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Open and Closed Kinetic Chain Exercises in the Early Period after Anterior Cruciate Ligament Reconstruction

Improvements in Level Walking, Stair Ascent, and Stair Descent

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ABSTRACT

Thirty-seven patients who had undergone anterior cruciate ligament reconstruction were tested in a gait analysis laboratory at 2 and 6 weeks after surgery. Between test sessions, patients were randomly assigned to a course of either closed or open kinetic chain resistance exercises (3 sessions per week for 4 weeks). Gait analysis consisted of bilateral calculations of knee joint angle, moment, and power during level walking, stair ascent, and stair descent. An analysis of variance on the effects of training group and test session indicated that the only variable to be significantly affected by the type of exercise program was the amount of knee flexion at the beginning of step-up ($P < 0.05$). All other measures of knee angle, moment, and power (16 total variables) showed no significant difference between the exercise groups. All variables measured on the injured side showed significant improvement from test 1 to test 2 ($P < 0.05$), but the injured leg remained functionally deficient when compared with the uninjured leg. These data suggest that there are no clinically significant differences in the functional improvement resulting from the choice of open or closed kinetic chain exercises in the early period after this surgery.

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Over the past decade there has been a shift in clinical practice toward the use of closed kinetic chain rather than open kinetic chain resistance training, especially after ACL reconstruction. The promotion of closed kinetic chain training has been based on three primary concepts.[10] The first is the assumption that because closed kinetic chain exercises appear to better replicate functional tasks, they should enhance functional performance to a greater extent than open kinetic chain exercises.[17,18,20,21,23] The second reason for the shift toward closed kinetic chain exercises was the publication of data reporting that the strain on the ACL was greater during open kinetic chain exercises.[2,4,5,9,19,26] The third reason closed kinetic chain exercise has been favored is the belief that this exercise will be less harmful to the patellofemoral joint.[23] Despite popular opinion favoring closed kinetic chain exercise, there is a lack of prospective clinical data comparing these two types of training methods. Furthermore, there is recent evidence to suggest that strain in the ACL is not significantly different during select open kinetic chain and closed kinetic chain exercises.[6] A need was therefore recognized to test these two types of rehabilitation programs in a controlled clinical trial.

The authors have been able to locate only one prospective investigation comparing open and closed kinetic chain exercises after ACL reconstruction. Bynum et al.[7] compared the effects of open and closed kinetic chain exercises on knee laxity, passive range of motion, and patients' responses on questionnaires. In that study, members of the closed kinetic chain group reported that they returned to work earlier and tended to be more satisfied with their surgical outcome. Despite these subjective evaluations, biomechanists have yet to implement the rigorous techniques of gait analysis to evaluate whether patients treated with either open or closed kinetic chain training after ACL reconstruction experience different levels of functional improvement. Gait analysis has been used to successfully identify changes in knee kinematics due to ACL deficiency and reconstruction.[1,3,8,14,24] A well-known example of this technology being used to study knee abnormalities was the discovery of "quadriceps avoidance gait" in patients with ACL deficiency.[3] These techniques should also be used to explore the functional outcomes resulting from open and closed kinetic chain training after ACL reconstruction. The purpose of this study was to conduct a randomized prospective clinical trial to determine whether there were differences in the functional improvement of the knee, defined by gait analysis, after either open or closed kinetic chain training during the first 6 weeks after ACL reconstruction.

MATERIALS AND METHODS

Overview

This clinical trial of rehabilitation after ACL reconstruction surgery was designed to study the biomechanical differences in knee function before and after physical therapy based on either open or closed kinetic chain exercises of the hip and knee extensor muscles. Patients meeting all inclusion criteria were studied in a gait analysis laboratory 2 weeks after ACL reconstruction surgery (test 1). Patients were then randomly assigned to 4 weeks of either open or closed kinetic chain training. On completion of training, patients were recalled to the laboratory for a second gait analysis (test 2).

Subjects

Potential subjects were identified for this study from the inpatients recovering from ACL reconstruction at five National Health Service and private hospitals in the East London area. Subjects were recruited for the study if they fulfilled all of the following criteria: 1) no history of pathologic conditions requiring medical attention in the contralateral lower extremity, 2) no history of injury to the PCL in the operated knee, and 3) since the operation, no accident or problem with the affected lower extremity that required more than standard postoperative medical attention. Subjects were approached within the first 2 weeks after surgery, given a written and verbal explanation of the study, and invited to participate in the study. Patients were allowed to begin participation in the study if they could achieve 90° of passive knee flexion in the operated knee and they were able to walk without a walking aid. Table 1 describes the patients completing this study.

Surgical Technique

Three orthopaedic surgeons participated in the study. All surgeries took place between May 1997 and November 1998. One surgeon (JK) performed ACL reconstruction using the technique described by Kennedy et al.[13] This technique consisted of a ligament augmentation device (3M, Minneapolis, Minnesota) with a thin graft of the patellar tendon. The tendon graft remained anchored to the tip of the tibial tuberosity. It was threaded through a tibial bone tunnel, passed through the joint with an "over the top" technique, and then fixed with a lateral screw. Two other surgeons performed arthroscopically assisted ACL reconstruction after harvesting a bone-patellar tendon-bone graft from the central third of the extensor mechanism via an anterior midline incision. The free graft was then inserted through tunnels in the tibia and femur and fixed with interference screws or staples.

Controlled Resistance Training

After initial testing, subjects were assigned to one of two treatment groups using block randomization and asked to attend physical therapy sessions three times per week for the 4-week training period of the study (the block randomization randomized blocks of four subjects at a time to ensure that nearly equal numbers were assigned to each group). Sessions took place in the outpatient physical therapy departments at one of two National Health Service hospitals in the East London area (Mile End Hospital or Whipps Cross Hospital). Because block randomization (four per block) was initiated before the inclusion of both sites, randomization was not separated for the two treatment sites.

Subjects in the closed kinetic chain group performed unilateral resistance training of the hip and knee extensors on a leg press machine (Horizontal Leg Press, Tech-

TABLE 1
Characteristics of the Open Kinetic Chain (OKC) and Closed Kinetic Chain (CKC) Groups

Variable	CKC (*N* = 18)	OKC (*N* = 19)
Sex	13 m, 5 f	16 m, 3 f
Height (meters)	1.76 (0.11)	1.78 (0.07)
Body mass at test 1 (kg)	75.1 (12.3)	77.4 (15.3)
Body mass at test 2 (kg)	75.8 (12.3)	77.4 (15.7)
Time from injury to surgery (months)	50.3 (61.8)	34.1 (30.4)
Number of patients with a ligament augmentation device	5	9
Number of patients with a partial medial meniscectomy	3	2
Number of patients with a partial lateral meniscectomy	1	3
Number of patients with a partial medial and lateral meniscectomy	1	0
Injured side	9 L, 9 R	8 L, 11 R
Dominant side = injured side	9	10

TABLE 2
Means and Standard Deviations of Kinematic and Kinetic Variables of the Knee During Level Walking

Biomechanical variable[a]	Test	Injured		Uninjured	
		CKC[b]	OKC[c]	CKC	OKC
Knee flexion at heel-strike[d] (deg)	1	0 (3)	1 (3)	2 (5)	4 (4)
	2	1 (4)	2 (2)	4 (6)	4 (4)
Midstance excursion angle[d] (deg)	1	5 (4)	4 (2)	13 (5)	13 (5)
	2	8 (4)	6 (4)	14 (2)	13 (6)
Knee flexion at toe-off[d] (deg)	1	24 (3)	23 (8)	32 (6)	35 (5)
	2	28 (9)	30 (7)	34 (7)	36 (4)
Flexor impulse (N·m·s)	1	3.1 (3.2)	3.1 (3.1)	7.6 (6.1)	6.7 (5.1)
	2	2.3 (2.3)	3.7 (2.8)	4.7 (2.8)	5.1 (3.7)
Extensor impulse (N·m·s)	1	3.7 (3.8)	3.6 (4.9)	4.4 (2.6)	5.9 (4.6)
	2	4.5 (2.5)	3.6 (3.5)	5.5 (2.7)	6.3 (4.3)
Eccentric energy[d] (joules)	1	3.7 (2.5)	3.0 (3.0)	8.1 (2.9)	9.2 (4.9)
	2	5.7 (1.9)	4.2 (3.3)	8.7 (2.7)	8.6 (3.6)
Concentric energy[d] (joules)	1	1.9 (1.2)	1.7 (1.0)	4.1 (1.4)	4.9 (2.0)
	2	2.5 (1.1)	2.5 (1.0)	4.4 (1.6)	4.6 (1.6)

[a] Impulse and energy are normalized to body mass multiplied by subject height.
[b] Closed kinetic chain.
[c] Open kinetic chain.
[d] Indicates a significant improvement in the injured knee from test 1 to test 2 for both groups ($P < 0.05$).

nogym UK, Bracknell, United Kingdom), with all subjects using the same device for this exercise regardless of treatment site. The leg press machine was set so that the patient was supine with the hip and knee in approximately 90° of flexion for the start of each lift and the trunk slightly inclined from a position parallel to the floor. A small block of wood was placed under the heel of the exercise leg and the patient was instructed to perform the exercise without making contact between the forefoot and the leg press platform. This was done to prevent the subjects from using their plantar flexor muscles during this exercise. Plantar flexor resistance exercise was excluded from this study because open kinetic chain exercise of the plantar flexor muscles of adequate intensity is not possible using standard equipment.

Subjects in the open kinetic chain group exercised the same leg muscle groups in the open kinetic chain using either ankle weights or machines designed for isolated resistance of these muscle groups (that is, knee and hip extension machines), with various types of this equipment used throughout the study. The attending therapist was urged to use machines as early as possible in the subjects' training to allow greater standardization of the resistance loads and training speeds. Patients who were particularly weak or in pain had to use ankle weights until they could achieve the minimum weight on the knee extensor machine.

For the hip and knee extensor muscle resistance exercises, regardless of kinetic chain training type, 3 sets of 20 repetition maximum were used in each session. No other resistance training exercises of these types were allowed. The training range of motion for the hip and knee extensors in both groups was 90° to 0°. To control velocity, subjects used Right Weigh exercise timing feedback devices (Baltimore Therapeutic Equipment, Baltimore, Maryland). These machines gave immediate feedback to the subjects about the speed of their weight training movement as they trained relative to a target speed. The target time setting used was 1.5 seconds for the concentric phase and 3.0 seconds for the eccentric phase of a training repetition, with a 1.0-second interval between phases. These represent average angular velocities of 60 deg/sec for the concentric phase and 30 deg/sec for the eccentric phase.

Resistance training of other leg muscles was not controlled. For the most part, these additional exercises were of the hip adductors and abductors and knee flexors. Endurance training of the leg muscles with a stationary cycle was allowed in both groups. Subjects in both groups and at both treatment sites cycled for 10 minutes per session. The decision to use cycling and the intensity of this exercise was left to the discretion of the attending therapist. Neuromuscular stimulation and EMG biofeedback of the hip extensors, knee flexors and extensors, and ankle plantar flexors were not allowed during the training period.

No limits were placed on methods used to treat pain, swelling, or hypomobility although complete records of methods were kept. In addition, training to enhance lower extremity balance and proprioception, which consists of minor resistance to the lower extremity muscles was neither restricted nor controlled, although guidance was offered so that the two training sites were using roughly the same exercise types, frequencies, and durations. No treatment restrictions were imposed before or after the study training period.

Functional Assessment

Patients were asked to complete a modified version (changed from American English to British English) of the Hughston Clinic visual analog scale subjective knee questionnaire at test 1 and test 2.[11,12] This questionnaire consisted of 28 questions covering topics such as knee pain, swelling, and ability to perform simple and competitive tasks. Each question required the patient to place a tick along a 10-cm visual analog scale. The questionnaire

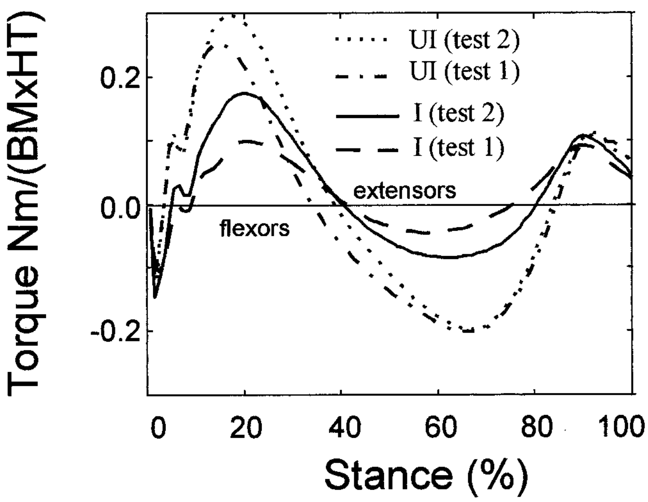

Figure 1. Knee moments in the injured (I) and uninjured (UI) knee during the stance phase of level walking at test 1 and test 2. Curves are pooled over open and closed kinetic chain groups (*N* = 37). BM, body mass; HT, height.

was scored by measuring the location of the tick marks on the scale and adding these 28 values. The value was divided by a possible score of 280, and that percentage was subtracted from 100. Possible scores range from 0 to 100, with a score of 100 describing a knee with no disability.

On completion of the Hughston Clinic visual analog scale questionnaire, subjects were requested to perform three repeated trials of level walking and ascending and descending stairs. The walkway was 10 meters in length with a force platform located in the middle. The laboratory staircase consisted of four steps and had a tread length and rise height of 28.5 and 18 cm, respectively. Ground-reaction forces were recorded at 200 Hz from a force platform (Model 4020H, Bertec Corporation, Columbus, Ohio) mounted in the floor during walking trials. The same force plate was later moved to the second step of the staircase during the stair ascent and descent trials. Three infrared cameras (MIE Medical Research, Leeds, United Kingdom) recorded three-dimensional positions of reflective markers placed over the fifth metatarsal, lateral malleolus, anterior surface of the midshank, lateral aspect of the knee joint space, anterior surface of the midthigh and greater trochanter, and over the anterior and posterior superior iliac spines. Three-dimensional coordinates of the surface markers were measured at 50 Hz. Position and ground-reaction data were used to calculate the angles and external torque and power of the knee joint during stance phase. Joint angles were expressed relative to the relaxed standing configuration to account for the position of the reflective markers on each limb segment and the knee brace.

Data Analysis

To reduce the chance of type I error, a select number of variables were chosen to describe each task. The variables used for statistical analysis included the amount of knee flexion at the beginning and end of stance, midstance excursion angle,[22] peak knee moments, and concentric and eccentric powers.

Gait analysis scores were averaged over the repeated trials, and these means were analyzed using Statistical Package for the Social Sciences software (version 7.5.1 SPSS Inc., Chicago, Illinois). Student's *t*-tests were used to compare the makeup of the open and closed kinetic chain groups. Gait analysis scores measured from the injured knee at the first test session were also compared between the two training groups to detect significant differences in baseline values. An analysis of variance was applied to all variables to study the effects of rehabilitation group (closed versus open kinetic chain) and test session (test 1 and test 2) on the operated knee. Student's *t*-tests were used to compare the injured and uninjured knees at test 1 and test 2. The critical α level required for statistical significance was set at 0.05.

RESULTS

Two subjects participating in the first test session did not complete the second test session because training conflicted with commitments unrelated to the investigation. Three patients were excluded because they attended fewer than 7 treatment sessions, and another was excluded because there were more than 34 days between test sessions. No subjects dropped out of the trial because of graft loosening or failure. Thirty-seven patients completed both tests. Two of these patients were unable to descend stairs in a reciprocal gait manner on one or both tests, so these patients were not included in the subsequent analysis. Student's *t*-tests of the two exercise groups confirmed that the body mass, height, age, and the time from initial injury to surgery were not significantly different between the groups. The tests of baseline levels for the gait analysis variable indicated that there were no significant dif-

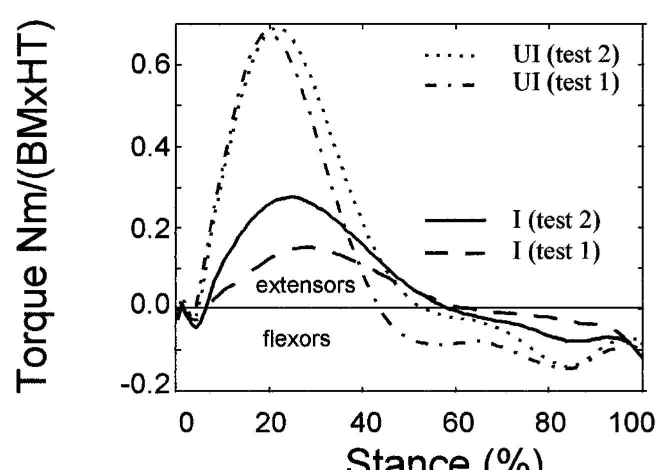

Figure 2. Knee moments in the injured (I) and uninjured (UI) knee during the stance phase of stair ascent at test 1 and test 2. Curves are pooled over open and closed kinetic chain groups (*N* = 37). BM, body mass; HT, height.

TABLE 3
Means and Standard Deviations of Kinematic and Kinetic Variables of the Knee During Stair Ascent

Biomechanical variable[a]	Test	Injured		Uninjured	
		CKC[b]	OKC[c]	CKC	OKC
Knee flexion at heel-strike[d,e] (deg)	1	45 (7)	44 (10)	58 (7)	59 (5)
	2	51 (7)	55 (8)	60 (8)	61 (5)
Peak extensor moment[d] (N·m)	1	0.22 (0.18)	0.17 (0.13)	0.70 (0.16)	0.73 (0.26)
	2	0.32 (0.21)	0.31 (0.18)	0.75 (0.14)	0.72 (0.15)
Extensor impulse[d] (N·m·s)	1	8.0 (7.7)	5.7 (6.2)	17.4 (6.0)	18.6 (10.2)
	2	9.5 (7.0)	8.0 (5.7)	17.9 (4.5)	18.1 (7.3)
Peak concentric power[d] (watts)	1	0.43 (0.34)	0.37 (0.30)	1.32 (0.35)	1.43 (0.52)
	2	0.74 (0.43)	0.73 (0.43)	1.56 (0.36)	1.44 (0.25)
Concentric energy[d] (joules)	1	10.5 (9.2)	7.8 (6.7)	31.4 (8.8)	34.0 (12.3)
	2	16.6 (10.9)	16.1 (10.8)	34.9 (8.2)	33.4 (8.1)

[a] Impulse, power, and energy are normalized to body mass multiplied by subject height.
[b] Closed kinetic chain.
[c] Open kinetic chain.
[d] Indicates a significant improvement in the injured knee from test 1 to test 2 for both groups ($P < 0.05$).
[e] Indicates a significant group by test interaction in the injured knee ($P < 0.05$).

TABLE 4
Means and Standard Deviations of Kinematic and Kinetic Variables of the Knee During Stair Descent

Biomechanical variable[a]	Test	Injured		Uninjured	
		CKC[b]	OKC[c]	CKC	OKC
Knee flexion at heel-strike[d] (deg)	1	62 (9)	57 (16)	83 (6)	85 (5)
	2	73 (10)	75 (13)	86 (8)	85 (4)
Peak extensor moment[d] (N·m)	1	0.31 (0.19)	0.30 (0.21)	0.76 (0.12)	0.83 (0.17)
	2	0.39 (0.16)	0.38 (0.15)	0.76 (0.16)	0.76 (0.20)
Extensor impulse (N·m·s)	1	9.4 (9.1)	10.2 (10.8)	22.1 (6.9)	26.9 (12.6)
	2	11.1 (5.9)	11.7 (9.4)	22.9 (11.2)	20.1 (7.6)
Peak eccentric power[d] (watts)	1	0.91 (0.49)	0.75 (0.41)	1.96 (0.64)	2.09 (0.52)
	2	1.59 (0.61)	1.50 (0.65)	2.27 (0.50)	2.39 (0.42)
Eccentric energy[d] (joules)	1	15.6 (11.1)	12.5 (7.4)	47.3 (7.8)	54.0 (10.6)
	2	23.5 (10.7)	23.0 (10.2)	50.4 (14.0)	47.1 (11.8)

[a] Impulse, power, and energy are normalized to body mass multiplied by subject height.
[b] Closed kinetic chain.
[c] Open kinetic chain.
[d] Indicates a significant improvement in the injured knee from test 1 to test 2 ($P < 0.05$).

ferences between the injured knees of patients entering either the open or closed kinetic chain groups ($P < 0.05$).

The analysis of variance indicated that the mean score on the Hughston Clinic visual analog scale improved from test 1 to test 2 ($P \leq 0.001$) and that the score was not affected by the type of training. At test 1 the mean scores were 45% (SD, 15%) and 47% (SD, 14%) for the closed and open kinetic chain groups, respectively. At test 2, the mean scores improved to 61% (SD, 14%) for the closed kinetic chain group and 61% (SD, 15%), as well, for the open kinetic chain group.

During *walking*, the amount of knee flexion at heel-strike and toe-off and the midstance excursion angle were significantly increased at test 2 compared with test 1, but there was no significant difference between the training groups (Table 2). In studying these results in Table 2 it is important not to forget that knee angles are expressed relative to the standing position and that the flexion angles presented for the injured leg have an offset included. The same was true for the amount of eccentric and concentric energy transfer at the knee during stance phase. Flexion angles and energy levels were significantly greater in the uninjured knee at both tests. Flexor and extensor muscle impulses were not significantly changed by the rehabilitation programs. Figure 1 shows the resulting knee moments on each leg and at each test, pooled over groups. The curve representing the injured leg is similar in shape to the curve for the uninjured leg, but with lower peak amplitudes.

During *stair ascent*, the angle of the knee at foot contact was significantly ($P < 0.05$) improved in the open kinetic chain group compared with the closed kinetic chain group (Table 3). Subjects in the closed kinetic chain group had their knees at an average of 45° (SD, 7°) at test 1, and this value increased to 51° (SD, 7°) at test 2. Those in the open kinetic chain group had an average of 44° (SD, 10°) at test 1, which increased to 55° (SD, 8°) at test 2. The peak extensor torque in the knee (Fig. 2), peak concentric power, and total concentric work done by the knee during stair ascent were all significantly improved by therapy, but with no significant differences between the training groups. All biomechanical variables studied were greater in the uninjured leg than in the injured leg at both test sessions.

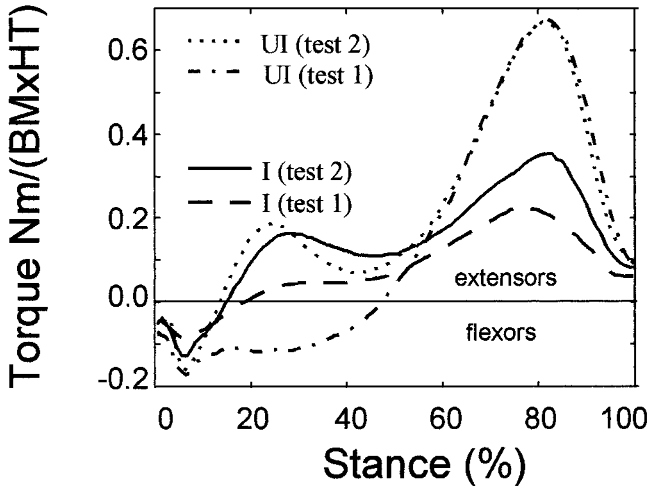

Figure 3. Knee moments in the injured (I) and uninjured (UI) knee during the stance phase of stair descent at test 1 and test 2. Curves are pooled over open and closed kinetic chain groups ($N = 35$). BM, body mass; HT, height.

The analysis of *stair descent* produced similar findings (Table 4). Peak extensor torque, peak eccentric power, and total eccentric energy absorbed during stair descent were all improved from test 1 to test 2, but the differences between the training groups were not statistically significant. The peak extensor torque in the knee occurred late in the stance phase (Fig. 3). At test 1 there was a noted absence of the first peak extensor torque associated with a loading response (at approximately 20% of stance). At the second test session, this characteristic feature was evident in both the injured and uninjured knees. The amount of flexion in the knee at terminal stance was greater after rehabilitation in both training groups.

DISCUSSION

The primary objective of this work was to detect whether clinically relevant functional differences occurred between open and closed kinetic chain training of the knee and hip extensors in the early period after ACL reconstruction. Despite safety recommendations concerning the use of open and closed kinetic chain exercises after ACL reconstruction[26] and the common belief that closed kinetic chain tasks better represent functional activities,[7,17,18,23] our results did not offer any quantitative evidence to prefer closed kinetic chain over open kinetic chain exercise in the 6 weeks after ACL reconstruction. Seventeen knee variables were studied in the current investigation, and the only statistically significant difference between the groups was found in the angle of the knee at the onset of stance during stair ascent. This finding might suggest that open kinetic chain exercises offered a faster return of functional range of motion, but it may also be the result of a type I error. The small magnitude of the difference in knee angle at the beginning of the stair ascent between open and closed kinetic chain training groups also raises the question of whether this difference is clinically significant, despite the statistical significance.

This study has shown that patients experienced significant improvements in nearly all biomechanical variables from 2 to 6 weeks after surgery. Similar work by Devita et al.[8] reported knee kinetics at 3 and 5 weeks after ACL reconstruction. The joint moment curves described in this study differ from those of Devita et al. in that we saw external extension torque (resisted by knee flexors) between 40% and 80% of the stance phase. Their curves indicated a constant knee extensor torque throughout stance that was attributed to an overly flexed knee during walking. Devita et al. reported an average peak extensor torque in the injured knee of 25 N·m at both 3 and 5 weeks, whereas in this report the peak extensor torques were approximately 14 N·m and 23 N·m at 2 and 6 weeks, respectively. Reports of knee function during stair climbing in the early period after ACL reconstruction could not be located for comparison.

There is a noticeable shortage of prospective data that can be used as a basis for decision-making regarding the selection of open or closed kinetic chain training methods in patients recovering from ACL reconstruction. In a prospective study by Bynum et al.,[7] analysis of subjective questionnaires indicated that a significantly higher percentage of patients in the closed kinetic chain group thought they returned to work earlier than expected ($P < 0.01$). However, when considering the Lysholm score, Tegner activity score, overall subjective rating of the knee, and lasting extension and flexion deficits, there were no significant differences between groups ($P > 0.05$). The follow-up period in the current study was much shorter than that of Bynum et al. (6 weeks versus 19 months), and this may account for the lack of agreement between the two investigations.

Another comparison of two rehabilitation programs used in patients after ACL reconstruction has been performed by Shelbourne and Nitz.[21] Their study was a retrospective review comparing the results of traditional rehabilitation based solely on open kinetic chain exercises and an "accelerated" rehabilitation program that consisted exclusively of closed kinetic chain exercises. They reported greatly improved results using the accelerated rehabilitation program, including greater return of knee extension and strength while maintaining stability and preventing anterior knee pain. However, their work must not be viewed as a direct comparison of open and closed kinetic chain exercise because the two programs were fundamentally different in the desired progression of training. The clinical trial described here suggests that it may be the intensity of early training that is critical to the rapid return of knee function described by Shelbourne and Nitz,[21] and not the choice of open or closed kinetic chain exercises.

Comments on Study Design

The lack of evidence to support the use of closed over open kinetic chain exercises after ACL reconstruction highlights the need for prospective randomized trials in orthopaedic physical therapy practice. In this investigation many factors were controlled, including the frequency and duration of structured physical therapy, time frames for rehabilitation and laboratory testing, and confounding injuries. The greatest concern for control was in regard to the intensity of physical therapy prescribed by the clinical investigators. The physical therapists participating in this study were aware of recommendations in the literature to avoid open kinetic chain exercises after ACL reconstruction and, because of this, the investigators thought that treatment might be biased toward less rigorous exercise in the open kinetic chain group compared with the closed kinetic chain group. Efforts to control training intensity included the installation of the Right-Weigh timing devices to control lifting speed and periodic on-site training reviews. It is believed that these procedures adequately controlled the training intensity between groups. The amount of patient activity that occurred outside of structured physical therapy may be another confounding factor in this clinical trial. The authors recommend that future investigators arrange to give each participant a pedometer to quantify the distance walked each day or some other device to record daily knee function.

The closed kinetic chain exercise implemented in this study was the leg press, which is similar in design to the squat lift. In this study, the leg press was chosen over the squat lift because it was necessary to have subjects train unilaterally so that the effects of training could be isolated to the injured leg. A unilateral squat exercise would be difficult to complete so soon after surgery, and the bilateral equivalent would be susceptible to load shielding of the injured knee. But despite the apparent similarity of these methods, the squat exercise has been found to elicit significantly greater activity from the knee flexors than does the leg press,[9,25] probably because of the different positions of the trunk in relation to the knee in each exercise.[16] It is the presence of antagonist muscle activity by the flexors that has contributed to the shift in rehabilitation practice toward closed kinetic chain exercise of the knee extensors. From a functional standpoint, it is the activity of the knee flexors during closed kinetic chain training that is thought to be responsible for encouraging functional improvements by requiring muscle coordination across the hip, knee, and ankle joints.[17,18] The lack of significant differences between the two groups could be a result of the similarity of muscle force activation patterns between the leg extension and leg press exercises, regardless of their traditional open and closed kinetic chain classifications.

CONCLUSIONS

We have conducted a randomized prospective clinical trial of open and closed kinetic chain exercises in the early period after ACL surgery. This article addresses the possible differences in the effects of these two exercise methods on knee function during gait. These exercises have also been compared for their effects on knee pain and stability (Ref. 15; M. C. Morrissey et al., unpublished data, 1999). A proper conclusion requires consideration of the findings for all of these methods of evaluation. With the use of gait analysis we were unable to identify any clinically relevant significant differences in functional variables between the closed and open kinetic chain groups during the first 6 weeks after ACL reconstruction. These exercises also do not appear to have different effects on knee pain or laxity during this critical period of rehabilitation after ACL reconstruction (Ref. 15; M. C. Morrissey et al., unpublished data, 1999). From these first investigations comparing closed and open kinetic chain training in the early rehabilitation period, it is suggested that a cautious approach to open kinetic chain knee extensor training may be unnecessary during this period. However, additional studies are needed to more fully understand the potential differences between open and closed kinetic chain exercise as the time from surgery increases.

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