

# Comparison of Home Versus Physical Therapy–Supervised Rehabilitation Programs After Anterior Cruciate Ligament Reconstruction

## A Randomized Clinical Trial

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**Background:** Because of health care funding and policy changes, there is a need to examine the effects of an evolution toward patient-directed (ie, home-based) rehabilitation programs on clinical outcomes of patients undergoing anterior cruciate ligament reconstruction.

**Hypothesis:** There will be no difference in the effectiveness of a home-based rehabilitation program and a standard physical therapy–supervised rehabilitation program in patients 3 months after nonacute anterior cruciate ligament reconstruction with bone–patellar tendon–bone grafts.

**Study Design:** Randomized controlled clinical trial; Level of evidence, 1.

**Methods:** There were 145 patients (16–59 years) who attended a presurgery education class. Home-based patients attended 4 physical therapy sessions, and physical therapy–supervised patients attended 17 physical therapy sessions over the first 12 weeks after surgery. All patients followed the same standardized rehabilitation program. Study outcome measures included active-assisted knee flexion and passive knee extension range of motion, knee range of motion during walking, KT computerized arthrometer results, and isokinetic quadriceps and hamstrings strength. Patient outcomes were dichotomized as either clinically acceptable or unacceptable. Rehabilitation programs were compared by the proportion of acceptable patients in each group.

**Results:** The home-based group had a significantly higher percentage of patients with acceptable flexion and extension range of motion compared to the standard physical therapy group (flexion, 67% vs 47%; extension, 97% vs 83%). There were no significant differences between the groups in range of motion during walking, ligament laxity, and strength.

**Conclusion:** A structured, minimally supervised rehabilitation program was more effective in achieving acceptable knee range of motion in the first 3 months after anterior cruciate ligament reconstruction than a standard physical therapy–based program.

**Clinical Relevance:** Recreational athletes undergoing nonacute anterior cruciate ligament reconstruction can successfully reach acceptable rehabilitation goals in the first 3 months after surgery with a limited number of purposeful physical therapy education sessions, allowing recreational athletes more flexibility when integrating the necessary postoperative rehabilitation into their daily activities.

**Keywords:** anterior cruciate ligament (ACL); rehabilitation; cost effectiveness

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Early weightbearing, knee joint motion, low-level graft stress, and progressive strengthening have proven effective as components of a post-ACL reconstruction rehabilitation program.<sup>16,28,30,37</sup> These activities reduced the incidence of complications such as arthrofibrosis, patellar infera, chronic edema, and chronic strength deficit.<sup>28,30,37</sup> Patients need to be educated about how to optimally rehabilitate their knees and require periodic follow-up to ensure that complications do not arise. It is unknown how much or, perhaps more important from a cost-effectiveness viewpoint, how little direct supervision is required for the patient to attain successful outcomes.

The ability of patients to rehabilitate successfully with limited supervision after a musculoskeletal injury or surgery is multifactorial. These factors include the patient's motivation to return to preinjury activity levels, the amount of pre-injury/surgery and post-injury/surgery education that the patient receives, and the patient's past experience with exercising independently.<sup>17,26,31,36,38,39</sup> Patients undergoing ACL reconstruction tend to be young, are at least recreationally active, and are accustomed to exercising either independently or in a group setting (eg, team sports).<sup>2,9,31,44</sup> These characteristics are conducive to allowing patients with ACL reconstructions to rehabilitate successfully with a limited number of purposeful physical therapy sessions.

Two retrospective studies<sup>9,44</sup> and 2 randomized clinical trials (RCTs)<sup>14,33</sup> have compared various formats of limited versus traditionally supervised rehabilitation programs after ACL reconstruction. Although both retrospective studies demonstrated successful outcomes with 4 to 12 physical therapy sessions in the first 3 postoperative months, it is unknown how public versus private insurance coverage<sup>44</sup> and uncontrolled physical therapy prescription patterns<sup>9</sup> may have influenced those results.

In the RCTs by Schenck et al<sup>33</sup> and Fischer et al,<sup>14</sup> patients were randomized to either a limited supervision group (home based) or a standard program of supervised physical therapy. Fischer et al prescribed 6 treatment sessions to the home-based group (mean attendance was 5 sessions), whereas the physical therapy-supervised group was prescribed 24 (mean attendance was 19.9 sessions).<sup>14</sup> Alternatively, Schenck et al allowed the physical therapist to decide the number of limited sessions required by the home-based group (mean, 3). The physical therapy-supervised group attended a mean of 14 sessions, although it is unknown how that number was controlled.<sup>33</sup> In both studies, preoperative education was an integral part of the program for both groups. Neither study demonstrated any significant differences between the 2 rehabilitation programs over a wide range of outcome measures (range of motion [ROM], KT arthrometer results, hop tests, Lysholm scale, and thigh atrophy). Isokinetic strength was not evaluated. No statistical power calculation was included, and with no quantitative outcome data to evaluate, the likelihood of type II error could not be determined for those studies. The small sample sizes of  $N = 54$ <sup>14</sup> and  $N = 37$ <sup>33</sup> also contributed to the likelihood of type II error. These RCTs suggested that patients with ACL reconstructions were capable of successfully rehabilitating with a limited number of supervised physical therapy sessions. A larger study with

TABLE 1  
Study Inclusion and Exclusion Criteria

Inclusion:

- (1) 16 years of age or older
- (2) Surgery at least 6 weeks after injury to allow for a return of full range of motion, minimize swelling, and offset strength deficits due to pain/swelling<sup>14,28</sup>
- (3) ACL reconstruction with a bone-patellar tendon-bone autograft

Exclusion:

- (1) Previous or concomitant reconstruction of any knee ligament to either knee
- (2) Ongoing knee abnormality unrelated to the ACL injury (eg, evidence of changes on radiographs consistent with osteoarthritis)
- (3) Professional athletes or workers' compensation patients
- (4) Complications during surgery (eg, inadequate graft fixation requiring protocol modification)
- (5) Patients without access to local physical therapy services

sufficient power, therefore, was required to confirm or refute their findings.

A number of authors have recommended how successful rehabilitation could be accomplished with limited supervision. These recommendations included the need for quality preoperative education, detailed and concise exercise instruction booklets for the patients to take home, and the need for the attending surgeon and physical therapist to assess the appropriateness of each patient for a program of limited supervision (ie, assess patient motivation and compliance).<sup>1,9,14,21,33</sup> Less-supervised programs also shifted the responsibility for the rehabilitation to patients to attain their own goals, thereby empowering them to be successful. Given those recommendations, the purpose of this study was to determine if there were significant differences in patient outcome between a home-based rehabilitation program and a traditional physical therapy-supervised rehabilitation program in patients 3 months after ACL reconstruction.

## METHODS

The study was a 2-arm, single-blind RCT. Patients with ACL deficiency, who were referred to 1 of the 4 knee surgeons at a university-based sport medicine center, were consecutively recruited. The inclusion and exclusion criteria are listed in Table 1. Patients living in a region where physical therapy services were not readily available were excluded because the distance to physical therapy may have adversely affected attendance if they had been randomized to the physical therapy-supervised group.

Once enrolled, a stratified and blocked randomization procedure (opaque envelope draw) was used to ensure that no large differences existed in group size. Patients were stratified by surgeon to ensure that differences between surgeons did not influence the results. The group assignment was revealed to the patients after leaving the preoperative education session.

All patients attended a preoperative education session and baseline assessment within the 2 weeks before their ACL reconstruction surgeries. The baseline assessment included the outcome measures described below and a validated disease-specific quality-of-life questionnaire (ACL-QOL).<sup>27</sup> Patients were provided with specific handouts to take home. The handouts contained all of the information covered in the education session and allowed the patients to have continuous access to reference information throughout the study period. The rehabilitation program used in this study was developed based on an amalgamation of examples from the scientific literature<sup>2,9,33,37,39,44,45</sup> and from orthopaedic surgeons from across Canada. The protocol was reviewed by the physical therapists at the university-based sport medicine center and by the orthopaedic surgeons providing patients for the study. This program consisted of 4 phases requiring activity at home, ranging from at least 5 times per day in phase 1 to 4 to 7 times per week in phase 4. This home activity was in addition to any physical therapy sessions the patients in both groups attended. The protocol was combined with background information on cause of injury, knee anatomy, and the ACL reconstruction surgical procedure in a patient education booklet. Each of the 4 phases of the rehabilitation program was described. Each phase included sections for rehabilitation goals, knee immobilizer use, weightbearing, cryotherapy, stretching, strengthening, endurance activities, and proprioception. Instructions on how to perform the exercises, the number of sets and repetitions to perform, exercise progression criteria, and exercise precautions were included. All new activities/exercises were accompanied by a picture. The rehabilitation program was designed for home-based rehabilitation without an extensive equipment requirement. For those patients, in either group, with access to exercise equipment in the physical therapy department, at home, or at a fitness center, additional exercises were included at the end of each phase. Patients were instructed to only include these exercises on the advisement and instruction of their physical therapist.

All patients, regardless of grouping, followed the same rehabilitation protocol for the first week after surgery (phase 1). All patients commenced physical therapy 1 week after surgery.<sup>10</sup> It was the patients' responsibility to book their physical therapy sessions. Patients were to be seen by their surgeons at 1 to 2 weeks after surgery, at 6 to 7 weeks after surgery, and at 12 weeks after surgery according to the current local standard of care.

All patients randomized to the home-based rehabilitation (HB) group met with the same physical therapist at the sport medicine center at the initial scheduled visit 1 week after their surgeries. The HB group was considered to be the experimental arm of the study. The physical therapist provided the patients with information about the rehabilitation process and reviewed the patients' progress with the phase 1 exercises. At the end of the session, the exercises for phase 2 (weeks 2 and 3 postoperatively) were introduced. The patients were instructed to demonstrate the exercises independently to the physical therapist to ensure they understood how, and were able, to perform them properly. This process was repeated at each of the

subsequent 3 sessions. Patients were subsequently to be seen at the end of 3, 6, and 12 weeks after surgery for a total of 4 physical therapy sessions within the first 3 postoperative months. Patients were supplied with a Cryo/Cuff (Aircast Inc, Summit, NJ) for cold compression, 3 pieces of elastic tubing with increasing resistance (Physiotoners; Fitter Intl Inc, Calgary, Alberta, Canada), and a 40.6-cm-diameter adjustable-height wobble board (Fitter Intl Inc) for use in their home exercise programs.

Patients randomized to the physical therapy-supervised rehabilitation (PT) group commenced physical therapy 1 week after surgery. This group was the control arm of the trial. Patients were free to see the physical therapist of their choice at the clinic of their choice. Patients attended 2 sessions per week for weeks 2 through 7 and once per week for weeks 8 through 12 after surgery for a total of 17 sessions within the first 3 postoperative months. This attendance was consistent with the mean number of sessions routinely prescribed locally and elsewhere.<sup>14</sup>

The patients in the PT group received a copy of the 12-week rehabilitation protocol, with a cover letter describing the research study, to give to their physical therapists. Although the time lines for each phase of the rehabilitation were given, the progression through the protocol was directed by the physical therapist and was dependent on the patient's ability to meet the progression criteria. An attendance sheet was completed by each physical therapist and was faxed back to the investigators at the end of the 3-month treatment. The control group was designed to receive physical therapy treatment in a setting as close to the real world as possible. Attendance, therefore, was used as a measure of compliance. Patients were supplied with a Cryo/Cuff and 3 Physiotoners. They were not provided with a wobble board because it was standard physical therapy clinic equipment.

All patients were evaluated 3 times: preoperatively for baseline measurements, at 6 weeks postoperatively, and at 12 weeks postoperatively. The same person performed all assessments. The assessor was blinded to group assignment throughout the study. Patients were repeatedly told not to inform the assessor of their group assignment in any way.

\*Standard clinical goniometer measurements were performed to be consistent with previous studies. The estimated error with this technique is 3.1° to 4.0°.<sup>4</sup> Extension ROM was measured with patients positioned prone with the knee joint positioned slightly beyond the end of the plinth. For active-assisted knee flexion, the patient was supine on the plinth. A strap was placed around the ankle in a figure-of-8 fashion, and the patient held one end of the strap in each hand. While keeping the foot on the plinth, the patient pulled on the strap and used his or her hamstrings to flex the knee as far as comfortably possible and held it in that position while the measurement was taken. The knee popliteal angle was measured.

Sagittal plane knee laxity was measured with the computerized KT-2000 arthrometer (MEDmetric Corp, San Diego, Calif), which has a reported intratester intraclass correlation ranging from 0.98 to 1.00 with an SEM ranging from 0.00 to 0.28 mm.<sup>19</sup> Before anterior laxity evalua-

tion, each knee was manually assessed with the posterior sag test and posterior drawer test to ensure no patients had PCL deficiency. The KT-2000 arthrometer was used as directed.<sup>8,18,25,40,43</sup> The side-to-side difference at 135 N was used as the outcome measure because it was the most commonly reported and reliable applied force.<sup>2,14,24,33,41</sup>

Digitized 2-dimensional sagittal plane video was used to measure knee joint angle during walking. Video digitizing has previously been demonstrated to have excellent within-day and between-day reliabilities (coefficient of multiple correlation =  $0.991 \pm 0.005$  for within-day measures and  $0.987 \pm 0.012$  for between-day measures).<sup>22</sup> Video analysis of knee ROM during walking was performed after the other ROM and knee laxity assessments. A digital video camera (Sony Digital Handycam, model DCR-VX1000; Sony Corp, New York, NY) was set 8.8 m perpendicular to the plane of walking. The camera recorded at 30 Hz with a shutter speed of 1.4 milliseconds. Gait trials were performed barefooted to ensure the consistency of foot-floor interface and to ensure that the footwear did not have an effect on the walking pattern. Joint markers were 3 cm in diameter with black and white alternating quadrants. Approximate joint centers were palpated, and the joint markers were placed over the greater trochanter (hip), lateral femoral condyle (knee), and lateral malleolus (ankle).<sup>22</sup> Patients were instructed to walk at a comfortable, self-selected pace and had 3 to 4 practice trials to adjust their start positions to the camera's field of view.<sup>22</sup> Video data were transferred from the digital videotape to a multimedia computer, retaining full digital quality and aspect ratio ( $352 \times 240$  pixels). The video files were edited in Adobe Premiere 5.0 (Adobe Systems Inc, San Jose, Calif). Edited video files were exported at twice the original size ( $704 \times 480$  pixels) to facilitate digitization. Video files were imported into HU-M-AN software (HMA Technology Inc, Toronto, Ontario, Canada) for digitizing. A 3-point lower extremity system was used (hip, knee, ankle) to determine the popliteal knee angle. Optimal smoothing frequency was determined with a random sample of patient data and a second-order, low-pass Butterworth digital filter; 5 Hz was chosen as the smoothing frequency for all data. The mean of 3 trial values for each limb was calculated for both extension and flexion. These values were used as the respective outcome measures.

Isokinetic evaluation of thigh strength<sup>2,10,41</sup> has been shown to have intraclass correlation coefficients of 0.91 (at 150 deg/s) and 0.86 (at 210 deg/s) for extension and 0.86 (at 150 and 210 deg/s) for flexion.<sup>29</sup> After the video recording of the patients' gaits, the patients were taken to the Cybex NORM isokinetic dynamometer (Cybex, Ronkonkoma, NY) for the assessment of quadriceps and hamstrings strength. The Johnson antishear device (Cybex) was used for all assessments.<sup>20</sup> Anatomical zero was set as the patient's maximal extension, and the knee was flexed to 20° and set as the maximal allowable extension. The 20° extension block was set in place to avoid the arc of motion that would be the most stressful to the graft during the 12-week postoperative assessment. Gravity correction was set. The nonsurgical leg was assessed first. After 1 warm-up/accommodation set of 5 repetitions, a sec-

TABLE 2  
Acceptable Values for Each Outcome Measure

Outcome Measure	Acceptable Value at 3 Months Postoperatively
All range of motion measures	Surgical knee within 5° of the non-surgical knee
Sagittal plane knee laxity (KT arthrometer)	≤5 mm of side-to-side difference at 135 N
Peak quadriceps torque	Surgical leg ≥ 50% of the nonsurgical leg
Peak hamstrings torque	Surgical leg ≥ 75% of the nonsurgical leg

ond evaluation set was performed at 180 deg/s.<sup>45</sup> Strength was measured as the peak torque produced in concentric knee extension (quadriceps strength) and concentric knee flexion (hamstrings strength).

The patients completed the computerized version of the ACL-QOL questionnaire<sup>27</sup> (Mohtadi et al, unpublished data, 2001). The ACL-QOL determined if there were any clinically relevant differences in disease-specific quality of life at baseline. Patient quality of life was not expected to plateau by 3 months after surgery. The ACL-QOL scores were used as part of the preoperative assessment to compare the experimental and control groups.

A survey of the orthopaedic surgeons and physical therapists at the university-based sport medicine center determined "acceptable" values for the range of knee flexion and knee extension/hyperextension, computerized KT arthrometer measurements, and quadriceps and hamstrings ratios at 3 months after ACL reconstruction surgery. From these data, acceptable and unacceptable limits for each outcome measure were determined. Knee extension and flexion ROMs were felt to be the most important measures of rehabilitative success in the first 3 postoperative months, as strength and quality of life would expectedly continue to improve after the study end point and, to some extent, are both reliant on acceptable knee ROM. As such, knee flexion and extension ROMs were designated as the study's primary outcome variables. Acceptable results for each of the outcome measures are listed in Table 2.

Patient ROM, ROM during gait, computerized KT arthrometer measurements, and quadriceps and hamstrings ratio results were tabulated in  $2 \times 2$  tables (rehabilitation group  $\times$  acceptable/unacceptable), and 2-tailed Fisher exact tests were used to determine the existence of differences. Significant differences were concluded if  $P < .05$ . There was no adjustment for multiple comparisons because the effectiveness of the treatment was determined only by the primary outcome variables. Intercooled Stata V6.0 software (Stata Corp, College Station, Tex) was used for all statistical calculations.

A separate intention-to-treat analysis was performed for all of the clinical outcomes to ensure that losses to follow-up in either study group did not lead to biased results. Patients who declined participation postrandomization

were treated as worst-case outcomes (ie, unacceptable for all outcomes). Patients who did not decline participation but failed to attend any of the follow-up assessments (6 and 12 weeks) were also treated as worst-case outcomes. Patients who attended the 6-week assessment but did not return for the 12-week assessment were treated as last data carried forward.

The sample size for this trial was calculated based on the expected number of patients within each group (frequency) to achieve a satisfactory knee ROM at the 3-month follow-up period. Data from a comparable study suggested that approximately 95% of clinic-based patients should achieve an acceptable ROM at 3 months after surgery.<sup>33</sup> It has been estimated that a 20% difference in the number of patients attaining an acceptable ROM would be clinically important. Fifty-nine subjects per group were required to have a power of 80% and an  $\alpha$  of .05. To account for an estimated 15% drop-out rate, the study required 70 patients per group. Thus, the current study more than doubled the sample sizes of previous studies in the area.

The study received approval from the university Conjoint Health Research Ethics Board, and all patients read and signed an informed consent form.

## RESULTS

There were 152 patients enrolled in the study. Of these patients, 7 were excluded postrandomization for the following reasons: (1) no reconstruction was performed after examination under anesthesia ( $n = 2$ ), (2) the patient underwent reconstruction with a semitendinosus graft ( $n = 3$ ), (3) the patient disclosed that he was bilaterally ACL deficient ( $n = 1$ ), and (4) the patient required concurrent repair of the Humphry ligament with repair of an avulsed lateral meniscus ( $n = 1$ ).

These postrandomization exclusions left 145 patients (85 male and 60 female patients) enrolled in the study. The 145 patients were randomized to either the HB group ( $n = 73$ ) or the PT group ( $n = 72$ ). There were no clinically relevant differences demonstrated at baseline between the 2 groups (Table 3).

Three patients declined to participate in the study postrandomization. All of those patients were randomized to the HB group. Two of those patients declined based on the recommendation of a family/personal friend who was a physical therapist. That friend recommended that the patients would not likely achieve optimal rehabilitation if they saw a physical therapist only 4 times in the first 3 postoperative months. The third patient was a high-level snowboard athlete who had aspirations of making national team standards but did not meet the study exclusion criteria. In light of her desire to reach the elite level, she decided to decline and attend physical therapy on a more regular basis.

The HB group averaged  $3 \pm 1$  physical therapy sessions (range, 0-8 sessions). One person did not attend any postoperative physical therapy, whereas 5 patients attended more than the prescribed 4 sessions (3 patients had 5, 1 patient had 6, and 1 patient had 8 sessions). The majority

TABLE 3  
Group Comparisons of Variables  
Before Surgery (Baseline)

Variable	Home	Physical Therapy
Age, y ( $\pm$ SD)	29.1 $\pm$ 9.2	29.5 $\pm$ 10.2
Height, cm ( $\pm$ SD)	173.8 $\pm$ 8.3	170.3 $\pm$ 8.1
Mass, kg ( $\pm$ SD)	82.1 $\pm$ 14.4	77.6 $\pm$ 17.2
Gender, % male	64.4	52.8
Age at injury, y ( $\pm$ SD)	26.2 $\pm$ 8.6	25.7 $\pm$ 8.6
Extension difference, deg ( $\pm$ SD) <sup>a</sup>	-1 $\pm$ 3	-2 $\pm$ 3
Flexion difference, deg ( $\pm$ SD) <sup>a</sup>	4 $\pm$ 8	2 $\pm$ 7
Video extension difference, deg ( $\pm$ SD) <sup>a</sup>	-3 $\pm$ 5	-1 $\pm$ 5
Video flexion difference, deg ( $\pm$ SD) <sup>b</sup>	-2 $\pm$ 5	0 $\pm$ 5
KT arthrometer difference, mm ( $\pm$ SD) <sup>c</sup>	5.0 $\pm$ 3.0	4.9 $\pm$ 3.2
Quadriceps ratio, % ( $\pm$ SD) <sup>d</sup>	88.4 $\pm$ 12.2	87.2 $\pm$ 13.3
Hamstrings ratio, % ( $\pm$ SD) <sup>d</sup>	98.5 $\pm$ 15.4	97.4 $\pm$ 15.7
Mean ACL quality-of-life score ( $\pm$ SD) <sup>e</sup>	30.3 $\pm$ 13.9	29.7 $\pm$ 14.8
Median time from injury to surgery, mo	17	20

<sup>a</sup>Nonsurgical leg - surgical leg; negative value indicates hyperextension—the nonsurgical leg had a greater range of motion.

<sup>b</sup>Nonsurgical leg - surgical leg; negative value indicates the surgical leg had a greater flexion angle.

<sup>c</sup>Surgical leg - nonsurgical leg.

<sup>d</sup>Surgical limb as a percentage of nonsurgical limb (ie, surgical/nonsurgical  $\times$  100).

<sup>e</sup>Score out of 100, with 100 being perfect quality of life.

of the PT group attended the university-based sport medicine center for physical therapy treatments (66.7%, 48/72). The remaining 24 patients were equally split between other clinics within and outside the city. The PT group attended  $14 \pm 4$  treatment sessions (range, 2-20 sessions).

Of the 145 patients enrolled in the study, 129 patients attended the 12-week assessment (study end point). These patients included 66 patients in the PT group and 63 patients in the HB group. The descriptive values for each study group for all of the outcome measures are included in Table 4. Because of the lack of a normal distribution in some of the outcome measures, the data have been presented as group median values with interquartile range. The percentage of acceptable patients by rehabilitation group for each variable and the Fisher exact test results are listed in Table 5.

Two patients in the PT group had to undergo a manipulation under anesthesia (MUA) and an extension casting procedure within the 12-week study period (1 patient at 8.5 weeks and 1 patient at 10 weeks postoperatively). The decision to undergo an MUA was made by the patient's surgeon and was based on a serial assessment of ROM with a lack of progression over time. Data for these 2 patients are not included in Table 4. The 2 patients who underwent an MUA were coded as unacceptable for the passive exten-

TABLE 4  
Study Outcome Measures According to Treatment Group

Variable	Home		Physical Therapy	
	Median	Inter-quartile Range	Median	Inter-quartile Range
Extension range of motion difference, deg <sup>a</sup>	-2	-3 to -1	-3	-5 to -1
Flexion range of motion difference, deg <sup>b</sup>	3	0 to 8	6	4 to 11
Video extension range of motion difference, deg <sup>a</sup>	-4	-8 to -1	-5	-9 to -1
Video flexion range of motion difference, deg <sup>b</sup>	-1	-5 to 1	-1	-3 to 3
KT arthrometer side-to-side difference, mm <sup>c</sup>	2	0 to 4	2	0 to 3
Quadriceps ratio, % <sup>d</sup>	61	53 to 70	60	51 to 71
Hamstrings ratio, % <sup>d</sup>	94	84 to 102	93	85 to 101

<sup>a</sup>Nonsurgical leg – surgical leg; negative value indicates the nonsurgical leg was more extended.

<sup>b</sup>Nonsurgical leg – surgical leg; negative value indicates the surgical leg had a greater flexion angle.

<sup>c</sup>Surgical leg – nonsurgical leg.

<sup>d</sup>Surgical limb as a percentage of nonsurgical limb (ie, surgical/nonsurgical × 100).

TABLE 5  
Percentage of Acceptable Patients in Each Study Group for the Study Outcome Measures

Variable	n	Home Based, %	Physical Therapy, %	P
Extension range of motion	129	96.8	83.3	.02
Flexion range of motion	129	66.7	47.0	.03
Video extension range of motion	129	57.1	48.5	.38
Video flexion range of motion	116 <sup>a</sup>	94.5	85.2	.13
KT arthrometer side-to-side difference	127 <sup>b</sup>	88.9	93.8	.36
Quadriceps strength	126 <sup>b,c</sup>	83.9	78.1	.50
Hamstrings strength	126 <sup>b,c</sup>	93.5	87.5	.36

<sup>a</sup>Thirteen patients walked through the video's field of view without reaching maximal flexion during any trials.

<sup>b</sup>Data were censored for the 2 physical therapy patients who underwent manipulations under anesthesia.

<sup>c</sup>One patient did not have strength testing performed postoperatively because of excessive pain during the activity.

sion and active-assisted flexion ROM and the video gait ROM. Because of the required intervention (ie, MUA), the ligament laxity and strength data could no longer solely represent rehabilitation outcome and were therefore censored (ie, treated as missing). The 6-week data (ie, pre-MUA) for the ligament laxity were included in the intention-to-treat analysis. The strength data were consequently treated as worst-case scenarios for the intention-to-treat analysis, as there was no 6-week assessment of strength.

TABLE 6  
Proportion of Acceptable Patients in Each Study Group, Including All Losses to Follow-up

Variable	n	Home Based, %	Physical Therapy, %	P
Extension range of motion	145	86.3	80.6	.38
Flexion range of motion	145	60.3	45.8	.10
Video extension range of motion	145	53.4	48.6	.62
Video flexion range of motion	131 <sup>a</sup>	84.4	82.1	.82
KT arthrometer side-to-side difference	145	80.8	90.3	.16
Quadriceps strength	144 <sup>b</sup>	72.2	69.4	.86
Hamstrings strength	144 <sup>b</sup>	80.6	77.8	.84

<sup>a</sup>Thirteen patients at 12 weeks and 1 patient who only attended the 6-week assessment walked through the video's field of view without reaching maximal flexion during any trials.

<sup>b</sup>One patient did not have strength testing performed postoperatively because of excessive pain during the activity.

Of the 145 patients enrolled, 16 were lost to follow-up. These included the 3 patients discussed previously who declined postrandomization. Eight patients attended their 6-week (midpoint) assessment but did not return for their final 12-week assessment (study end point). Five patients did not return for either their 6-week or 12-week assessment. Given that 16 patients either declined postrandomization or were partially or completely lost to follow-up, an intention-to-treat analysis was performed (Table 6).

## DISCUSSION

After reviewing ACL postoperative rehabilitation studies and, specifically, studies that compared a limited to standard frequency physical therapy rehabilitation program, it was obvious that despite the importance of regaining full knee ROM, no studies reported that variable concisely and completely.<sup>2,14,33</sup> Range of motion is an important early outcome measure, as restricted ROM affects activities of daily living such as sitting, walking, and stair climbing.

When current ROM data were dichotomized into acceptable or unacceptable categories, significantly more patients in the HB group attained acceptable outcomes (97% vs 83% for extension; 67% vs 47% for flexion). Schenck et al<sup>33</sup> reported that 35 of 37 (95%) patients attained full ROM by 3 months after surgery. However, they did not define what they considered "full" ROM, and they did not report to which group the 2 patients belonged who failed to attain full ROM. Previous studies have not reported bilateral differences, making comparisons difficult.<sup>2,9,14,33</sup> Our finding that the HB group had a better return of knee ROM is consistent with previous studies.<sup>9,14</sup> Although the resultant median differences ( $-2^\circ$  vs  $-3^\circ$  for extension;  $3^\circ$  vs  $6^\circ$  for flexion) may be of questionable clinical relevance, they support the difference in the number of patients attaining acceptable outcomes in each group.

The findings that only 47% in the PT group and 67% in the HB group in the current study attained acceptable flexion ROM were troubling. With no other comparable published data, it was difficult to assess the relevance of this finding. One explanation revolved around the method of measurement. Although descriptions of exact measurement methods were not frequently reported, the limited reports available described "active-assisted" as using only the active contraction of the hamstrings to attain full flexion.<sup>9,14</sup> Without the assistance of the patient's arms pulling on the strap, the effects of knee pain, apprehension, and muscle inhibition likely affected the ability to reach the knee's end range of flexion. Thus, in earlier studies, the measurement of "full flexion" did not represent the full range of possible joint motion (active assisted) but the maximal flexion possible under active hamstrings control only. Assuming there were no major ROM restrictions, in those studies, the end range was less likely to be affected by variables related to the surgical rehabilitation (eg, residual swelling, apprehension, and pain). Therefore, patients were more likely to produce a flexion range equal to (or approximately equal to) that of their nonoperative knee. Given the active-assisted method used in the current study, a more liberal goal of being within 10° of the contralateral side may have been more reasonable. If that theory was explored, the relative proportion of acceptable patients would increase to 86% for the HB group and 71% for the PT group ( $P = .06$ ). Although these numbers were expectedly higher, they still identified that a substantial number of patients did not recover "full" flexion ROM by 3 months after surgery. This trend between the HB and PT groups may have resulted from less emphasis by the physical therapists on regaining flexion and more emphasis on extension, strength, and normal gait recovery.

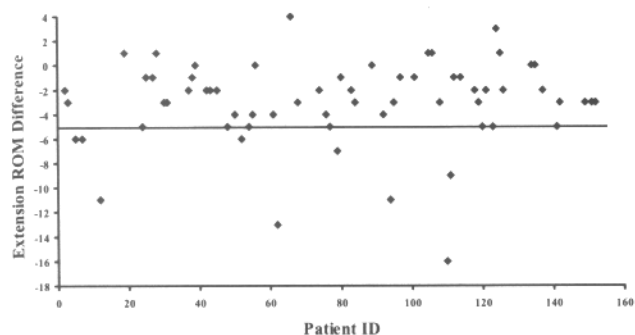
Gait adaptations in patients with ACL deficiency have been frequently studied. During the acute stage after ACL injury or reconstruction, the gait parameters of cadence, stride length, and stride velocity were usually unchanged from normal.<sup>3,5,6,7,11,42</sup> Patients with torn or reconstructed ACLs, however, tended to keep their knees more flexed than normal near heel strike.<sup>3,6,11</sup> The greater than normal flexion in this phase of gait may have improved the mechanical advantage for the hamstrings to assist with controlling the anterior tibial translation due to quadriceps activity.<sup>23</sup> Previous studies have demonstrated that peak extension values at heel strike returned to normal as early as 5 weeks after surgery.<sup>5,12</sup> When patient-acceptable outcomes were analyzed, however, only 57% of home patients and 49% of physical therapy-supervised patients had acceptable extension differences 3 months after surgery.

As a whole, patients were more likely to attain acceptable peak flexion values (HB group, 95%; PT group, 85%) than peak extension values. During gait, the patients flexed to less than half of peak active-assisted values. Thus, midrange motion should not have been restricted by potential knee ROM, and one would expect the proportion of acceptable outcomes to be near or equal to 100% for both groups at the 3-month postsurgery end point. It was surprising to find that 15% of the PT group patients were not able to acquire peak flexion values within 5° of the con-

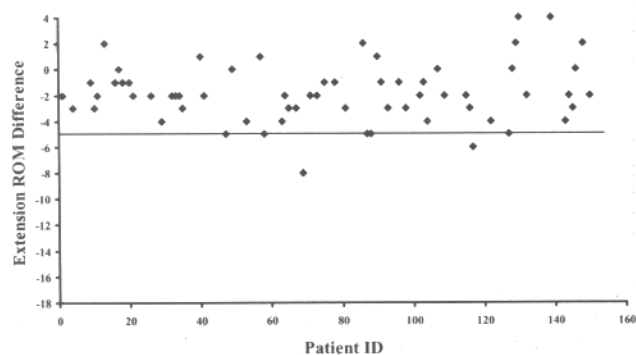
tralateral knee. This deficit occurred despite the fact that these patients would likely have received more cueing from the physical therapists about the normalization of gait during the first 3 postoperative months.

Ligament laxity in the current study was the only outcome measure that showed a trend (not significant) of the PT group having a higher proportion of acceptable patients at 3 months after surgery (PT group, 94%; HB group, 89%). The small difference between the groups was supported by the group means (PT and HB groups, 2-mm side-to-side difference at 135 N). Given the strong statistical power of the current study, however, this value did not represent a clinically meaningful difference. These results were similar in trend but lower in the magnitude of the difference to those of Beard and Dodd.<sup>2</sup> Combining the current results with other similar studies<sup>31,33</sup> and other studies of accelerated rehabilitation<sup>10,35,37</sup> revealed that 2 mm of laxity difference bilaterally was common. Previous studies of limited physical therapy rehabilitation programs after ACL reconstruction did not identify any significant increases in laxity compared to a standard physical therapy program<sup>14,33</sup> or to the published literature on standard accelerated rehabilitation patients.<sup>31</sup> With the lack of a significant difference in measured ligament laxity between the 2 study groups, the agreement with published laxity values, and the fact that passive anterior sagittal translation was not related to patients' objective and subjective functional outcomes,<sup>13,15,32,34</sup> the current study found that there was no difference in knee ligament laxity between the HB group program and the PT group program. It is important to note, however, that 3 months after surgery is early with respect to graft remodeling, and long-term follow-up is required to make any definitive statement regarding laxity.

The ratio of quadriceps strength between the surgical and nonsurgical limb was approximately 60% at 3 months after surgery (HB group, 61%; PT group, 60%). These values were lower than data reported by Beard and Dodd<sup>2</sup> (58% and 68%, respectively, measured at 60 deg/s), the data of Shelbourne and Nitz<sup>37</sup> (66% measured at 180 deg/s), and the accelerated rehabilitation group in the study by DeCarlo et al<sup>10</sup> (70% measured at 180 deg/s). Our results were, however, within the 95% confidence limits for the mean in the study by Beard and Dodd (50%-66% and 52%-84% for the HB and PT groups, respectively), demonstrating concordance in the study sample outcomes. The limited published data on strength at 3 months after surgery made comparison to other studies difficult. When the strength data were dichotomized into patients who were or were not able to attain at least a 50% ratio, an interesting trend emerged. The difference in the proportion of patients with acceptable outcomes was larger than the difference in the group means (percentage acceptable: HB group, 84%; PT group, 78%). The results for the hamstrings strength followed a similar trend to that for the quadriceps strength. The group median values for hamstrings strength were similar (HB group, 94%; PT group, 93%), whereas the comparison of the proportion of acceptable patients demonstrated a wider spread (HB group, 94%; PT group, 88%). Consistent with the other secondary out-



**Figure 1.** Scatterplot of physical therapy group outcomes for passive extension range of motion (ROM). The horizontal line identifies the acceptable cutoff of  $\leq 5^\circ$  difference ( $n = 64$ , the data points were censored for the 2 patients who underwent manipulations under anesthesia).

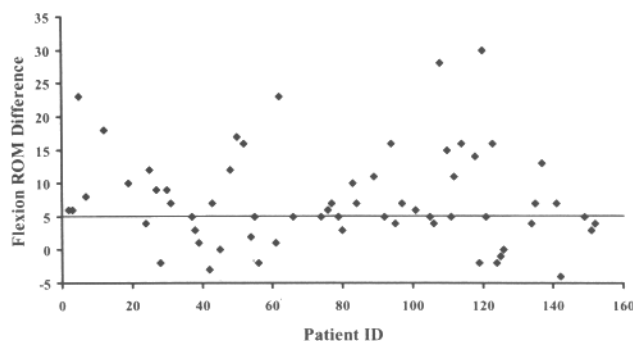


**Figure 2.** Scatterplot of home-based group outcomes for passive extension range of motion (ROM). The horizontal line identifies the acceptable cutoff of  $\leq 5^\circ$  difference ( $n = 63$ ).

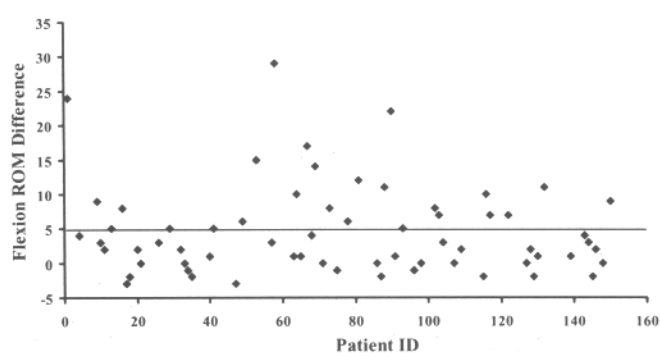
comes, there were no differences between the groups for quadriceps or hamstrings strength.

The current study has identified how outcome information may be reliant on the choice of analysis. Many studies rely on a comparison of means for continuous data. Means, however, are sensitive to outliers in the data and do not give information regarding the range of patient results. In clinical research, as in clinical practice, we are interested in those patients who do well, but more important, we are interested in those who do not do well so that we can guide our treatment programs to improve overall outcome. In planning the current study, we chose to analyze our outcomes in a clinically relevant manner—how many patients were able to attain clinically acceptable outcomes. This analysis allowed statistical significance to equate clinical importance.

Across all outcomes, the group median values were similar comparing HB group patients to PT group patients. Based on these data, there were no differences in outcome between the 2 rehabilitation programs. When we look specifically at those patients who did not attain what we felt were acceptable rehabilitation goals for the first 3 postoperative months, we see that group medians do not



**Figure 3.** Scatterplot of physical therapy group outcomes for passive flexion range of motion (ROM). The horizontal line identifies the acceptable cutoff of  $\leq 5^\circ$  difference ( $n = 64$ , the data points were censored for the 2 patients who underwent manipulations under anesthesia).



**Figure 4.** Scatterplot of home-based group outcomes for passive flexion range of motion (ROM). The horizontal line identifies the acceptable cutoff of  $\leq 5^\circ$  difference ( $n = 63$ ).

provide all the pertinent information. A  $1^\circ$  difference in the median passive knee extension ROM is not clinically relevant. Figures 1 and 2, however, demonstrate the range of patient outcomes in the PT and HB groups and how many patients in the PT versus HB group were not able to attain acceptable outcomes. This information is both clinically and statistically significant because it identifies a true benefit in using the HB group's program to improve patient outcome. A similar result was demonstrated with active-assisted knee flexion ROM (Figures 3 and 4). As an aside, goniometric measurement error has been demonstrated to be in the range of  $3.1^\circ$  to  $4.0^\circ$ .<sup>4</sup> A comparison of outcomes based on a  $5^\circ$  difference is therefore not only clinically relevant but accurate as well. Although there were no significant differences between the rehabilitation groups for any of the secondary outcome variables, differences in the proportion of patients with acceptable outcomes can similarly be explained by differences in the number of patients near the low end of the respective outcome range.

The intention-to-treat analysis demonstrated, for the most part, a regression to the null. Ten patients in the HB

group were lost to follow-up (including the 3 who declined participation postrandomization), whereas there were 6 lost from the PT group. The between-group difference in the proportion of acceptable outcomes decreased (but did not reverse) for all variables except for ligament laxity, in which the difference increased. The intention-to-treat analysis, however, did not produce changes to the original interpretation of the data. This analysis minimized the differences between the 2 groups. Despite this very conservative approach, the home program was equally effective compared to the standard physical therapy-supervised program.

Apart from the potential limitations resulting from the use of categorical data that have been discussed above, this study was also limited by 2 common concerns, namely volunteer bias and a short follow-up. This study was able to enroll 75% of eligible patients. Of those who were not enrolled, 11 (5%) refused to be contacted for any research and therefore were never informed of the study. A further 17 patients (8%) declined because they were not willing to be randomized to the HB group. The remainder of the declines were unrelated to volunteer bias. In the worst-case scenario, the inclusion of 28 patients biased against the success of the HB group's program would be unlikely to cause the PT group's program to be significantly more effective and therefore change the outcome of the study. This study used an end point of 3 months after surgery, as patients are generally on a predominantly home-based program after this time frame. This issue will be addressed, however, by a 2- to 4-year follow-up study that is currently underway.

A case could be made that the PT group program was less standardized because of the variety of physical therapists involved. The use of a single, standardized rehabilitation program for both groups and the introductory letter to all physical therapists requesting them to respect the provided protocol were designed to provide rehabilitation standardization across the study groups. This factor may be a real result, however, in that a more standardized home-based program is more effective. Alternatively, the reduced supervision in the HB group may have resulted in less standardization. The effects of these facts must ultimately be interpreted by each individual reader.

In summary, the HB group had significantly more patients with acceptable knee ROM, and there were no differences between the rehabilitation groups for any of the secondary outcome measures. Therefore, the HB group's program was more effective than was the PT group's program at 3 months after ACL reconstruction. This study did not include acutely injured patients with residual swelling and ROM restrictions. The effectiveness of a limitedly supervised rehabilitation program in that patient population has therefore not been determined. Although there may be select patients with substantial compliance or complication issues who will benefit from more postoperative supervision, this study showed that the majority of patients attain clinically acceptable outcomes with limited supervision and appropriate oral and written education. This finding was established in a large population of recreational athletes that included a wide range of age (16-59

years), injury chronicity (2-204 months), sport background, and previous exercise experience. It is important to note that this recommended change toward more limitedly supervised rehabilitation increases the importance of the physical/athletic therapists in their role as a patient educator and motivator. Whether any differences in patient outcome and satisfaction would develop in the long term needs to be determined.

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## REFERENCES

- Ageberg E, Zatterstrom R, Moritz U, Friden T. Influence of supervised and nonsupervised training on postural control after an acute anterior cruciate ligament rupture: a three-year longitudinal prospective study. *J Orthop Sports Phys Ther.* 2001;31:632-644.
- Beard DJ, Dodd CAF. Home or supervised rehabilitation following anterior cruciate ligament reconstruction: a randomized controlled trial. *J Orthop Sports Phys Ther.* 1998;27:134-143.
- Beard DJ, Soundarapandian RS, O'Connor JJ, Dodd CAF. Gait and electromyographic analysis of anterior cruciate ligament deficient subjects. *Gait Posture.* 1996;4:83-88.
- Boone DC, Azen SP, Lin CM, Spence C, Baron C, Lee L. Reliability of goniometric measurements. *Phys Ther.* 1978;58:1355-1360.
- Bulgheroni P, Bulgheroni MV, Andriani L, Guffanti P, Giughello A. Gait patterns after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 1997;5:14-21.
- Chmielewski TL, Rudolph KS, Fitzgerald GK, Axe MJ, Snyder-Mackler L. Biomechanical evidence supporting a differential response to acute ACL injury. *Clin Biomech (Bristol, Avon).* 2001;16:586-591.
- 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.
- Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. *J Bone Joint Surg Am.* 1985;67:720-726.
- DeCarlo MS, Sell KE. The effects of the number and frequency of physical therapy treatments on selected outcomes of treatment in patients with anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 1997;26:332-339.
- DeCarlo MS, Shelbourne KD, McCarroll JR, et al. Traditional versus accelerated rehabilitation following ACL reconstruction: a one-year follow-up. *J Orthop Sports Phys Ther.* 1992;15:309-316.
- Devita P, Hortobagyi T, Barrier J, et al. Gait adaptations before and after anterior cruciate ligament reconstruction surgery. *Med Sci Sports Exerc.* 1997;29:853-859.
- DeVita P, Torry M, Glover KL, Speroni DL. A functional knee brace alters joint torque and power patterns during walking and running. *J Biomech.* 1996;29:583-588.

13. Eastlack ME, Axe MJ, Snyder-Mackler L. Laxity, instability, and functional outcome after ACL injury: copers versus noncopers. *Med Sci Sports Exerc.* 1999;31:210-215.
14. Fischer DA, Tewes DP, Boyd JL, Smith JP, Quick DC. Home based rehabilitation for anterior cruciate ligament reconstruction. *Clin Orthop.* 1998;347:194-199.
15. Fitzgerald GK, Lephart SM, Hwang JH, Wainner RS. Hop tests as predictors of dynamic knee stability. *J Orthop Sports Phys Ther.* 2001;31:588-597.
16. Frank CB. Ligament healing: current knowledge and clinical applications. *J Am Acad Orthop Surg.* 1996;4:74-83.
17. Frost H, Klaber Moffett JA, Moser JS, Fairbank JC. Randomised controlled trial for evaluation of fitness programme for patients with chronic low back pain. *BMJ.* 1995;310:151-154.
18. Giannotti BF, Fanelli GC, Barrett TA, Edson C. The predictive value of intraoperative KT-1000 arthrometer measurements in single incision anterior cruciate ligament reconstruction. *Arthroscopy.* 1996;12:660-666.
19. Holcomb KR, Skaggs CA, Worrell TW, et al. Assessment of knee laxity following anterior cruciate ligament reconstruction. *J Sport Rehabil.* 1993;2:97-103.
20. Johnson D. Controlling anterior shear during isokinetic knee extension exercise. *J Orthop Sports Phys Ther.* 1982;4:23-30.
21. Jokl P, Stull PA, Lynch JK, Vaughan V. Independent home versus supervised rehabilitation following arthroscopic knee surgery: a prospective randomized trial. *Arthroscopy.* 1989;5:298-305.
22. Kadaba MP, Ramakrishnan HK, Wootten ME, Gainey J, Gorton G, Cochran GV. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. *J Orthop Res.* 1989;7:849-860.
23. Liu W, Maitland ME. The effect of hamstring muscle compensation for anterior laxity in the ACL-deficient knee during gait. *J Biomech.* 2000;33:871-879.
24. Maitland ME, Bell GD, Mohtadi NGH, Herzog W. Quantitative analysis of anterior cruciate ligament instability. *Clin Biomech (Bristol, Avon).* 1995;10:93-97.
25. Malcom LL, Daniel DM, Stone ML, Sachs R. The measurement of anterior knee laxity after ACL reconstructive surgery. *Clin Orthop.* 1985;196:35-41.
26. McCarthy CJ, Mills PM, Pullen R, Roberts C, Silman A, Oldham JA. Supplementing a home exercise programme with a class-based exercise programme is more effective than home exercise alone in the treatment of knee osteoarthritis. *Rheumatology (Oxford).* 2004;43:880-886.
27. Mohtadi NGH. Development and validation of the quality of life outcome measure (questionnaire) for chronic anterior cruciate ligament deficiency. *Am J Sports Med.* 1998;26:350-359.
28. Mohtadi NGH, Webster-Bogaert S, Fowler PJ. Limitation of motion after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1991;19:620-625.
29. Montgomery LC, Douglass LW, Deuster PA. Reliability of an isokinetic test of muscle strength and endurance. *J Orthop Sports Phys Ther.* 1989;11:315-322.
30. Paulos L, Meislin R. Patellar entrapment following anterior cruciate ligament injury. In: Jackson DW, ed. *The Anterior Cruciate Ligament: Current and Future Concepts.* New York, NY: Raven Press; 1993:357-363.
31. Reat JF, Lintner DM. One- versus two-incision ACL reconstruction: a prospective, randomized study. *Am J Knee Surg.* 1997;10:198-208.
32. Risberg MA, Holm I, Tjomsland O, Ljunggren E, Edeland A. Prospective study of changes in impairments and disabilities after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 1999;29:400-412.
33. Schenck RC Jr, Blaschak MJ, Lance ED, Turturro TC, Holmes CF. A prospective outcome study of rehabilitation programs and anterior cruciate ligament reconstruction. *Arthroscopy.* 1997;13:285-290.
34. Sernert N, Kartus J, Kohler K, et al. Analysis of subjective, objective and functional examination tests after anterior cruciate ligament reconstruction: a follow-up of 527 patients. *Knee Surg Sports Traumatol Arthrosc.* 1999;7:160-165.
35. Shelbourne KD, Gray T. Anterior cruciate ligament reconstruction with autogenous patellar tendon graft followed by accelerated rehabilitation: a two- to nine-year follow-up. *Am J Sports Med.* 1997;25:786-795.
36. Shelbourne KD, Klootwyk TE, DeCarlo MS. Update on accelerated rehabilitation after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 1992;15:303-308.
37. Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1990;18:292-299.
38. Shelbourne KD, Patel DV. Rehabilitation after autogenous bone-patellar tendon-bone ACL reconstruction. *Instr Course Lect.* 1996;45:263-273.
39. Shelbourne KD, Rask BP. Controversies with anterior cruciate ligament surgery and rehabilitation. *Am J Knee Surg.* 1998;11:136-143.
40. Stratford PW, Miseferi D, Ogilvie R, et al. Assessing the responsiveness of five KT1000 knee arthrometer measures used to evaluate anterior laxity at the knee joint. *Clin J Sport Med.* 1991;1:225-228.
41. Timm KE. The clinical and cost-effectiveness of two different programs for rehabilitation following ACL reconstruction. *J Orthop Sports Phys Ther.* 1997;25:43-48.
42. Timoney JM, Inman WS, Quesada PM, et al. Return of normal gait patterns after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1993;21:887-889.
43. Torzilli PA, Panariello RA, Forbes A, Santner TJ, Warren RF. Measurement reproducibility of two commercial knee test devices. *J Orthop Res.* 1991;9:730-737.
44. Treacy SH, Barron OA, Brunet ME, Barrack RL. Assessing the need for extensive supervised rehabilitation following arthroscopic ACL reconstruction. *Am J Orthop.* 1997;26:25-29.
45. Wilk KE, Andrews JR. Current concepts in the treatment of anterior cruciate ligament disruption. *J Orthop Sports Phys Ther.* 1992;15:279-293.

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