfortable about their knee and feel apprehensive about quick movements. They may have joint line pain because of the bone bruise or capsular inflammation.

DeCarlo: With bone bruising, and given that the swelling has only recently been reduced, the gait has only recently been normalized, and the leg control has only recently been improved, I would be very apprehensive about having the patient do a single hop, let alone the other hop tests that were described.

Rothstein: The authors don't report patients having any problems with these tests. That seems miraculous.

Irrgang: They may have had neuromuscular control or, at least, the propensity toward it before they even started rehabilitation.

Wilk: The subjects weren't consecutive patients. Perhaps Dr Axe [orthopedic surgeon and co-author] unconsciously "preselected" for patients who had less inflammation and a truly isolated injury and who didn't have a big bone bruise. Such patients would naturally do better than others might. . . . For readers who treat ACL injuries only occasionally, and even for readers who treat many ACL injuries, this study makes the case that they should consider proprioceptive, neuromuscular, perturbation-type training in all phases of the rehabilitation. And perhaps not just for patients with ACL injuries, but for all patients. This study supports the idea that dynamic stabilization is important to the knee—and probably to all joints in the body.

DeCarlo: As with all research investigations, this study raised some questions. This particular approach using perturbation training was geared toward a short-term option for specific patients. It would be interesting to continue this study to determine the long-term success of these particular patients who have chosen a nonoperative approach. These individuals were able to return to their sport. But for a patient with an ACL-deficient knee who is wearing a custom-made brace, *what is the level of activity?*

Irrgang: The authors did a good job of identifying a problem and designing and testing an intervention. It does provide some evidence for the perturbation training. It would be interesting apply these same types of techniques in a randomized way to support their use for other conditions, including post-op. We may believe that these techniques work, but a randomized trial would provide a higher level of evidence then just our opinions. The authors provide a first step—and a framework that other researchers can apply to studying other conditions.

Rothstein: This study describes an intervention that should be in the physical therapist's repertoire, to be used not with all patients but with the *appropriate* patient. Appropriateness is based not only on the screening, the ACL status, and the functional status, but on what the patient needs to be able to do in the short term and the long term. You three are experts who at times may be the last resort for people with ACL injuries, so you don't necessarily see patients like those in this study; but then again, we don't know who *does*, because we as a profession don't yet have enough data about our patterns of practice. In our rush to have outcomes data, we may not think about these unique differences between patients and individual physical therapy practices. But if we don't factor in these differences, the information we collect will not give us the answers that we need and that insurers demand.

References

1 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;65:163–173.

2 Daniel DM, Stone ML, Dobson BE, et al. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med.* 1994;22:632–644.

3 Barber-Westin SD, Noyes FR, McCloskey JW. Rigorous statistical reliability, validity, and responsiveness testing of the Cincinnati Knee Rating System in 350 subjects with uninjured, injured, or anterior cruciate ligament-reconstructed knees. *Am J Sports Med.* 1999;27:402–416.

4 Corrigan JP, Cashman WF, Brady MP. Proprioception in the cruciate deficient knee. *J Bone Joint Surg Br.* 1992;74:247–250.

5 Branch TP, Hunter R, Donath M. Dynamic EMG analysis of anterior cruciate-deficient legs with and without bracing during cutting. *Am J Sports Med.* 1989;17:35–41.

6 Kalund S, Sinkjaer T, Arendt-Nielson L, et al. Altered timing of hamstring muscle action in anterior cruciate ligament deficient patients. *Am J Sports Med.* 1985;13:34–39.

7 Walla DJ, Albright JP, McAuley E, et al. Hamstring control and the unstable anterior cruciate ligament-deficient knee. *Am J Sports Med.* 1985;13:34–391.

8 Rudolph KS, Eastlack ME, Axe MJ, Snyder-Mackler L. 1998 Basmajian Student Award Paper: Movement patterns after anterior cruciate ligament injury: a comparison of patients who compensate well for the injury and those who require operative stabilization. *J Electromyogr Kinesiol.* 1998;8:349–362.

9 Ciccotti M, Kerlan R, Perry J, et al. An electromyographic analysis of the knee during functional activities, II: the anterior cruciate-deficient and -reconstructed profiles. *Am J Sports Med.* 1994;22:651–658.

10 Sinkjaer T, Arendt-Nielsen L. Knee stability and muscle coordination in patients with ACL injuries: an EMG approach. *J Electromyogr Kinesiol.* 1991;1:209–217.

11 Moul JL. Differences in selected predictors of anterior cruciate ligament tears between male and female NCAA Division I collegiate basketball players. *Journal of Athletic Training.* 1998;33:118–121.

12 Smith J, Szczerba JE, Arnold BL, et al. Role of hyperpronation as a possible risk factor for anterior cruciate ligament injuries. *Journal of Athletic Training.* 1997;32:25–28.

13 Loudon JK, Jenkins W, Loudon KL. The relationship between static posture and ACL injury in female athletes. *J Orthop Sports Phys Ther.* 1996;24:91–97.

14 Woodford-Rogers B, Cyphert L, Denegar CR. Risk factors for anterior cruciate ligament injury in high school and college athletes. *Journal of Atheletic Training.* 1994;29:343–346, 376–377.

15 Beckett ME, Massie DL, Bowers KD, Stoll DA. Incidence of hyperpronation in the ACL injured knee: a clinical perspective. *Journal of Athletic Training.* 1992;27:58–62.

16 Berchuck M, Andriacchi TP, Bach BR, Reider B. Gait adaptations by patients who have a deficient anterior cruciate ligament. *J Bone Joint Surg Am.* 1990;72:871–877.

17 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.

18 Snyder-Mackler L, Delitto A, Bailey SL, Stralka WS. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament: a prospective, randomized clinical trial of electrical stimulation. *J Bone Joint Surg Am.* 1995;77:1166–1173.

19 Pattee GA, Fox JM, Del Pizzo W, Friedman MJ. Four- to ten-year follow-up of unreconstructed anterior cruciate ligament tears. *Am J Sports Med.* 1989;17:430–435.

20 Noyes FR, Mooar P, Matthews DS, Butler DL. The symptomatic anterior cruciate-deficient knee, part I: the long-term functional disability in athletically active individuals. *J Bone Joint Surg Am.* 1983;65:154–162.

21 Hawkins RJ, Misamore GW, Merritt TR. Follow-up of the acute nonoperated isolated anterior cruciate ligament tear. *Am J Sports Med.* 1986;14:205–210.

22 Noyes FR, Barber SD, Mooar LA. A rationale for assessing sports activity levels and limitations in knee disorders. *Clin Orthop.* 1989;246:238–249.

Author Comment

We appreciate the opportunity to respond to and clarify some of the issues raised during this provocative discussion of our article. The program we described is designed to help clinicians both identify and manage athletes with an anterior cruciate ligament (ACL) injury who may have the ability to return, at least temporarily, to premorbid levels of physical activity after nonoperative treatment. We view our treatment approach not as an alternative to ACL reconstruction but as a method for improving the risk/benefit ratio for nonoperative management in special circumstances—that is, when patients want to delay surgery and play out the remainder of the season.

Mr Wilk questioned whether the randomization failed with respect to the level of physical activity to which our subjects returned after rehabilitation. He also questioned whether the screening and rehabilitation are timely enough for an athlete to return for a competitive season. At the time subjects returned to full sports participation, mean scores in both groups for the global rating of knee function (Fig. 6) and the Sports Activity Scale (Fig. 7) were greater than 90%. As indicated in Table 2, 5 subjects in the standard group and 7 subjects in the perturbation training group returned to competition at the collegiate, high school, semiprofessional, or senior Olympic levels. Nine subjects in the standard group and 5 subjects in the perturbation group returned to recreational athletics. In addition, one of the collegiate football players (defensive end) in the perturbation group made second team All-Conference Team, even though he missed the first half of the season. The second football player (kick-off return specialist and running back) in the perturbation group not only completed the season, but opted not to have surgery and completed the entire football season the following year without an incident of injury. The high school field hockey player in the standard group made the All-Conference Team in her season following rehabilitation, and the recreational tennis player in the perturbation group placed second in a regional singles tennis tournament within the 6-month period following rehabilitation. We are confident that the distribution in activity levels between groups was similar and that our program allowed subjects in both groups to return to premorbid levels of physical activity.

Mr Wilk suggested that subjects in this study were not consecutive patients and may have been unconsciously "pre-selected" by Dr Axe for participation in the study. In fact, Dr Axe referred, and continues to refer, *all* patients with a new ACL injury who meet the screening criteria (regular participants in level I and II sports, no concurrent grade II or III multiple ligament injury, no meniscal damage requiring surgical repair, and no evidence of chondral defects larger than 1 cm associated with the ACL injury).[1] We examined more than 90 patients with our screening examination to obtain the 28 subjects who met the inclusion criteria in the study. Patients who were screened and who did not meet the criteria for participating in the study ultimately went on to have ACL reconstructive surgery.

Dr Rothstein contended that our study may provide inspiration but not evidence for all patients with ACL injuries because subjects in our study were not necessarily representative of the typical patient with an ACL injury who is examined and treated by most physical therapists. The subjects in our study—whom we classified as rehabilitation candidates after passing the screening examination and who ultimately attempted nonoperative management of their injuries—are indistinguishable, we believe, from the typical patient with an acute ACL injury in most ways. They are young, active, and anxious to get back to full activity. They are part of the 60% who do not have concomitant significant pathology, those whom therapists and surgeons are most likely to allow to "try" to play out the season.[2,3]

The results of our randomized clinical trial provide ample evidence that a subgroup of patients with ACL injuries benefited from the intervention program; however, evidence exists to suggest that the overall approach we used is applicable to all patients with ACL injuries. We are now in the midst of the fourth year of performing preoperative screening examinations on patients with an acute ACL injury. Data from the first 2 years of this demographic study,[1] in which *all* patients in a population were accounted for, demonstrated that the patients who pass the screening examination comprise more than 20% (39/181) of the population of those with acute ACL injuries, including those with concomitant serious pathology, and more than 40% (39/94) of those with "isolated" ACL injuries. In our opinion, this percentage is hardly insignificant. The Conference discussants expressed an opinion that our subjects belong to a population of individuals who would not be typically examined or treated by physical therapists; we believe that the demographic data do not support that opinion.

The comments that few patients need this approach because most have surgery right away are culturally biased. Although this scenario may be true in the United States, Europe, and Canada, patients elsewhere often wait a year or more for elective surgery such as ACL reconstruction. The patient classification process used alone and the patient classification used in combination with the treatment procedures described in our Journal article better the odds over the historical success rate, as pointed out both in the paper and by Mr Wilk and Dr Irrgang. The screening and treatment procedures can be performed by physical therapists in virtually any clinical setting. We are happy that our results may be inspiring. The results of our randomized clinical trial also provide evidence that matching appropriate patients with the intervention program outlined in this study improves the likelihood that a significant subgroup of individuals with an ACL injury can safely return to high-level sports for the season without surgery.

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References

1 Fitzgerald GK, Axe, MJ, Snyder-Mackler L. A decision-making scheme for returning patients to high-level activity with non-operative treatment after anterior cruciate ligament rupture. *Knee Surgery, Sports Traumatology, Arthroscopy*. In press.

2 Daniel DM, Stone ML, Dobson BE, et al. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med*. 1994;22:632–644.

3 Shelton WR, Barrett GR, Dukes A. Early season anterior cruciate ligament tears: a treatment dilemma. *Am J Sports Med*. 1997;25:656–658.