Open Kinetic Chain Exercises in a Restricted Range of Motion After Anterior Cruciate Ligament Reconstruction

A Randomized Controlled Clinical Trial

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Background: Recent studies have shown that an early start of open kinetic chain (OKC) exercises for quadriceps strengthening in a full range of motion (ROM) could increase anterior knee laxity after anterior cruciate ligament (ACL) reconstruction with flexor tendons. However, there are no clinical trials that evaluated outcomes of OKC exercises in a restricted ROM for pain, function, muscle strength, and anterior knee laxity at 1 year after surgery.

Purpose: To determine if an early start of OKC exercises for quadriceps strength in a restricted ROM would promote a clinical improvement without causing increased anterior knee laxity in patients after ACL reconstruction.

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

Methods: A total of 49 patients between 16 and 50 years of age who underwent ACL reconstruction with semitendinosus and gracilis autografts were randomly assigned to an early start OKC (EOKC) exercise group or a late start OKC (LOKC) exercise group. The EOKC group (n = 25; mean age, 26 years) received a rehabilitation protocol with an early start of OKC (fourth week postoperatively) within a restricted ROM between 45° and 90°. The LOKC group (n = 24; mean age, 24 years) performed the same protocol with a late start of OKC exercises between 0° and 90° (12th week postoperatively). Quadriceps and hamstring muscle strength, 11-point numerical pain rating scale (NPRS), Lysholm knee scoring scale, single-legged and crossover hop tests, and anterior knee laxity were measured to assess outcomes at the 12-week, 19-week, 25-week, and 17-month postoperative follow-up (range, 13-24 months).

Results: No difference ($P < .05$) was noted between groups with respect to demographic data. Both groups (EOKC and LOKC) had a higher level of function and less pain at the 19-week, 25-week, and 17-month assessments when compared with 12 weeks postoperatively ($P < .05$). The EOKC group had improved quadriceps muscle strength at the 19-week, 25-week, and 17-month follow-up when compared with 12 weeks postoperatively ($P < .05$); the LOKC group showed improvement only at the 17-month postoperative assessment. However, the analysis between groups showed no difference for all pain and functional assessments, including anterior knee laxity ($P > .05$).

Conclusion: An early start of OKC exercises for quadriceps strengthening in a restricted ROM did not differ from a late start in terms of anterior knee laxity. The EOKC group reached the same findings in relation to pain decrease and functional improvement when compared with the LOKC group but showed a faster recovery in quadriceps strength. The nonweightbearing exercises seem appropriate for patients who have undergone ACL reconstruction, when utilized in a specific ROM. The magnitude of difference in quadriceps strength between the 2 rehabilitation protocols was around 5%; however, this difference was not clinically significant, especially because both groups had equal function on the hop tests.

Keywords: ACL; knee; reconstruction; rehabilitation; exercise therapy

Surgical reconstruction of the ruptured anterior cruciate ligament (ACL) is a common orthopaedic knee surgery and is usually followed by 4 to 9 months of physical therapy. In recent decades, several forms of ACL reconstruction have been discussed. The choice of the hamstring tendons as a graft has increased in popularity with the justification of generating minor complications such as anterior knee pain and strength deficit of extension, although leading to a possible deficit of flexion.[1,8,15,16]

After surgery, graft healing is characterized by a process called ligamentization. During this period, the graft will

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undergo changes, becoming similar to intact ligament tissue, and will be especially vulnerable during the necrosis and revascularization stages.[6,11,27] Therefore, one of the major challenges in the postoperative rehabilitation of ACL reconstruction is muscle strengthening, especially the quadriceps muscles, without compromising the graft healing process and thus avoiding an increase in anterior knee laxity and possible damage to the articular cartilage.[17,18,23]

Accelerated rehabilitation protocols after ACL reconstruction have been increasingly used because they allow an early range of motion (ROM) and weightbearing as well as a faster return to normal function and sports activity.[13,28] Closed kinetic chain (CKC) or weightbearing exercises are widely used in these protocols because of their known effects of articular compression and knee stabilization.[3,17] However, controversies exist regarding the onset of open kinetic chain (OKC) exercises.[30] Clinical and biomechanical studies have shown that nonweightbearing exercises may promote greater anterior tibial translation at specific angles of knee flexion, thereby increasing the graft tension.[3,21] In contrast, some authors have shown that quadriceps strengthening in OKC exercises can provide an improved muscle torque without damaging the normal laxity of the knee joint as well as favoring a return to preinjury levels.[4,5,22]

Heijne and Werner[17] showed that an early start of OKC exercises after ACL reconstruction with a hamstring graft promotes greater anterior knee laxity compared with a late start. However, Escamilla et al[9] and Fleming et al[13] demonstrated that it is possible to perform OKC exercises for quadriceps strengthening without overloading the graft by providing a restricted ROM, that is, performing quadriceps activation between 90° and 45° of knee flexion.

Despite numerous studies showing the advantages and risks of adding OKC exercises during the rehabilitation of patients after ACL reconstruction, there is limited information concerning the appropriate time to introduce these exercises, the best manner to prescribe them in relation to the ROM in the sagittal plane, and the possible influence on anterior laxity. Thus, the purpose of this study was to determine whether an early start of OKC exercises using a restricted ROM would promote a clinical improvement without causing increased anterior laxity in patients after ACL reconstruction.

MATERIALS AND METHODS

Study Design and Participants

A total of 64 patients who had undergone an ACL reconstruction were evaluated between March 2008 and July 2011; however, based on exclusion criteria discussed below, only 49 patients participated in this clinical trial and were randomized into 2 groups: 25 patients in the early start OKC (EOKC) group, and 24 participants in the late start OKC (LOKC) group. Two patients in the EOKC group and 2 patients in the LOKC group did not complete the 25-week rehabilitation protocol. In addition, 5 patients in each group did not attend the 17-month follow-up (Figure 1). Among those, 2 patients in each group had a graft failure and underwent a new surgical reconstruction. Finally, 18 patients in the EOKC group and 17 patients in the LOKC group were assessed at the longer follow-up, and only 1 patient in each group did not return to the preinjury activity level.

The sample size estimation calculations were justified based on the change of anterior laxity between the injured limb and the contralateral limb. A 2.0-mm difference between limbs in the EOKC and LOKC groups and a corresponding standard deviation of 2.0 mm were considered to be clinically relevant.[4,5] It was determined that a sample size of 15 patients per group would be necessary to detect the 2.0-mm difference with 80% power when α was set equal to .05. Anticipating that we would lose 20% of participants enrolled during a longer follow-up (mean, 17 months), we planned to enroll 25 patients in each group.

The patients were between 16 and 50 years of age and were included if they had undergone an ACL reconstruction surgery. The study was carried out at a single treatment center, and patients were referred to our sector by the orthopaedic surgeons of the sports medicine group. Single-bundle arthroscopic reconstruction was performed in all cases with the 4-strand semitendinosus and gracilis tendon autograft as well as partial meniscectomy if necessary. The surgery was performed using the nonanatomic transtibial technique, with 2 portals (anteromedial and anterolateral), and fixation of the graft in the femoral tunnel with a transverse pin (TLC, Proind, Cotia, SP, BR) and the tibial tunnel with a washer lock screw (Arruela denteada, Prosintese, Cotia, SP, BR). Patients were excluded if they had a previous injury or surgery to either knee, had missed more than 10% of treatment sessions, had a simultaneous fracture or a concurrent injury to the posterior cruciate ligament, had other ligament injuries, had demonstrable radiographic evidence of osteoarthritis, had total meniscectomy or meniscus repair, had cartilage lesions with exposed bone, had suffered from a disease such as diabetes or rheumatoid arthritis, or were pregnant. Furthermore, the patients who had surgery to reconstruct the ACL with a patellar graft or contralateral flexor tendons were also excluded.[4,5,17]

All volunteers were informed about the procedures for the study and signed informed consent documents written in accordance with National Health Council Resolution CNS-196/96. This study was approved by the investigating institution's Research Ethics Committee.

After determining the inclusion of the participants, a single examiner was responsible for the administration

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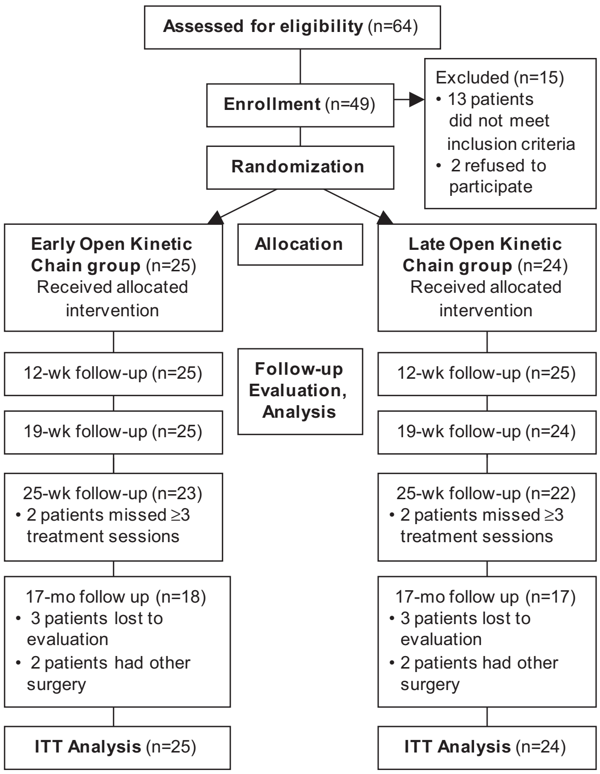

Figure 1. CONSORT flow chart, including intention-to-treat (ITT) analysis.

of all tests and questionnaires at 12 weeks, 19 weeks, 25 weeks, and 17 months after surgery. This examiner was blinded to the group assignment of the patients and did not participate in the intervention. The assignment of patients in the 2 groups was performed randomly using opaque and sealed envelopes containing the names of the groups: EOKC or LOKC. The envelopes were selected by a person not involved in this study.

Intervention

The intervention protocol of the EOKC and LOKC groups had a duration of 25 weeks (approximately 6 months). The patients from both groups completed 3 treatment sessions per week, for approximately 70 sessions. All patients started the postoperative protocol between the first and second week after surgery. Both protocols have emphasized an increase in ROM, lower limb strengthening, and balance control. Isometric CKC exercises for hip and knee strengthening started at the second postoperative week, followed by dynamic CKC exercises at the sixth postoperative week. However, patients in the EOKC group started quadriceps strengthening with OKC exercises (isotonic knee extension) at 4 weeks postoperatively, restricting the knee ROM between 90° and 45° of flexion. These exercises were performed in a knee extension machine with a lock for restricting motion. The LOKC group utilized the same exercises only at 12 weeks after surgery, at a full ROM, that is, between 0° and 90° of flexion. Thus, the rehabilitation protocol was exactly the same for the 2 groups of patients, with the only difference being the onset of OKC activities.

Partial weightbearing with crutches was performed for 2 weeks after surgery in patients from both groups. It is important to highlight that they did not use an orthotic brace to restrict ROM after surgery. The protocol applied to the EOKC and LOKC groups is described in detail in Appendix 1 (available in the online version of this article at http://ajs.sagepub.com/supplemental/). Four therapists trained in the rehabilitation protocol for the study were responsible for all treatments.

Evaluation

Muscle Strength. Muscle strength of the quadriceps and hamstrings was evaluated by measuring the maximum isometric voluntary contraction using a handheld dynamometer (Lafayette Instrument Co, Lafayette, Indiana).[29] For the quadriceps, the patient was asked to sit on the table, with arms held against the body and hips and knees at 90° and 60° of flexion, respectively.[7] The dynamometer was positioned 2 inches proximal to the lateral malleolus on the anterior aspect of the tibia, and the leg was stabilized by an inelastic band. This band was placed to fix the dynamometer to the front face of the leg, being fixed on the base of the table. For the hamstrings, the patient was in a prone position on the table, with the knee flexed at 30°. The dynamometer was placed 2 inches proximal to the lateral malleolus on the posterior aspect of the leg, being stabilized by an inelastic band. This band was fixed directly to the ground. During strength testing, we used 2 submaximum trials to familiarize the patients with each test position. This was followed by 3 trials with maximum isometric effort for each muscle group. For data analysis, the average values of the 3 trials with maximum effort were used. Ten healthy volunteers (5 men and 5 women) were tested according to the protocol described above for quadriceps and hamstring strength as a pilot study. The results indicated good and excellent reliability, with intraclass correlation coefficients (ICCs) of 0.89 and 0.92, respectively.

Anterior Knee Laxity. Anterior knee laxity was analyzed by the Rolimeter (Aircast, Vista, California). Previous studies have shown similar accuracy of this arthrometer when compared with the KT-1000 arthrometer.[14] The patient was in a supine position on the table, with a cushion under the knee to stabilize the joint at 25° of flexion. The Rolimeter was fixed to the patient's leg with a single adjustable ankle strap distally. It was positioned such that a curved proximal plate lay on the center of the patella. One of the examiner's hands was placed on this, stabilizing the plate to the patella and thus fixing the femur. A metal stylus was then placed on the patient's tibial tuberosity. A Lachman test was then performed to quantify the anterior tibial dislocation. This anterior displacement of the stylus could then be read directly from the 2-mm calibrations on the shaft of the stylus.[14] The

TABLE 1
Demographic Data of the Early OKC and Late OKC Groups[a]

	Early OKC (n = 23)	Late OKC (n = 22)	*P* Value
Age, y	26.5 ± 8.5	23.9 ± 5.5	.41
BMI, kg/m^2	25.2 ± 3.5	23.9 ± 3.2	.36
Injured limb			
Left	11 (48)	9 (40)	
Right	12 (52)	13 (60)	
Sex			
Male	16 (70)	13 (60)	
Female	7 (30)	9 (40)	
Time between injury and surgery, mo	14.3 ± 13.4	10.4 ±12.3	.41
Partial meniscectomy	12 (52)	10 (45)	
Time of follow-up, mo	16.5 ± 3.8	17.2 ± 3.6	.44

[a]Data are expressed as mean ± standard deviation or n (%). OKC, open kinetic chain; BMI, body mass index. Only those patients remaining at the end of the intervention are included.

examiner applied maximum manual force until the anterior end point was reached. Three measurements were performed on each side, and the average was obtained. Thus, the difference between sides was considered for data analysis.

Pain and Function. An 11-point numerical pain rating scale (NPRS) was used to measure pain, where 0 corresponded to "no pain" and 10 corresponded to "worst imaginable pain." The patients rated their worst level of pain during the last week. The NPRS has been shown to be reliable and valid, with a minimum clinically important difference (MCID) of 2 points for general knee pain, although we have not found specific values for ACL reconstruction.[12]

The single-legged hop test and crossover hop test were used as functional tests, according to the standardization of a previous study.[26] Three measurements were performed for each test in both lower limbs, and the first was performed to familiarize the patient with the test. The average of the last 2 measurements was used for final analysis. The performance of the surgically treated limb was expressed as a percentage of the healthy limb.

The Lysholm knee scoring scale was used to measure function and symptoms. This scale is an 8-item functional assessment tool with Portuguese language validation. The final result is expressed in a nominal and ordinal form, with a rating score of excellent (95-100 points), good (84-94 points), regular (65-83 points), and bad (≤64 points).[24] However, the MCID in functional status has not been established.

Statistical Analysis

Data were analyzed with SPSS version 13.0 (SPSS Inc, Chicago, Illinois). Descriptive statistics for demographic data and all outcome measures were expressed as means ± standard deviations. Comparison between the groups was performed using an independent *t* test for age, body mass index, and time between injury and surgery to determine whether the groups presented similar demographics. The data for muscle strength (quadriceps and hamstrings), anterior knee laxity, the single-legged and crossover hop tests, the NPRS, and the Lysholm knee scoring scale were analyzed using a separate 2 × 4 (group by time) mixed-model analysis of variance (ANOVA). The factor group had 2 levels (EOKC and LOKC), and the repeated factor time had 4 levels (12, 19, and 25 weeks as well as 17 months after surgery). An intention-to-treat analysis was performed using the last-value-carried-forward method to input values for all missing data.

RESULTS

Demographic Data

There was no statistically significant difference ($P > .05$) for age, height, body weight, body mass index, and time to surgery between the EOKC and LOKC groups (Table 1). The mean follow-up of the last evaluation was 17 ± 5 months (range, 13-24 months).

Muscle Strength

There was a statistically significant group-by-time interaction for the 2 × 4 mixed-model ANOVA for both quadriceps and hamstring strength assessments ($P = .004$ and $P = .039$, respectively). Planned pairwise comparisons for quadriceps strength indicated that the patients in the EOKC group had improved strength at 19 and 25 weeks after surgery and at 17 months when compared with 12 weeks ($P = .023$, $P = .009$, and $P < .001$, respectively). The same analysis showed that the patients in the LOKC group presented a significant difference only at the 17-month follow-up ($P = .041$). The hamstring strength evaluation showed that compared with 12 weeks after surgery, both groups had improved strength only at the 17-month follow-up ($P = .380$ and .005, respectively). We did not find any between-group difference for quadriceps and hamstring strength at 12, 19, and 25 weeks and at 17 months after surgery ($P > .05$) (Table 2).

TABLE 2
Outcome Measures After Surgery for the Early OKC (n = 18) and Late OKC (n = 17) Groups[a]

	Time After Surgery			
	12 Weeks	19 Weeks	25 Weeks	17 Months
Quadriceps strength				
Early OKC	81.2 ± 11.0 (76.1-86.3)	91.8 ± 11.9 (86.3-97.3)	94.1 ± 12.0 (88.5-99.7)	99.7 ± 7.2 (96.3-103.1)
Late OKC	81.6 ± 17.3 (73.4-89.8)	87.0 ± 13.5 (80.5-93.5)	89.5 ± 10.7 (84.4-94.6)	95.1 ± 11.8 (89.5-100.7)
Hamstring strength				
Early OKC	77.0 ± 15.9 (69.6-84.4)	82.5 ± 13.5 (76.0-89.0)	84.5 ± 14.4 (77.8-91.2)	91.2 ± 14.5 (84.4-98.0)
Late OKC	80.5 ± 10.7 (75.4-85.6)	87.8 ± 14.4 (84.3-91.3)	87.4 ± 16.0 (70.8-95.0)	98.0 ± 12.3 (92.1-103.9)
Single-legged hop test, cm				
Early OKC	82.4 ± 17.0 (74.5-90.3)	88.7 ± 8.1 (84.8-92.6)	92.3 ± 8.1 (88.4-96.2)	98.5 ± 6.5 (95.5-101.5)
Late OKC	79.3 ± 12.3 (73.4-85.2)	88.1 ± 10.1 (83.3-92.9)	94.9 ± 6.7 (91.7-98.1)	96.9 ± 7.9 (89.6-104.2)
Crossover hop test, cm				
Early OKC	84.5 ± 13.3 (78.3-90.7)	90.4 ± 8.9 (86.2-94.6)	94.0 ± 6.4 (91.0-97.0)	98.8 ± 6.5 (95.8-101.8)
Late OKC	81.9 ± 12.2 (76.1-87.7)	87.0 ± 11.0 (81.7-92.3)	92.5 ± 7.6 (88.9-96.1)	96.2 ± 8.4 (92.2-100.2)
Lysholm (0-100)				
Early OKC	88.3 ± 7.6 (84.8-91.8)	95.5 ± 5.1 (93.1-97.9)	95.8 ± 4.9 (93.5-98.1)	96.5 ± 4.7 (94.3-98.7)
Late OKC	89.3 ± 9.0 (85.0-93.6)	94.9 ± 4.6 (92.7-97.1)	94.3 ± 12.4 (88.4-100.2)	99.0 ± 4.8 (96.7-101.3)
NPRS (0-10)				
Early OKC	1.1 ± 1.0 (0.6-1.6)	0.6 ± 1.2 (0.0-1.2)	0.4 ± 0.8 (0.0-0.8)	0.4 ± 1.2 (–0.2 to 1.0)
Late OKC	2.3 ± 1.8 (1.4-3.2)	0.9 ± 1.1 (0.4-1.4)	0.2 ± 0.5 (0.0-0.4)	0.1 ± 0.3 (0.0-0.2)
Anterior laxity, mm				
Early OKC	2.7 ± 1.8 (1.9-3.5)	2.9 ± 1.4 (2.3-3.5)	3.0 ± 1.5 (2.4-3.6)	2.7 ± 1.4 (2.1-3.3)
Late OKC	2.6 ± 1.9 (1.7-3.5)	2.7 ± 1.9 (1.8-3.6)	3.0 ± 1.7 (2.2-3.8)	3.5 ± 1.8 (2.6-4.4)

[a]Data are expressed as mean ± standard deviation (95% confidence interval). OKC, open kinetic chain; NPRS, numerical pain rating scale.

Anterior Knee Laxity

There was no statistically significant group-by-time interaction ($P > .05$); that is, no difference was found within and between groups for all evaluation times, indicating that an early start of OKC exercises did not increase anterior knee laxity (Table 2). At the 17-month follow-up, among the 18 patients who finished the study in the EOKC group, 7 (39%) presented anterior laxity between 3 and 5 mm, and 2 (12%) presented greater than 5 mm. Moreover, among the 17 patients who finished the study in the LOKC group, 10 (59%) presented anterior laxity between 3 and 5 mm, and 2 (12%) presented greater than 5 mm.

Pain and Function

A significant group-by-time interaction was found for the NPRS ($P = .031$), single-legged and crossover hop tests ($P = .005$ and $P = .003$, respectively), and Lysholm scale ($P = .004$). Planned pairwise comparisons for the NPRS showed decreased pain in both the EOKC and LOKC groups at the 25-week and 17-month assessments when compared with the 12-week assessment ($.01 < P < .05$). Both groups also demonstrated significant improvement on the single-legged and crossover hop tests at 19 and 25 weeks and at 17 months when compared with the 12-week assessment ($.01 < P < .05$). Finally, in the functional assessment by the Lysholm scale, the EOKC and LOKC groups improved statistically at 19 and 25 weeks and at 17 months when compared with the 12-week assessment ($.01 < P < .05$). However, no difference was found for all pain and functional assessments in the between-group analysis at the 12-week, 19-week, 25-week, and 17-month follow-up ($P > .05$) (Table 2). The results of the intention to treat analysis were consistent with the per-protocol analysis, providing evidence that the missing data had no influence on the overall results.

DISCUSSION

The aim of this prospective, randomized, and evaluator-blinded clinical trial was to evaluate whether an early start of OKC quadriceps exercises in a restricted ROM would promote a clinical improvement without causing anterior knee laxity in patients after ACL reconstruction with flexor tendon grafts. The principal findings of the present investigation were that the early start of non-weightbearing exercises using a restricted ROM did not differ from a late start in terms of anterior knee laxity. Moreover, the EOKC group reached the same results for pain and function as did the LOKC group but presented a faster quadriceps strength recovery. The magnitude of difference in quadriceps strength between the 2 rehabilitations protocols was around 5%; however, this difference was not clinically significant, especially because both groups had equal function on the hop tests.

These findings are in discord with those of Heijne and Werner[17,18] and Kvist and Gillquist[21] who showed a significant increase in anterior knee laxity in patients with a reconstructed hamstring tendon graft who performed early OKC exercises when compared with late OKC exercises. This laxity probably occurred because of the early introduction of quadriceps exercises (approximately 4 weeks postoperatively) in a full ROM. It is believed that the graft undergoes a remodeling process, including necrosis, in the first few weeks after surgery, suggesting that the ACL graft might have its lowest mechanical strength around 6 to 8 weeks, followed by a ligamentization process that can last up to 1 year.[6,11,20,27] The present study demonstrated that nonweightbearing exercises can be confidently utilized at an early stage, if performed between a knee flexion of 90° and 45°. Several authors postulated that this ROM is safe to strengthen the quadriceps muscle without anterior shear, that is, without tension to the graft.[2,9,10,19]

Mikkelsen et al[22] also demonstrated the benefits of quadriceps strengthening in OKC exercises in an initial postoperative stage when compared with a specific CKC exercise program. The authors added weightbearing exercises without increasing anterior knee laxity. However, this study assessed patients with patellar tendon graft reconstruction.

Similar to previous studies,[4,16,18,19,25,31] our protocol was based on controlled ROM, knee and hip muscle strengthening, functional and neuromuscular control, sensorimotor training, and sports activities for a total period of approximately 6 to 7 months. It is important to highlight that the same protocol was applied in both groups, except when starting the nonweightbearing exercises.

No postoperative laxity values were measured directly after the surgical procedures, meaning that information regarding how the surgery may have influenced anterior knee laxity is not known. In addition, we also did not evaluate preoperative laxity. This might be regarded as a limitation of the study. Five orthopaedic surgeons experienced in ACL reconstruction were involved in the surgical procedures. Of these, 2 surgeons were more involved than the others by performing 70% of the reconstructions. The number of surgeons may be considered a weakness of the study. However, the single-bundle technique for ACL reconstruction was used in all cases. A strong point of the study is that the rehabilitation was performed at one outpatient rehabilitation sports clinic and supervised by physical therapists with considerable patient rehabilitation experience after ACL reconstruction. We also performed all assessments at 4 different phases: 12 weeks, 19 weeks, 25 weeks, and 17 months after surgery.

Based on the obtained results, it is thought that quadriceps strengthening with OKC exercises in a restricted ROM appears not to increase postoperative anterior knee laxity. These data should be confined to flexor tendon reconstruction and not to a patellar tendon or even double-bundle anatomic technique. However, it remains unclear how quickly the frequency and magnitude of quadriceps activation can be increased without creating an increase in anterior knee laxity. Furthermore, a more specific assessment of the ligament tissue and lower limb kinematics must be addressed in future studies.

CONCLUSION

A start of OKC exercises at 4 weeks postoperatively for quadriceps strengthening through a restricted ROM (90°-45°) did not differ from a start at 12 weeks postoperatively in terms of anterior knee laxity. The EOKC group reached the same findings in relation to pain decrease and functional improvement when compared with the LOKC group but showed a faster recovery of quadriceps strength. However, all other outcome measures, including functional hop tests, did not differ between the 2 groups. The nonweightbearing exercises seem appropriate for patients who have undergone ACL reconstruction, when utilized in a specific ROM.

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