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Open Versus Closed Chain Kinetic Exercises After Anterior Cruciate Ligament Reconstruction

A Prospective Randomized Study*

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ABSTRACT

We conducted a prospective, randomized study of open and closed kinetic chain exercises during accelerated rehabilitation after anterior cruciate ligament reconstruction to determine if closed kinetic chain exercises are safe and if they offer any advantages over conventional rehabilitation. The closed kinetic chain group used a length of elastic tubing, the Sport Cord, to perform weightbearing exercises and the open kinetic chain group used conventional physical therapy equipment. Results are reported with a minimum 1-year followup (mean, 19 months). Pre- and postoperative evaluation included the Lysholm knee function scoring scale, Tegner activity rating scale and KT-1000 arthrometer measurements. Overall, stability was restored in over 90% of the knees. Preoperative patellofemoral pain was reduced significantly; 95% of the patients had a full range of motion. The closed kinetic chain group had lower mean KT-1000 arthrometer side-to-side differences, less patellofemoral pain, was generally more satisfied with the end result, and more often thought they returned to normal daily activities and sports sooner than expected. We concluded that closed kinetic chain exercises are safe and effective and offer some important advantages over open kinetic chain exercises. As a result of this study, we now use the closed kinetic chain protocol exclusively after anterior cruciate ligament reconstruction.

The benefits of accelerated rehabilitation after ACL reconstruction have been well described.[7,9,20,22–24,28–30,35] Controversy still exists over the optimum strength training protocol. Various authors recommend isotonic, isokinetic, open kinetic chain, and closed chain exercises.[1,5,6,12,15,26,31,32,34,36] Closed kinetic chain exercises are performed near full extension (0° to 30° of knee flexion) with the foot on a surface and the entire limb loaded (e.g., squats and leg presses). This causes joint compression and, theoretically, added joint stability. Additionally, the stresses placed on the limb are similar to normal weightbearing with expected beneficial effects including proprioception and prevention of bone and muscle atrophy. In contrast, open kinetic chain exercises are generally performed in the 30° to 90° range of knee flexion with the foot free (e.g., knee extension exercises) with less joint compression and larger shear forces across the joint.

The results of several recent studies suggest that closed kinetic chain exercises can be safely performed in the early stages of ACL rehabilitation. In an in vivo strain gauge study, Henning et al.[14] found that the half squat (closed kinetic chain) caused significantly less ACL elongation than a leg lift with a 20-pound weight (open kinetic chain). In cadaveric studies, Markolf and associates[19] demonstrated that joint loading acts to protect the ACL from high forces generated by an applied anterior tibial force. Ohkoshi et al.,[25] using EMG analysis of the thigh muscles of standing subjects, found that the mean shear force was posterior (posterior drawer) at all knee flexion angles. Drez et al.[11] and Yack et al.[36] found significantly less anterior

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tibial translation in ACL-deficient knees with closed kinetic chain exercises compared with open kinetic chain exercises.

The purpose of this study was to compare open and closed kinetic chain exercises during accelerated rehabilitation after ACL reconstruction. In the open kinetic chain exercises we used conventional rehabilitation techniques and in the closed kinetic chain exercises we used the Sport Cord (Innovation Sports, Irvine, California), a specialized length of elastic tubing with handles at both ends to provide resistance during weightbearing concentric and eccentric exercises, in the exercise regimen. Specifically, we wanted to determine if closed kinetic chain exercises were safe and if they offered any advantages over conventional ACL rehabilitation protocols.

MATERIALS AND METHODS

Between March 1989 and October 1990, patients undergoing arthroscopically assisted ACL reconstruction with an autograft of the middle third of the patellar tendon were voluntarily and prospectively enrolled in the study. This study had Institutional Review Board approval and all patients signed consent forms. One hundred patients met the inclusion criteria: minimum age 18, isolated ACL tear, normal contralateral knee for comparison, and rigid graft fixation. Graft fixation was routinely obtained with 9-mm interference screws. The surgeries were performed under the direct supervision of staff orthopaedic surgeons. Postoperatively, the patients were assigned to one of the two rehabilitation protocols by opening a sealed and numbered envelope, the contents of which were determined by a computer-generated table of random numbers. The patients received their therapy in the physical therapy department under the direct supervision of a trained physical therapist experienced in knee rehabilitation.

After reconstruction, all operated knees were placed in a long leg hinged knee brace allowing 0° to 90° of motion. Continuous passive motion from 0° to 60° was begun in the recovery room and continued for a minimum of 12 hours daily and progressed as tolerated until discharge. Rehabilitation was begun on the day after surgery with passive, active-assisted, and active motion without resistance, in the brace. Partial weightbearing on crutches was allowed and progressed to full weightbearing as tolerated. Well-leg training and aerobic conditioning were emphasized throughout this period. The rehabilitation protocols are summarized in Tables 1 and 2.

TABLE 1
Open kinetic chain exercise protocol

Time	Exercise
0–3 weeks	Cocontraction isometrics; hamstring concentric and eccentric isotonics
3 weeks	30° of flexion straight leg raises
6 weeks	Quadriceps isotonics with low weights; low resistance stationary biking and proprioception training
8 weeks	Isokinetic hamstrings
12 weeks	Unrestricted quadriceps eccentric and concentric isotonic
16 weeks	Treadmill jogging; forward and backward running; single-leg deep knee bends
24 weeks	Isokinetic quadriceps training; unrestricted progressive resistance training
7–8 months	Progressive running and sport-specific
9 months	Noncutting, jumping, and pivoting sports
12 months	Unrestricted sports

TABLE 2
Closed kinetic chain exercise protocol using the Sport Cord

Time	Exercise
0–8 weeks	Double one-third knee bends; seated leg presses; hamstring curls
6 weeks	Stationary biking; proprioception training
8 weeks	Single one-third knee bends; forward and backward walking against cord resistance; gradual progression to slow motion jogging against cord resistance
12 weeks	Slow, deep side-to-side jumping against cord resistance; previous exercises continued with added resistance from stiffer cord
16 weeks	Advance to more aggressive training such as free weight leg presses and squats; sport-specific exercises with the cord
24 weeks	Progressive running and sport-specific
9 months	Noncutting, jumping, and pivoting sports
12 months	Unrestricted sports

Evaluation

Pre- and postoperative evaluations were performed at 3-month intervals for the 1st year and then yearly by orthopaedic residents in our staff-supervised ACL clinic. The residents were blinded to the patients' rehabilitation protocol.

Subjective evaluation was based on findings including the Lysholm knee function scoring scale,[16,18] a modified Tegner activity rating scale,[33] and an overall patient assessment rating.[a]

Objective evaluation included range of motion, presence of patellofemoral tenderness, and manual and instrumented (KT-1000 arthrometer) testing of laxity. The KT-1000 knee arthrometer (MEDmetric, San Diego, California) measurements were made by a physical therapy technician who demonstrated proficiency in its use.

Each patient was asked to complete a satisfaction survey at the completion of their rehabilitation program, rating their satisfaction with the rehabilitation protocol and the end result of their surgery and rehabilitation (Table 3).

Statistical Analysis

The paired *t*-test and chi-square analysis were used to analyze for differences between the protocols. A P value < 0.05 was considered significant.

RESULTS

Of the 100 patients, 2 had early (less than 3 months postoperatively) graft failure, and 1 patient sustained a patella fracture when she fell while using crutches 9 days after

[a] If you wish to have a copy of this comprehensive table, please write to the corresponding author and request this.

TABLE 3
Results of satisfaction survey

Question	Answer	Group[a] OKC (N = 30) No.	(%)	CKC (N = 29) No.	(%)	P value
Rate your satisfaction with your rehabilitation protocol.	Very satisfied	16	(53)	16	(55)	
	Satisfied	14	(47)	12	(41)	0.57
	Dissatisfied	0		1	(3)	
Rate the end result of your surgery and rehabilitation.	Excellent	15	(50)	16	(55)	
	Good	9	(30)	12	(41)	0.13
	Fair	6	(20)	1	(3)	
When did you return to normal daily activities?	Sooner than expected	10	(33)	21	(72)	
	When expected	14	(47)	7	(24)	0.007
	Later than expected	6	(20)	1	(3)	
When did you return to sports?	Sooner than expected	13	(43)	12	(41)	
	When expected	5	(17)	11	(38)	0.118
	Later than expected	12	(40)	6	(21)	
Knowing what you do now, would you have the surgery again?	Yes	27	(90)	28	(97)	
	No	3	(10)	1	(3)	0.63

[a] OKC, open kinetic chain; CKC, closed kinetic chain.

surgery. These three patients could not complete the rehabilitation protocol. The remaining 97 patients made up the current study group. Forty-seven patients were randomized to the open kinetic chain protocol and 50 to the closed kinetic chain protocol. The mean age of the 88 men and 9 women was 26 years (range, 18 to 48). All surgeries were performed at least 4 weeks after injury and after the patient had regained full motion of the injured knee. Twenty-two patients (7 closed kinetic chain, 15 open kinetic chain) had their surgeries 4 to 12 weeks after injury, 19 patients (10 closed kinetic chain, 9 open kinetic chain) had their surgeries 3 to 12 months after injury, and 56 patients (33 closed kinetic chain, 23 open kinetic chain) had their surgeries 1 year or more after injury. Reconstructions were performed on 56 left and 41 right knees. Eighty percent (78) of the operated knees had associated meniscal tears. Preoperatively, there was no statistical difference between the groups in any subjective or objective category, including average time from injury to surgery (Table 4).

TABLE 4
Preoperative comparison of study groups

	Group[a] OKC (N = 47)		CKC (N = 50)	
Male	45		43	
Female	2		7	
Age, mean	26		27	
Left knee	29		27	
Right knee	18		23	
Meniscal tear	36	(77%)	42	(84%)
Injury to surgery				
4–12 weeks	15		7	
12–52 weeks	9		10	
>1 year	23		33	
Lysholm score	66		68	
Tegner activity level	4		4	
Subjective rating	63%		59%	
Patellofemoral pain	19	(41%)	21	(42%)
KT-20 mean side-to-side difference (mm)	3.4		3.5	
KT-max mean side-to-side difference (mm)	6.2		6.5	

[a] OKC, open kinetic chain; CKC, closed kinetic chain.

Followup of 1 year or more (mean, 19 months; range, 12 to 36) was available on 85 (88%) of the patients (44 closed kinetic chain, 41 open kinetic chain). Six patients in each group were lost to followup. Sixty-four (66%) of the patients returned for subjective and objective evaluation (32 closed kinetic chain, 32 open kinetic chain). Another 21 patients were contacted by phone. There was no significant difference in the mean Lysholm score, mean Tegner activity level, or mean subjective rating at final followup between those patients who were contacted by phone and those who returned for objective evaluation. Therefore, their subjective results were combined.

Combined Groups

In the 64 patients who returned for objective evaluation, the pivot shift was eliminated or reduced to a trace positive in 57 (89%) and the Lachman was reduced to 0 or 1+ in 58 (91%). The mean KT-20 (KT-1000 arthrometer with 20 pounds of applied force) side-to-side difference was 1.6 mm (range, −3 to 10). Fifty-four patients (84%) had a KT-20 side-to-side difference of 3 mm or less, 8 (13%) had 3 to 5 mm difference, and 2 (3%) had greater than 5 mm difference. The mean KT-max (KT-1000 arthrometer with maximum manual applied force) was 2.5 mm (range, −3 to 12.5). Forty-four patients (69%) had a KT-max side-to-side difference of 3 mm or less, 11 (17%) had a 3 to 5 mm difference, and 6 (9%) had greater than a 5 mm difference (Table 5).

At final followup, the mean extension deficit was 1.0° (range, 0° to 10°). Sixty-one patients (95%) had an extension deficit of 5° or less or had full extension. Three patients (5%) had extension deficits of 6°, 8°, and 10°, respectively, but did not feel functionally limited and declined intervention to attempt to obtain terminal extension. The mean

flexion deficit was 2.0° (range, 0° to 20°). Sixty-two patients (97%) had flexion deficits of 10° or less or full flexion. Two patients (3%) had flexion deficits of 15° and 20°, respectively, but did not require treatment.

In the 85 patients who completed the subjective portion of the evaluation, there was a significant improvement in all categories. Subjective rating increased from 61% to 85% ($P = 0.0001$), Lysholm score increased from 67 to 87 ($P = 0.0001$), and Tegner activity level increased from 4.0 to 6.0 ($P = 0.0001$). Patellofemoral pain severe enough to interfere with activities was present in 36 patients (42%) before surgery but had decreased significantly to 21% ($P = 0.004$) at final followup (Table 5).

Fifty-nine of the 85 patients (69%) completed the satisfaction survey (29 closed kinetic chain, 30 open kinetic chain). Fifty-eight (98%) were satisfied or very satisfied with their rehabilitation protocols. Fifty-two (88%) rated the end result of their surgeries and rehabilitation as excellent or good. Fifty-five (93%) of the patients said they would have the surgery again (Table 3).

Comparison of Protocols

The mean KT-20 side-to-side difference was 1.1 mm in the closed kinetic chain group and 2.2 mm in the open kinetic chain group ($P = 0.057$). The mean KT-max side-to-side difference was 1.6 and 3.3 mm in closed kinetic chain and open kinetic chain groups, respectively ($P = 0.02$). There were no significant differences in the pivot shift, Lachman, distribution of KT-20 or KT-max side-to-side difference, mean extension deficit, or mean flexion deficit between the groups (Table 5).

Patellofemoral pain severe enough to restrict activities was significantly less in the closed kinetic chain group at 9 months (15% versus 38%, $P = 0.046$) and also tended to be less in this group at all other follow-up periods. There were no significant differences in subjective rating, Lysholm score, or Tegner activity levels between the groups.

A greater percentage of the closed kinetic chain group rated the end result of their surgeries and rehabilitation as excellent or good (97% versus 80%, $P = 0.13$). Seventy-two percent (21) of the closed kinetic chain group stated they returned to normal daily activities sooner than expected, compared with only 33% (10) in the open kinetic chain group ($P = 0.007$). Also, more patients in the closed kinetic chain group stated that they returned to sports as expected or sooner than expected (79% versus 60%, $P = 0.118$) (Table 3).

TABLE 5
Postoperative comparison of study groups

	Group[a]		*P* value	Combined
	OKC	CKC		
Lysholm score[b]	86	88	0.55	87
Tegner activity level[b]	6	6	0.25	6
Subjective rating[b]	86%	84%	0.36	85%
Patellofemoral pain[b]	10 (24%)	8 (18%)	0.48	18 (21%)
Extension deficit (>5°)[c]	1 (3%)	2 (6%)	0.50	3 (5%)
Flexion deficit (>10°)[c]	0	2 (6%)	0.17	2 (6%)
Lachman 0/1 +[c]	28 (88%)	30 (91%)	0.6	58 (91%)
Pivot shift 0/trace[c]	29 (90%)	28 (89%)	0.82	57 (89%)
KT-20 mean side-to-side difference[c]	2.2 (mm)	1.1	0.057	1.6
KT-max mean side-to-side difference[c]	3.3 (mm)	1.6	0.018	2.5

[a] OKC, open kinetic chain; CKC, closed kinetic chain.
[b] $N = 41$ for OKC, 44 for CKC, 85 for combined group.
[c] $N = 32$ for OKC, 32 for CKC, 64 for combined group.

TABLE 6
Postoperative KT-1000 arthrometer differences (in millimeters) among chronic subgroups

Time	Group[a]					
	OKC			CKC		
	N	KT-1000 (20 pound)	KT-1000 (max)	*N*	KT-1000 (20 pound)	KT-1000 (max)
4–12 weeks	11	1.8	3.0	4	1.0	1.0
13–52 weeks	6	2.0	3.1	3	1.7	2.3
>12 months	15	2.6	3.5	20	1.7	1.9

[a] OKC, open kinetic chain; CKC, closed kinetic chain.

Surgical Delay Versus Results

No patients were operated on acutely (<4 weeks). There were no differences in Lysholm scores, Tegner activity levels, subjective ratings, patellofemoral pain, pivot shift, Lachman, flexion deficit or extension deficit between the chronic ACL deficiency subcategories (4 to 12 weeks, 13 to 52 weeks, >1 year). The postoperative KT-1000 arthrometer side-to-side differences tended to be larger after longer injury-to-surgery intervals, but the small numbers in each subgroup precluded valid statistical comparison (Table 6).

DISCUSSION

To our knowledge, this is the first published prospective, randomized study designed to compare open and closed kinetic chain exercises after ACL reconstruction. Closed kinetic chain exercises have been used by other investigators as part of an accelerated rehabilitation protocol, but none of these studies compared their results to open kinetic chain exercises.[8,10,17,29]

In the oft-quoted study of Shelbourne and Nitz,[29] accelerated rehabilitation emphasizing closed kinetic chain exercises reduced patellofemoral pain and incidence of flexion contracture without compromising stability. However, their study was retrospective and followup was on only 29.5% of the 247 patients after 2 years. Our study was prospective and we had 66% (64 patients) objective and 88% (85 patients) subjective followup at 19 months.

Our results suggest that there are advantages to closed kinetic chain exercises. The closed kinetic chain group had less patellofemoral pain, suggesting that closed kinetic chain exercises place less stress on the patellofemoral joint. This is most likely because of the reduction in patellofemoral joint forces during closed kinetic exercises, which are generally performed near full extension, compared with those forces generated during open kinetic exercises performed in the 30° to 90° range of motion. We acknowledge that the small differences in patellofemoral pain between the groups may not be clinically significant and that the reduction in preoperative patellofemoral pain may be

solely due to the effects of accelerated rehabilitation rather than the effects of closed kinetic chain exercises.

The closed kinetic chain group had lower mean KT-20 and KT-max side-to-side differences. This may not be clinically significant, but it does suggest that closed kinetic chain exercises place less stress on the maturing graft and confirms the safety of their use in early ACL rehabilitation. This study does not present the long-term stability results after ACL reconstruction. The KT-1000 arthrometer data are presented as a means of comparison between the groups and to show that accelerated rehabilitation with closed kinetic chain exercises does not appear to compromise stability. Ninety percent of the patients available for followup in the closed kinetic chain group had a KT-20 side-to-side difference of 3 mm or less and all were less than 5 mm. These early results compare very favorably with other studies using open kinetic exercises in both delayed and accelerated protocols.[8,20,29]

Subjectively, the closed kinetic chain group, the group using the Sport Cord, was more satisfied with the end result of their surgeries and rehabilitation and thought that they returned to normal daily activities and sports sooner than the open kinetic chain group. This is likely because of the functional similarity of closed kinetic chain exercises and normal weightbearing activities and the expected beneficial effects on muscle strength, endurance, and proprioception. Other advantages are the economy and convenience of closed kinetic chain training. The Sport Cord costs approximately $40.00, can be easily carried in a briefcase or suitcase, and a complete workout can be performed almost anywhere. This is in contrast to the expensive gymnasium- or therapy department-based equipment required for standard isotonic and isokinetic exercises. To our knowledge, this is the first published study on the use of the Sport Cord for rehabilitation of the knee after ACL reconstruction.

Our study also confirms the findings of other investigators that immediate full motion and early weightbearing and strength training reduce the incidence of stiffness and patellofemoral pain. With traditional rehabilitation protocols, the incidence of flexion contracture greater than 5° was 14% to 32%.[2,27] Shelbourne and Nitz[29] reduced their incidence of flexion contracture from 12% to 4% after implementing their accelerated rehabilitation protocol. Only 4% of our patients who returned for followup had flexion contractures greater than 5° and none exceeded 10°. The incidence of patellofemoral pain with traditional rehabilitation is reported to be as high as 47% to 65%.[2,27] Shelbourne and Nitz[29] noted a decrease in patellofemoral pain after implementing their accelerated rehabilitation. Only 21% (18) of our patients had significant patellofemoral pain and it is important to note that this is a significant improvement from a preoperative incidence of 42% ($P = 0.0039$). A major factor emphasized by this prospective study is that patellofemoral pain exists in a high percentage of patients preoperatively and is possibly the major explanation for postoperative patellofemoral pain.

This study also supports the findings of other studies that accelerated rehabilitation is well tolerated without major side effects.[4,20,29] Two of our original 97 patients had early graft failure that could possibly be related to accelerated rehabilitation. One failure occurred as a result of a fall several weeks after surgery; the cause of the other is unknown. Both failures were in patients in the open kinetic chain group. Eighty-four percent of the patients who returned for followup had a KT-20 side-to-side difference of 3 mm or less and 97% were 5 mm or less, which is similar to other studies using both delayed and accelerated protocols.[4,8,20,29]

Considerable attention has been given to the timing of surgery. Several authors have independently recommended deferring surgery for 4 weeks to avoid postoperative flexion contracture and stiffness.[13,21,29] None of our patients were operated on acutely because we are careful to defer surgery until the patient has nearly full motion and minimal swelling. This is an additional factor that helps account for our low incidence of flexion contracture and reoperation. The noted trend of looser knees with an increasing interval to surgery is probably due to loss of secondary restraints, as suggested by Bach et al.[3] We agree that there are no advantages of urgent early ACL reconstruction and also prefer an elective, subacute (more than 4 weeks, less than 12 weeks) reconstruction when motion and effusion goals have been achieved.

CONCLUSIONS

The results of this study support the premise that closed kinetic chain exercises, when used as part of an accelerated protocol, are a safe and effective means of rehabilitating the knee in the early stages after ACL reconstruction. The results also suggest that closed kinetic chain exercises may offer additional advantages of less stress on the maturing graft and the patellofemoral joint, cost effectiveness and convenience, and excellent patient acceptance and satisfaction. This study also confirms that accelerated rehabilitation emphasizing immediate full motion and early weightbearing and strength training reduces the incidence of postoperative flexion or extension loss and patellofemoral pain without any major negative side effect. As a result of this study, we now use the closed kinetic chain protocol exclusively for rehabilitation after ACL reconstruction.

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