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Effects of Distally Fixated Versus Nondistally Fixated Leg Extensor Resistance Training on Knee Pain in the Early Period After Anterior Cruciate Ligament Reconstruction

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Abstract

Background and Purpose. Nondistally fixated (ie, what is often referred to as "open kinetic chain" [OKC]) knee extensor resistance training appears to have lost favor for some forms of rehabilitation due partly to concerns that this exercise will irritate the extensor mechanism. In this randomized, single-blind clinical trial, nondistally fixated versus distally fixated (ie, often called "closed kinetic chain" [CKC]) leg extensor training were compared for their effects on knee pain. **Subjects.** Forty-three patients recovering from anterior cruciate ligament (ACL) reconstruction surgery (34 male, 9 female; mean age=29 years, SD=7.9, range=16–54). **Methods.** Knee pain was measured at 2 and 6 weeks after ACL reconstruction surgery using visual analog scales in a self-assessment questionnaire and during maximal isometric contractions of the knee extensors. Between test sessions, subjects trained 3 times per week using either OKC or CKC resistance of their knee and hip extensors as part of their physical therapy. **Results.** No differences in knee pain were found between the treatment groups. **Discussion and Conclusion.** Open kinetic chain and CKC leg extensor training in the early period after ACL reconstruction surgery do not differ in their immediate effects on anterior knee pain. Based on these findings, further studies are needed using different exercise dosages and patient groups.

Key Words: Anterior knee pain · Patellofemoral joint · Resistance training

Introduction

We believe that since the early 1990s, there has been a shift among clinicians regarding the type of resistance exercise used for the knee extensors in knee rehabilitation. The shift, in our view, has been from exercise where the resistance to the knee extensors occurs with the distal segment of the limb not fixated to exercise where the distal segment is fixated (for example, the leg squat exercise). These 2 forms of exercises are commonly referred to as "open kinetic chain" (OKC) and "closed kinetic chain" (CKC) exercises, respectively. The shift appears to have been most widespread in rehabilitation of patients with anterior cruciate ligament (ACL) injury, with or without surgical reconstruction. The support for exercises with distal fixation has been due to the early laboratory findings indicating that ACL strain is greater with nonfixated as compared with distal segment-fixated exercise.[1–3] Knee extensor exercises with distal fixation have also been adopted because of the suspicion that this type of exercise will result in greater enhancement of function[4–6] and is safer for the patellofemoral joint[7] than nondistally fixated resistance of the knee extensors.

The belief that knee extensor CKC resistance exercise is safer than OKC exercise for the patellofemoral joint is based on the finding of decreased joint pressure with the CKC method during resistance of the knee extensors in the more extended range of motion (ROM).[7–9] There appears to be a concern that the increased patellofemoral joint pressure in OKC knee extensor resistance exercise will lead to anterior knee pain and even to damage of the articular cartilage. Only the issue of pain has been studied when two exercise routines were examined for their effects on knee pain after ACL reconstruction.[10] Although the method for measuring knee pain was unclear, the authors found in one instance that patellofemoral pain severe enough to restrict activities was less in the group using CKC exercise at 9 months after ACL reconstruction versus the OKC training group (15% versus 38%). In another part of the article, the authors reported no differences in the prevalence of patients with patellofemoral pain in their follow-up testing, with 24% (n=10) of the OKC group and 18% (n=8) of the CKC group having pain. The ability to select CKC versus OKC knee extensor training due to possible pain effects is limited from these data for several reasons. The method used to determine whether a patient's patellofemoral pain was severe enough to restrict activities was unclear. Whether the treatment groups differed in their prerehabilitation patellofemoral pain also was unclear. In addition, it is possible that a type I error occurred due to the lack of alpha level adjustment in this multiple-comparison study.

There is little evidence that knee extensor CKC and OKC training differ in their effects on knee pain, at least in ACL rehabilitation. Despite this lack of evidence, we believe clinicians continue to prefer CKC exercise partly due to their belief that it is less harmful to the extensor mechanism than OKC exercise. The purpose of our study was to evaluate the immediate changes in knee pain resulting from knee extensor CKC and OKC training in the early period after ACL reconstruction in an effort to increase our understanding of possible differences in the effects of these exercise methods.

Materials and Methods

SUBJECTS

Potential subjects were identified for this study from inpatients recovering from ACL reconstruction at 5 National Health Service and private hospitals in the East London area. Subjects were deemed suitable for inclusion in the study if they had no prior history of pathology requiring medical attention in the contralateral lower extremity. Within the first 2 weeks following surgery, these subjects were given a written and verbal explanation of the study and were invited to participate in the study. Subjects were included in the study if all of the following criteria were met: (1) number of days between surgery and pretest was less than 20, (2) number of days between the pretest and the posttest was less than 35, and (3) there were 8 to 13 treatment sessions between the pretest and the posttest. Forty-three out of 53 patients satisfied these criteria and are described in Table 1.

View this table: [in this window] [in a new window] **Table 1.** Subject Characteristics[a]

After initial testing, subjects were assigned to 1 of 2 treatment groups using block randomization. Subjects were assigned to treatment groups in blocks of 4 assignments, with each block containing equal numbers of CKC and OKC assignments. This was done to keep a balance of subjects in each group throughout the study to ensure interim analysis could be performed with nearly equal numbers of subjects in the groups. Of the 21 subjects in group C (CKC training), 17 subjects had knee surgery prior to the ACL reconstruction surgery and 4 subjects had additional procedures (eg, partial meniscectomy) at the time of the ACL reconstruction surgery. Of the 22 subjects in group O (OKC training), 18 subjects had knee surgery prior to the ACL reconstruction surgery and 6 subjects had additional procedures at the time of the ACL reconstruction surgery. The mean period between original knee injury and ACL reconstruction surgery was 43 months (SD=57, range=4–204) for group C and 36 months (SD=30, range=3–91) for group O. There appeared to be no obvious differences between the 2 groups in the clinical course prior to participation in the study.

SURGICAL PROCEDURES

Three orthopedic surgeons participated in the study. Surgeon A performed ACL reconstruction surgery using the technique described by Kennedy et al.[11] This technique consists of use of a ligament augmentation device* with a small film of the patellar tendon. The tendon graft remains anchored at the tip of the tibial tuberosity. It is threaded through a tibial bone tunnel and then passed through the joint with an over-the-top technique and fixed with a lateral screw. Surgeons B and C performed arthroscopically assisted ACL reconstruction surgery 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 with fixation using interference screws or staples.

TESTING

The target date for test initiation was 2 weeks post-ACL reconstruction surgery. Subjects were allowed to participate in the study if passive flexion of their injured knee was near 90 degrees and they were able to walk without a walking aid. These criteria were used to avoid having subjects enter the study before their walking and stair climbing could be tested. After subjects read and signed an informed consent form, they participated in the following tests: knee laxity using a ligament arthrometer, knee status self-assessment questionnaire, knee girth using a cloth tape; passive ROM in knee flexion and extension using a standard goniometer, isotonic knee extensor muscle performance in the OKC (1 repetition maximum [RM] on a knee extensor machine with movement from 90° to 0° of knee flexion), isotonic knee and hip extensor muscle performance in the CKC (1 RM on a leg press machine), biomechanical analysis of knee function during walking and stair use, isokinetic performance of the hip extensors in the OKC (with movement from 90° to 0° of hip flexion at 210°/s), and isometric (60° of flexion) and isokinetic performance of the knee flexors and extensors in the OKC (with movement from 90° to 0° of knee flexion at 60° and 210°/s).

The Hughston Clinic Questionnaire[12] was used to evaluate the subjects' self-assessment of their knee condition. This questionnaire consists of 28 questions in which people are asked to respond by marking a horizontally orientated 10-cm-long visual analog scale (VAS). The validity and reliability of VAS measurements have been reported.[13,14] Only the first 2 questions and question 25 of this questionnaire (ie, those that concerned knee pain) were used in the analysis for this report. These questions (and descriptors at each end of the scale) were: (1) How often does your knee hurt? (never; daily, even at rest), (2) How bad is the pain at its worst? (none; severe, requiring pain pills every few hours), and (3) Does your knee ache while you are sitting? (never; always). The last question was included because it concerns the "cinema sign" commonly used to evaluate the patellofemoral joint by the assessment of pain during prolonged knee flexion.[15] Marks on the horizontal line separating the 2 descriptors were converted to a number by measuring the distance, to the nearest 0.5 cm, from the left end of the scale. When values were between 0 and 0.5, the values were always rounded up. Rounding was done in this fashion to ensure consistency of the data among examiners. No attempt was made to determine the location of the knee pain for the subjects' responses to these questions.

Visual analog scales were also used in the isometric and isokinetic knee testing. Pain amount (VAS score) and location were assessed after each contraction during this test series. We have chosen to include only the data from the knee extensor tests in order to focus analysis on anterior knee pain. The pain during isometric testing was chosen because it was the highest during testing. Isometric testing was performed using the Lido Multi-Joint II isokinetic system.† Testing was performed with the subjects sitting with their hips flexed to approximately 80 degrees and the knee held by the actuator arm at 60 degrees of flexion, as indicated on the Lido system's computer screen and verified with observation by the examiner. Stabilization straps were placed across the subjects' hips and chest, and the subjects gained further stabilization by gripping 2 metal bars positioned at both sides of the test chair near their hip joints. The injured leg was tested first.

Prior to the start of each subject's efforts, the machine weighed the leg by moving the subject's leg passively through the ROM, in order to account for the torque caused by the weight of the lower leg and fixation assembly. Prior to each isometric contraction, the subject was instructed to "push (for knee extensors, or 'pull' for knee flexors) as hard as you can until I tell you to stop." No further verbal encouragement was given. No warm-up contractions were included, and each subject performed a 5-second maximal contraction of the knee extensors followed by 10 seconds of rest and then a 5-second maximal contraction of the knee flexors followed by 10 seconds of rest. This was repeated 3 times. After each contraction, the subjects completed a pain VAS with descriptors ranging from "no pain" to "worst pain ever experienced" at the left and right ends of the VAS, respectively. The subjects were masked to previous marks on the VAS form. Once the subjects marked the VAS for each repetition, they were asked to tell the examiner the location of their pain by pointing at their most painful area. For the first 17 subjects in the study, the examiner selected 1 of the 8 major quadrants of the knee for describing the site of greatest pain. For the anterior aspect of the knee, the quadrants' (inferomedial, inferolateral, superomedial, and superolateral) center point was the midpoint of the patella. For the posterior aspect of the knee, the quadrants' center point was the midpoint of the popliteal space. This system was replaced because of our dissatisfaction with the subjects' inability to more precisely describe the pain site and the difficulties it presented for structures that crossed quadrant borders, such as the patellar ligament. For the last 26 subjects in the study, the examiner selected one of the descriptors in Table 2 to describe the structure that the subjects were pointing at when asked for the location of their greatest pain.

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Table 2. Pain Site Descriptors Used by Examiner to Describe Location of Pain Pointed to by Subjects During Isometric Testing of Knee Muscles

For each session, the following were recorded for the isometric contraction that produced the greatest torque: (1) pain amount, (2) pain location, and (3) torque output. The examiners were masked to subject group assignment.

TRAINING

Subjects were asked to attend physical therapy sessions 3 times per week for the 4-week training period of the study. Sessions were conducted in the outpatient physical therapy departments at 1 of 2 National Health Service hospitals in the East London area (Mile End Hospital or Whipps Cross Hospital). Because block randomization (4 assignments per block) was initiated prior to the inclusion of both sites, subjects were randomly assigned to treatment groups without respect to treatment site.

The 2 treatment groups differed in the type of isotonic resistance training used for their hip and knee extensors. Subjects in group C performed unilateral CKC resistance training of the hip and knee extensors on a leg press machine (Horizontal Leg Press‡), with all subjects in this group using the same device for this exercise regardless of treatment site. The leg press machine was set so that the subjects were positioned supine with the hip and knee in approximately 90 degrees of flexion at the beginning of each lift and the trunk slightly inclined from a parallel-to-floor position. A small block of wood was placed under the heel of the leg being exercised, and the subjects were instructed to perform the exercise without making contact between the forefoot and the leg press platform. This was done in an effort to prevent the subjects from using their plantar flexors during the exercise.

Subjects in group O exercised the same leg muscle groups (hip and knee extensors) in the OKC using either ankle weights or machines designed for isolated resistance of those muscle groups (ie, knee and hip extension machines). The equipment used was not standardized for the different training sites. The therapist managing the subjects was urged to use the machines (as compared with the ankle weights) as early as possible in the subjects' rehabilitation in order to allow greater standardization of the resistance loads and training speeds. Subjects who were not able to use the minimum weight on the knee extensor machine (due to pain or weakness) trained with the ankle weights instead.

For the hip and knee extensor muscle resistance exercises, regardless of training type (eg, distal fixation or nondistal fixation), 3 sets of 20 RM were done in each session. No other resistance training exercises of these types were allowed. The training ROM for both hip and knee extensors in both groups was 90 to 0 degrees. To control speed, subjects used Right Weigh exercise timing feedback devices.§ These machines gave immediate feedback to the subjects about the speed of their movements as they trained relative to a target speed. The target speed settings used were 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 settings represent average angular velocities of 60°/s for the concentric phase and 30°/s for the eccentric phase.

The resistance training exercises excluded in each group are summarized in Table 3. Resistance training of other 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 was allowed in both groups using a stationary cycle. The decision as to the use of cycling and the intensity, frequency, and duration of this exercise was left to the discretion of the therapist. The duration of this training was noted for each treatment session. Neuromuscular electrical stimulation and electromyographic biofeedback of the hip extensors, knee flexors and extensors, and ankle plantar flexors was not allowed during the training period.

View this table: **Table 3.** Exercises Excluded in the Training Groups[a]
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No controls were placed on methods used to manage pain, swelling, and hypomobility, although recordings of the methods used were kept by the attending therapist for possible later analysis. In addition, training designed to enhance lower-extremity balance and position sense, which consisted of resistance applied to the lower-extremity muscles, was neither restricted nor controlled. Guidance, however, was offered so that the 2 training sites were using roughly the same exercise types, frequencies, and durations. No treatment restrictions were imposed before or after the study training period.

DATA ANALYSIS

The data were processed to yield the following variables for the pretest and posttest for each subject: (1) VAS scores for questions 1, 2, and 25 of the Hughston Clinic Questionnaire, (2) maximum isometric torque of the knee extensors in the injured and uninjured legs, and (3) VAS scores for pain during the maximum isometric torque repetition of the knee extensors. For statistical analysis, the posttest pain values were subtracted from the pretest pain values, and the change scores were compared for the training groups.

Analysis was also performed to evaluate whether the non-resistance training portion of the physical therapy differed in the two groups. This analysis first consisted of one of the authors reviewing all of the physical therapy notes and removing, with correction fluid, any information that would indicate treatment group. A team of three other authors then reviewed the notes and documented the following: (1) total duration of stationary cycling used during the 4-week training period, (2) number of treatment sessions where methods were applied to manage pain and swelling, (3) number of treatment sessions where methods were applied to manage hypomobility, and (4) number of treatment sessions where methods were applied to manage poor balance or position sense. In addition, a list of the methods used for these interventions was compiled.

Results

The results of the analysis comparing the treatment groups for the non-resistance training aspects of their physical therapy are presented in Table 4. For both groups, the treatment for pain or swelling consisted of one or more of the following: pulsed shortwave diathermy, electrical stimulation using interferential current, ultrasound, and ice. The hypomobility treatment consisted of one or more of the following: massage, manual stretches and self-stretches of leg muscles, and tibiofemoral and patellar mobilization. The treatment for poor balance or position sense for both groups consisted of unilateral standing on a wobble board. None of the variables appear to indicate clinically significant differences in the non-resistance training treatment rendered in the 2 groups.

View this table: **Table 4.** Variables Describing the Non-Resistance Training Components of Physical Therapy Offered to the Treatment Groups[a]
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The Kolmogorov-Smirnov test was used to confirm that the values for each of the outcome variables were normally distributed ($P \geq .05$). We assessed normality because it is an underlying assumption that needs to be met when using parametric analysis. The descriptive statistics for each of these variables are presented in Table 5. A paired t test was used for whole group analysis, and a statistically significant decrease in reported pain between the pretest and posttest administration of the Hughston Clinic Questionnaire was found (P<.01, P<.001, and P<.001 for questions 1, 2, and 25, respectively). A one-way analysis of variance (ANOVA) was used to compare the pain reduction in OKC versus CKC training. No significant difference in pain reduction was demonstrated (P=.66, P=.94, and P=.49, respectively, for questions 1, 2, and 25, respectively).

View this table: [in this window] [in a new window]	**Table 5.** Knee Pain and Muscle Performance in the Treatment Groups Before and After Training[a]

For the analysis of pain during maximum isometric contractions of the knee extensors, the torque data was first analyzed to determine whether one group was applying greater loads (ie, greater injured/uninjured ratios for maximum peak torque) to the knee than the other group during this testing. The injured/uninjured ratios were used instead of analyzing the torque in the injured leg alone. This was done to avoid problems that can occur when torque levels are influenced by factors other than the status of the injured knee (eg, lean body mass of the subject). That is, we wanted to compare the 2 groups for knee pain during knee physical stress, and we believed that this comparison required approximating the stress to tissue size (eg, of the patellar ligament). Thus, we standardized the torque of the injured knee to the torque of the uninjured knee torque. The one-way ANOVA yielded probability values of .47 and .56 for the difference between groups in pretest and posttest muscle performance, respectively. There was no difference between treatment groups in muscle performance at pretest and posttest. Therefore, the force applied to the knee during isometric knee extensor contractions was not a potential confounder of the pain data collected in these tests.

A paired t test was applied to the pain change (pretraining-posttraining) data for the whole group during the isometric knee extensor contractions, and a decrease was noted with pretest and posttest means of 4.2 (SD=2.6) and 2.7 (SD=2.7), respectively. The one-way ANOVA of the pain change in OKC versus CKC training indicated no difference (P=.67) in pain reduction between the treatment groups.

For the last 26 subjects who entered this study where anatomic-specific pain location was assessed, there were reports of pain in 46 of their 52 knee extensor isometric tests (26 subjects tested twice, pretraining and posttraining). The frequency distributions for pain site location are described in Table 6. These data indicate that only 2 of the 46 pain sites did not consist of the extensor mechanism. The patellar ligament was sited at least twice as often as any of the other sites.

View this table: [in this window] [in a new window]	**Table 6.** Frequency for Pain Site Location in Knee Extensor Isometric (60° of Flexion) Muscle Performance Testing

Discussion

The results of our study indicate that the changes in knee pain observed from week 2 to week 6 after ACL reconstruction surgery did not differ in groups trained using leg extension with the lower extremity distally fixated versus nondistally fixated (CKC versus OKC training). This finding contradicts what appears to be a widely accepted clinical belief that knee extensor OKC training is more irritating to the extensor mechanism and will lead to more anterior knee pain than CKC training. There are a number of possible reasons for our results. It is important to first consider the possible sources of knee pain during this period of rehabilitation following ACL reconstruction surgery.

Most discussions of the source of anterior knee pain focus on patellofemoral joint contact stresses.[16,17] Although contact stress may be an important factor in the development of articular cartilage and bone damage, we suspect that the patellar ligament graft site is the primary site of anterior knee pain in patients during early recovery from the type of ACL reconstruction surgery used in our study. This supposition is based on the great degree of trauma that occurs at this site during surgery, our clinical experience with these patients, and the great frequency with which our subjects pointed at their patellar ligament when asked to identify the site of pain. For the purposes of this discussion, we will consider strain in the extensor mechanism (especially in the patellar ligament), not patellofemoral contact stress, to be the most important source of anterior knee pain.

The most obvious reason for finding no differences in knee pain between groups despite the type of exercise used for knee extensor training after ACL reconstruction surgery is that distal fixation has no differential effect on knee pain. Despite the belief that knee extensor OKC training will result in more anterior knee pain compared with CKC training, there are no previous studies in which this has been clearly found.[10] If the development of pain is dependant on patellar ligament strain, the finding of no differences between CKC and OKC effects on anterior knee pain is expected. This is because the strain in the patellar ligament probably does not differ greatly between OKC and CKC isotonic knee extensor exercise and is, if anything, greater in CKC exercise than in OKC exercise.

We draw this conclusion from a close review of the cadaveric study by Huberti et al.[18] They noted that the patellar ligament force during simulated quadriceps femoris muscle contraction (equivalent to 17% of maximum force output) was 309 N (SD=81) at 30 degrees of flexion and 356 N (SD=105) at 90 degrees of flexion. In isotonic OKC exercise as used in our study, maximum resistance relative to the torque production capability of the quadriceps femoris muscle (and thus maximum force output) occurs as the knee approaches full extension. Thus, the patellar ligament force value at 30 degrees in the study by Huberti et al[18] ($\bar{X}$=309 N) is the best representation of maximum patellar ligament tension in OKC training. Conversely, for isotonic CKC exercise as used in our study, maximum resistance relative to the torque production capability of the quadriceps femoris muscle occurred at 90 degrees. Thus, the patellar ligament force value at 90 degrees in the study by Huberti et al[18] ($\bar{X}$=356 N) is the best representation of maximum patellar ligament tension in CKC training.

There may be differences between the 2 training methods in their deleterious effects (eg, articular cartilage damage) on the knee extensor mechanism, but these differences were not detectable in our study. These possible undetected differences may be due to: (1) low training dosage (frequency, intensity, and duration), such as that used in our study, (2) the emphasis on interventions designed to decrease pain, swelling, and immobility during early rehabilitation following ACL reconstruction surgery, and (3) the type of testing used. Four weeks of training 3 times per week with exercise loads that are largely governed by knee pain may not have been sufficient for the manifestation of any real differences in anterior knee pain between distally fixated versus nondistally fixated training. In contrast, we would expect that the knee extensor mechanism would be acutely susceptible to training differences during the early recovery phase after graft harvesting from the patellar ligament. Future studies are needed that include longer training periods applied at earlier and later phases of rehabilitation following ACL reconstruction surgery.

The method of measuring the effects of the 2 training regimens on the knee extensor mechanism may have been inadequate for detecting any difference. For example, it is possible that the 2 forms of training of the knee extensors differ in the amount of damage caused to the articular cartilage of the patellofemoral joint but that this difference is not detectable by assessing *immediate* changes in anterior knee pain. In this light, long-term follow-up testing is planned for the subjects in our study.

A more appropriate physical stress test of the extensor mechanism may exist than the test we used in our study (maximum knee extensor isometric contraction at 60° of flexion). We believe the test we chose is good, however, because it allows for great strain to be placed on the patellar ligament.[18] One of the failings of this test is that it does not offer maximum stress to all portions of the extensor mechanism. Specifically, not all portions of the patellar articular surface are in contact with the femur in this single joint angle test.[19] Thus, it is possible that one portion of the patella articular surface became damaged from one of the exercise regimens but that this damage remained undetected due to lack of contact of this patellar portion during the testing at 60 degrees of flexion.

The angle of maximum patellofemoral joint pressure for the 2 exercises, as used in our study (ie, from 90° to 0° of flexion), is 90 degrees for the CKC exercises and at the point of first contact between the patella and femoral trochlea for the OKC exercises.[9] The joint angle at which contact first occurs is controversial and differs among individuals[8] but occurs between 0 and 30 degrees of knee flexion. Contact first occurs in the distal patellar articular surface, and with increasing flexion, the contact region proceeds proximally until at 90 degrees the contact is primarily of the proximal patellar articular surface. The 60-degree angle used in our study is unlikely to favor (ie, hide the detection of patellar articular damage in) one training method over the other, as the patellar contact location and patellofemoral joint pressure are roughly halfway between these values for the 2 exercises. This potential problem may be avoided in the future by testing reported pain during resistance applied to the knee extensors at a number of points in the ROM.

Conclusion

The results of our study indicate that knee pain, especially in the anterior portion of the knee, is not affected differently by exercises of the leg extensors with the lower extremity distally fixated or not fixated in the early period of rehabilitation following ACL reconstruction surgery. When considered with the data showing that knee laxity[20] and function[21] are not affected differently by CKC and OKC training of the knee and hip extensors, we recommend that either training method can be used successfully in the early period after ACL reconstruction surgery using a patellar ligament graft. The most conservative approach, and the one in which no obvious reason exists for changing, is to continue to favor knee extensor CKC training until a fuller understanding is gained about the effects of these exercises.

Footnotes

Dr Morrissey provided concept/research design. Dr Morrissey, Ms Dreschsler, Mr Morrissey, and Ms Knight provided writing and data collection. Dr Morrissey, Ms Dreschsler, Mr Morrissey, Ms Knight, and Mr Armstrong provided data analysis. Dr Morrissey and Ms Dreschler provided project management, and Dr Morrissey and Mr Morrissey provided fund procurement. Mr Morrissey, Ms Knight, and Mr McAuliffe provided subjects and institutional liaisons, and Mr Morrissey and Ms Knight provided facilities/equipment. Mr Dreschsler provided clerical support. Ms Dreschsler, Mr Morrissey, Ms Knight, Mr Armstrong, and Mr McAuliffe provided consultation (including review of manuscript before submission). The authors thank David Hooper, PhD, Laura Hanna, MCSP, John B King, FRCS, Thomas Bucknill, FRCS, and Jane Dredge, MCSP, for their support of this study.

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This study was approved by the Ethics Committee of the University of East London.

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