

ORIGINAL INVESTIGATION (ARTIGO ORIGINAL)

# THE EFFECT OF CROSS EXERCISE ON QUADRICEPS STRENGTH IN DIFFERENT KNEE ANGLES AFTER THE ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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## Abstract

PAPANDREOU, M. G. ; PAPAIOANNOU, N. ; ANTONOGIANNAKIS, E. & ZEERIS, H. The effect of cross exercise on quadriceps strength in different knee angles after the anterior cruciate ligament reconstruction. *Brazilian Journal of Biomotricity*. v. 1, n. 4, p. 123-137, 2007. The patients following ACL reconstruction (ACL-R) demonstrate a substantial quadriceps strength weakness which is more pronounced in the early postoperative period. According with the consensus of cross exercise an eccentric training program applied toward resistance exercise on the uninjured knee may be ideally suited to enhance the quadriceps strength on the ACL reconstructed knee. So, the main purpose of this study was to investigate the effect of cross eccentric exercise (CEE) on quadriceps strength at the angles 45<sup>0</sup> and 90<sup>0</sup>, in the early

rehabilitation phase on the ACL reconstructed knee. Secondary aim was to evaluate the most effective frequency of CCE for enhancement of the quadriceps strength on the ACL-R knee. 42 patients who underwent ACL reconstruction participated in this study. Patients were randomly split into 3 groups, two experimental (E1, E2) and one control. All groups followed the same rehabilitation program. Additionally, the two experimental groups followed 8 weeks of CEE on the uninjured knee; E1-3days/week, and E2-5d/w respectively. The patients were evaluated by isokinetic dynamometer on quadriceps maximal isometric strength at 45° and 90° of the knee flexion, pre-operatively and nine weeks post-operatively at both limbs. Two-way ANOVA showed statistical significant differences ( $p < 0.05$ ) on quadriceps strength enhancement at 45° ( $F = 9.11$ ,  $p < 0.01$ ) and 90° ( $F = 46.28$ ,  $p < 0.01$ ) on the ACL reconstructed knee and the above significances observed in the first experimental group compared to the control one. No statistical significant differences were found between the two experimental groups. Adding CEE to ACL traditional rehabilitation program could be beneficial exercise for quadriceps strength enhancement at 45° and 90° of knee motion at a sequence of 3d/w, in the early phase of ACL reconstruction.

**Key Words:** cross exercise-education-training, bilateral exercise, eccentric exercise, quadriceps weakness, ACL reconstruction.

### Introduction

Cross exercise (CE) is the phenomenon of motor activity on the contralateral limb in order to increase the strength in the homologous muscle on the untrained limb, without directly involving the latter in the motor activity (ZHOU, 2000). CE probably involves mechanisms that reside in the nervous system, and the most dominant mechanism is based on the theory of the cerebral cortex (CARR et al., 1994; HERBERT et al., 1996; KRISTEVA et al., 1991). It has been speculated that during voluntary contraction of a muscle on the trained side, a facilitation effect on the same motor point in the opposite side of the cerebral cortex may be produced, which in turn elicits non-apparent activity of the opposite muscles (CARR et al., 1994; HORTOBAGYI et al., 1999).

The effect of CE has been extensively investigated on quadriceps strength using voluntary muscle contractions, in healthy subjects (HORTOBAGYI et al., 1996; KANNUS et al., 1992; SHIMA et al., 2002; TANIGUCHI et al., 1997; WEIR et al. 1995). As far as the type of CE is concerned, eccentric exercise has been found to have the greatest effect on quadriceps strength improvement compared with isometric and concentric exercise forces (HORTOBAGYI et al., 1996; 1997; 1999). In addition, the eccentric exercise benefits have been well established due to its unique activation strategies by the nervous system (AAGARD et al., 2000; ENOKA et al., 1996).

As for the frequency of CE is concerned, there does not seem to be an obvious relationship across studies between the frequency and the benefits of cross exercise on quadriceps performance. On the other hand, in most studies the frequency used was three days per week (HORTOBAGYI et al., 1997; 1999;

SHIMA et al., 2002; WEIR et al., 1995).

Thus, we hypothesized if the cross eccentric exercise (CEE) is applied more than three days per week- such as five days per week- its effect in cross transfer could be bigger. This decision based on, any exercise program must be performed for a sufficient duration of days or weeks to allow the muscle specific biochemical, mitochondrial and neurological adaptations to reach a steady state (approximately more than 4-5 weeks and 3-5 days per week) (ACSM, 1998).

Based on the aforementioned results, it is not unreasonable to assume that cross eccentric exercise would be equally efficacious as it was in healthy subjects applied to specific patient's populations such as in anterior cruciate ligament (ACL) reconstructed patients.

The patients following ACL reconstruction (ACL-R) demonstrate a substantial quadriceps strength weakness which is more pronounced in the early postoperative period (ARANGIO et al., 1997; KEAYS et al., 2000; KONISHI et al., 2002; LOPESTI et al., 1988; MCHUGE et al., 2002; SNYDER-MACKLER et al., 1994; URBACH et al., 2001). In the early postoperative rehabilitation programs (duration 1-6 or 8 weeks) should be protected the ACL graft and the healing tissues (MAJIMA et al., 2002; WILK et al., 2003) and any application of intensive rehabilitation protocols on the quadriceps is contradicted. According with the consensus of cross exercise an eccentric training program applied toward resistance exercise on the uninjured knee may be ideally suited to enhance the quadriceps strength on the ACL reconstructed knee.

The ACL rupture or reconstruction causes quadriceps strength weakness that is closely related with the ACL strain levels throughout in different knee angles motion (DUSLENEN et al., 1995; LI et al., 1999; MARKOLF et al., 1995; SUTER et al., 1996).

As known, quadriceps contraction produces an anterior tibia displacement in the range of  $0^{\circ}$  to approximately  $60^{\circ}$  or  $75^{\circ}$  of knee flexion and the maximal displacement occurs at  $45^{\circ}$  (DUSLENEN et al., 1995; HIROKAWA et al., 1992; HOWEL et al., 1990; LI et al., 1999; MCHUGE et al., 2002) (quadriceps mechanical disadvantage) and less at  $90^{\circ}$  of flexion (SUTER et al., 1996) (maximum strength produced).

Based on the above studies, we assume that applying the cross eccentric exercise (CEE), as an additional rehabilitation program, in corporation with the ACL traditional rehabilitation program could be enhanced the quadriceps strength- at  $45^{\circ}$ ,  $90^{\circ}$  of knee flexion on the ACL reconstructed knee- in the early postoperative period.

So, the primary purpose of this study was to investigate the effect of cross eccentric exercise (CEE) on quadriceps strength at the angles  $45^{\circ}$  and  $90^{\circ}$ , in the early rehabilitation phase on ACL reconstructed knee. The secondary aims were to investigate whether the greatest effect of CEE on quadriceps strength occurs when is applied three or five days per week on the ACL reconstructed knee.

## Methods

- Design: This study was an intervention, randomized controlled trial, investigating 3 conditions (2 experimental and 1 control) and consisted of two parts, a pretest-(three days before the operation) and a posttest-(nine weeks after the ACL reconstruction) procedure.

- Subjects: Forty two patients all male volunteers-soldiers in the Greek army-served as subjects for this investigation. All the patients sustained unilateral ACL rupture and were randomly assigned (by coin flip) into three groups, two experimental and one control, comprising fourteen subjects each.

The ACL rupture was confirmed by the same orthopaedic surgeon, as well as by the MRI examination.

In order to assure the groups homogeneity, the inclusion criteria of the patients were the following: a) their ages ranged between 20-25 years, b) they had completely rupture of ACL with no others recent or previous injuries that demanded surgical reconstruction, c) the side-to-side difference of tibia anterior translation (SD) was greater than 3mm on the KT1000 knee arthrometer, d) the objective part of 2000 IKDC (2000) knee examination form (surgical part) ranged from C level to D (indicating abnormal or severely abnormal), e) patients were not involve in systematic recreational or sports activities and their activity level was assessed by Tegner activity score questionnaire (TEGNER et al., 1985) and ranged from 0-5 level and f) they were classified in sub-acute phase of ACL injury – forty days to six months after the ACL rupture (SHELBOURNE et al., 1991; WASILEWSKI et al., 1993).

Subjects' characteristics and inclusion criteria are shown in Table 1.

**Table 1** - Patients' physical characteristics and admission criteria: the first experimental group (E1-3days/week, n=14), the second experimental group (E2-5d/w, n=14) and the control group (C, n=14).

Subjects characteristics	E-3d/w (n=14)	E-5d/w (n=14)	C (n=14)
	Mean±SD	Mean±SD	Mean±SD
Age (yrs)	23.64±2.56	25.07±2.40	23.14±2.71
Weight (kgr)	81.28±8.40	82.50±9.83	75.00±8.00
Height (cm)	179.07±5.18	182.21±4.70	175.85±5.78
BMI (kgr/m <sup>2</sup> )	24.80±2.20	25.24±2.90	25.80±4.73
Time of ACL injury (months)	4.42±1.79	4.42±1.75	3.67±1.78
SD (KT-1000)* (mm)	5.57±2.40	6.35±1.21	5.92±2.12
Tegner activity score (0-10)	3.07±1.32	3.28±1.32	2.92±1.43

\*Side-to-side difference: (SD) of tibia anterior translation on the injured side in mm  
BMI: body mass index

The above evaluation procedure was identical for all subjects, and was carried out by the same examiner.

Fifty eight subjects were totally assessed and the subjects who excluded were

positive on their clinical varus/valgus laxity or they had a known meniscus injury that needed surgery. Other exclusion criteria included painful knee active range of motion, joint swelling, leg length discrepancy, and a history of lower extremity pain in the last six months that was not related to ACL.

This study was conducted in General Army Hospital 401 (GAH 401).

The study received ethical approval from the Laboratory for Research of Musculoskeletal system at the University of Athens. All subjects signed-informed consent forms before participating.

- Procedures: Operative technique and ACL traditional rehabilitation program

An arthroscopically assisted autograft technique was used in all cases, using the semitendinosus and gracilis tendons in quadrapted fashion as a graft source (KARLSON et al., 1954). The same surgeon performed all ACL reconstructions for this study.

All subjects followed the traditional rehabilitation program for ACL reconstruction that it was based on Wilk et al.(2003) and Majima et al.(2002) rehabilitation principles for hamstrings and gracilis graft (Table 2). The ACL rehabilitation program, in this study, was the same for all subjects. All subjects commenced the rehabilitation program one week after the reconstruction and received the traditional ACL program five days per week (from Monday to Friday) for eight weeks.

**Table 2** - ACL post-surgical rehabilitation program (WILK et al., 2003; MAJIMA et al., 2002).

<b>Post operative phase</b>	<b>Rehabilitation regimen</b>
<b>Phase 1 Duration 2-4 weeks</b>	Immediate straight leg raising. Early range of motion exercise with an emphasis on gaining full knee extension (0°). Weight bearing full as tolerated. First week 70° of flexion. Static squat (90° flexion)
<b>Phase 2 Duration 2-3 months</b>	Endurance training (biking). Progressive resistance training (leg press, calf press, step up). Dynamic squat (0°-110°). Balance exercises. Beggings level plyometric exercises. Progressive resistance exercise full range of motion, hop on one leg without pain. Isokinetic exercise and assessment.
<b>Phase 3 Duration 3-6 months</b>	Continued progressive resistance and endurance training. Jogging/running, swimming. Advanced plyometric exercises. Strengthening and functional exercise training to prepare the individual for full return activity. Goals for returning to full activity: 80% strength and 85% functional ability and proprioception > 90% compared to the non-surgical lower extremity, extension/flexion strength difference > 70%, Lushom knee scoring >90, KT1000: 3-5 mm anterior tibia translation and 2.5mm side to side difference.
<b>Functional brace</b>	6 weeks

The program was delivered by two experienced physical therapists of the physiotherapy department of 401 GAH specializing in musculoskeletal conditions (mean experience in musculoskeletal physical therapy at least five years).

Prior to the commencement of the study the principal investigator performed a day's training to physical therapists involved, in order to review and standardize the rehabilitation protocol procedure. All patients were instructed by their physical therapists to wear their functional brace and use crutches for six weeks during their daily activities.

In order to ensure that all patients received similar amounts of exercise, a home exercise program was not given, and instant, exercise level was monitored by the physical therapists via a short of fixed questions which were asked to each patient prior to each treatment session. The questions involved information about their current state (i.e. joint effusion, any pain etc.), as well as the activities they performed between the treatment session, thus, enabling some monitoring of the patients' activities. Indeed, all patients complied with this program's routine.

- Contralateral eccentric exercise (CEE): The contralateral training was an eccentric exercise program applied on the quadriceps' uninjured knee (HOUSE

et al., 1996; WEIR et al., 1995). The CEE started concurrently with the ACL physiotherapy program (described previously) and was performed by the same physical therapist.

In order to assess the quadriceps strength on uninjured knee, it was determined by the one repetition maximum (1RM) in eccentric contraction on the isotonic leg extension machine. The subject was positioned on the leg extension device and the anatomical axis of the knee was aligned with the mechanical axis of the device.

The resistance was provided by a lever arm which was placed just above the medial malleolus.

The weight of determination of 1-RM eccentric strength involved a trial in which progressively heavier loads were applied until the subject was unable to satisfactorily complete the repetition. The eccentric exercise program consisted of two to three warm up sets with no loads and followed by five sets of six repetitions at 80% of 1RM of eccentric training intensity quadriceps strength (HORTOBAGYI et al., 1996; PLOUTZ et al., 1994). The intensity kept constant throughout the eight weeks period. Two minutes of rest was allowed between each set.

In order to standardise and monitor all patients, the contralateral eccentric training program was not differentiated throughout the training period for any of the experimental groups.

So, the resistance utilized ranged from  $60.85 \pm 13.93$  kg for the first and  $61.50 \pm 11.40$  kg for the second experimental group

The subjects performed each eccentric contraction by lifted the load to the starting position with one leg-the uninjured one (the lever arm was slightly above the horizontal plane). Each subject had to control the load and then gently released it at his own speed (PADDON-JONES et al., 2001).

The two experimental groups performed 8 weeks of contralateral eccentric exercise (CEE). The first experimental group followed the CEE at a frequency of three days per week (E-3d/w), the second experimental group followed the CEE at five days per week (E-5d/w). The patients of the two experimental groups participated at their CEE when the ACL rehabilitation program completed.

- Main Outcome Measure: The criteria of isokinetic assessment (following 8 weeks of rehabilitation) was identical for all patients, and comprised the following: no pain (indicating with a 0 on a 10cm visual analog scale), no effusion (as measured by joint circumference), walking independently,  $0^{\circ}$  to  $100\text{-}120^{\circ}$  knee motion, straight leg raising in all planes, low resistance (10 reps) and multiple reps (20) with no extension lag and mini-squats  $0^{\circ}\text{-}100^{\circ}$ .

The evaluation procedure was identical for all subjects, and it was carried out by the same examiner. All subjects were evaluated on quadriceps strength in two phases: three days pre-operatively (pretest) and eight weeks post-operatively (posttest) by Kin Com AT<sup>+</sup> isokinetic dynamometer that its good reliability has been established (PINCIVERO et al., 1997). Quadriceps strength was evaluated by isometric contraction at the angles  $45^{\circ}$  and  $90^{\circ}$  of knee flexion at

both knees (PAVONE et al., 1985). Subjects were positioned in a seated position, with the hips and knees at 90° flexion and the thighs, pelvis and upper body firmly strapped to the seat of the dynamometer. Prior to testing, a warm up consisting of five minute stationary bicycle at self selected sub-maximal intensity was completed.

The knee static angles were set by the dynamometer at 45° and 90° of flexion. Each subject performed three maximum isometric contractions of 5 seconds each for both phases (pretest and posttest). Subjects were given visual and verbal encouragement. The uninjured knee was tested first and was followed by the ACL injured one.

The peak torque value of each repetition was averaged and used for statistical analysis.

- Statistical analysis: Data were analyzed with SPSS software. Results were considered statistically significant if  $p$  values were less than .05.

To account for pretest differences of quadriceps strength scores among the groups, analysis of Covariance (ANCOVA) was applied to the dependent variables-quadriceps strength posttest scores at 45° and 90° of knee flexion.

Two factor ANOVA (group x time) was applied to test group differences for the dependent variables quadriceps isometric strength (QIS) at 45° and 90° respectively, where the group factor had three levels (C, E1-3d/w, E2- 5d/w), and the time factor had two levels (pre-operatively and post-operatively). Post hoc analysis based on Tukey HSD criterion was applied to determine the location of group differences after a significant F, on the ACL injured knee.

Determining power as the ability of a test to correctly reject the null hypothesis, four factors were used: a)  $Z\alpha$  level ( $p=0.05$ ), b) the differences of each of the two means values being compared between the groups and c) the SD, and d) the sample size of each of the group subjects.

On pretest evaluation at 45°, the power between the control (C) and first experimental group (E1) was 29.12%, in other words, there is a chance of 29.12% of rejecting the null hypothesis if the values given in the data section are true. The power between the C and second experimental group (E2) was 3.22% and between E1 and E2-55.96%. The power at 90° between the C and E1 was 14.69%, between the C and E2-10.56% and between the two experimental groups 3.22%.

On posttest evaluation at 45°, the power between the C and E1 was 74.22%, between the C and E2 was 22.12% and, between E1 and E2- 32.64%.

The power at 90° between the C and E1 was 89.44%, between the C and E2-36.22% and between the two experimental groups 55.96%.

## Results

Mean and standard deviation of quadriceps isometric strength (QIS) at 45° and 90° of flexion preoperatively and postoperatively on ACL injured knee, for all three groups are shown in Table 3.

**Table 3** - Mean and standard deviation (Mean±SD) of quadriceps isometric strength (Nm) at 45° and 90° between the two phases of evaluation on ACL injured knee, for all three groups.

Angles	Pretest evaluation			Posttest evaluation			Overall significance (Two-way ANOVA)
	E1 (3d/w)	E2 (5d/w)	C	E1 (3d/w)	E2 (5d/w)	C	
45°	329.9 ±69.6	273.3 ±73.5	282.2 ±98.2	312.5 ±106.1	259.0 ±71.2	214.0 ±96.0	0.00* S
90°	405.7 ±81.7	339.9 ±117.3	361.8 ±159.5	325.8 ±99.8	261.7 ±80.3	206.0 ±96.4	0.00* S

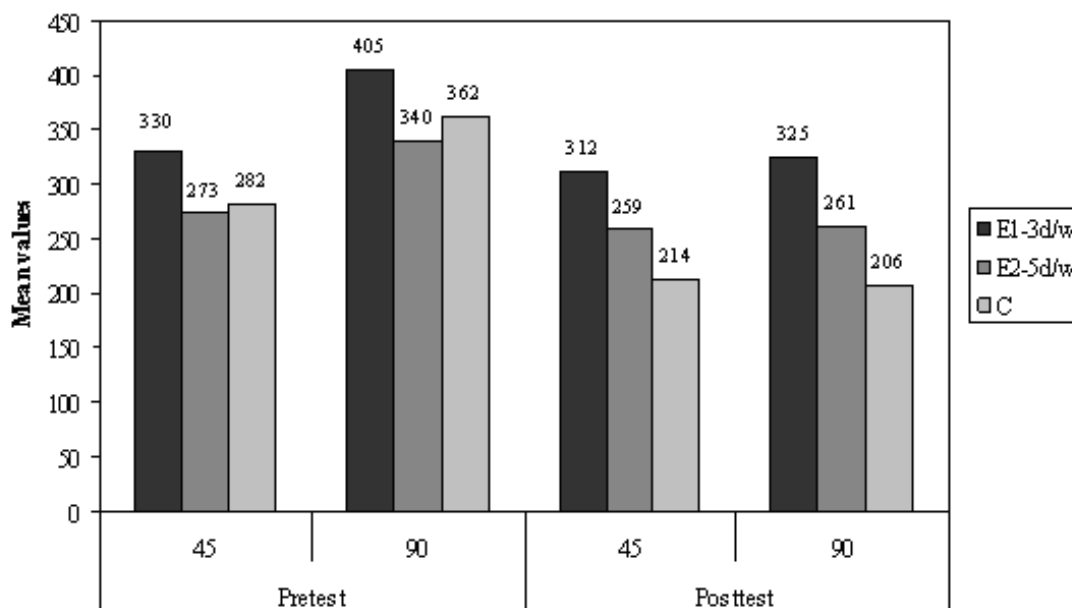
Abbreviations: E1(3 days/week) first experimental group (n=14); E2(5d/w) second experimental group (n=14); C control group (n=14).  
Statistical level  $P < 0.05$ , S=significance\*

ANCOVA revealed a statistical significant effect of the covariates-pretest QIS scores at 45° ( $F=34.81.64$ ,  $P < 0.01$ ) and 90° ( $F=21.71$ ,  $P < 0.01$ ) on depended variables QIS posttest scores. Thus, the QIS posttest means were influenced of the pretest QIS scores at 45° ( $R^2=0.45$ ) and; at 90° ( $R^2=0.33$ ) respectively. On the other hand, no statistical significant differences were observed among the groups on the pretets QIS scores at both angles.

Two factor ANOVA showed that the quadriceps isometric strength values yielded a significant group x time interaction at 45° ( $F=9.11$ ,  $p < 0.01$ ) and at 90° ( $F=46.28$ ,  $p < 0.01$ ) respectively (Table 3). Post hoc analysis by Tukey HSD determined that the above significant results arose from the first experimental group in comparison with the control group at 45° ( $D=98.4$ ,  $p=0.02$ ) and at 90° ( $D=119.8$ ,  $p < 0.01$ ) (Figure 1).

No significant differences on QIS were observed between the two experimental groups after the eight weeks of CEE, as well as between the second experimental and the control group at both angles.

## QUADRICEPS ISOMETRIC STRENGTH



**Figure 1** - The mean values of quadriceps isometric strength at 45° and 90° of flexion preoperatively and postoperatively- that define the statistical significant differences between the first experimental group (E1-3d/w) and the control one (C) postoperatively, on the ACL reconstructed knee (*Tukey HSD post hoc analysis*).

### Discussion

This study's primary aim was to explore the effect of cross eccentric exercise (CEE) on quadriceps strength enhancement when it was used as an additional rehabilitation to the traditional rehabilitation program after the ACL reconstruction.

Because of exercise in trained limb can produce a beneficial effect in the untrained one, this inter-limb interaction has been suggested as a potential means of rehabilitation for people suffering from conditions preventing them to exercise the injured limb (HOWARD et al., 1991; ZHOU 2000). Thus, the clinical significance of CE as a rehabilitative intervention has not been critically evaluated in the past and; therefore, the results of our investigation cannot be compared with previous studies because to the authors' knowledge this is the first study investigating the CE benefits in ACL reconstructed patients.

The results of this study produced statistical significance on the quadriceps strength enhancement at 45° and 90° on the ACL reconstructed knee, across the groups. Generally, we could assume that these significant results could have arisen from the eccentric exercise program which was performed though the entire range of knee motion. Most previous studies have showed that the eccentric exercise applied as CE had the greatest effect on quadriceps strength scores compared with other types of exercise (concentric or isometric)

(COLLIANDER and TESCH, 1990; ENOKA, 1996; HORTOBAGYI et al., 1997; AAGARD et al., 2000), as well as, accounting for the greater increases in isometric evaluated muscle forces (WEIR et al., 1995; HORTOBAGYI et al., 1999). On the other hand, the above statistical significant results should take into consideration, because of the posttest quadriceps scores were partially influenced of the pretest scores at both angles.

On the other hand, no statistically significant differences were observed on the pretest quadriceps values at both angles among the groups. Although, the effect of CEE was found after the ACL reconstruction, it is unclear whether the CEE mode of training was totally responsible for the positive efficacy results observed in this study. Future studies would be required to support this issue.

The secondary purpose of this study was to investigate whether the greatest effect of CEE occurred with a three or five days per week exercise frequency. Our results revealed that the CEE was more beneficial on quadriceps strength, at the first experimental group-received CE 3 days/week- compared to the control group. On the other hand, no statistical significant differences were found between the two experimental groups and between the second experimental group and the control one. The above finding may be attributed with the fact that the pre-operatively quadriceps strength values of E1-3d/w group were substantially greater than the other two groups. In addition, no reports have implicated that a particular frequency of exercise has the greatest amount of CEE benefits on quadriceps strength (ZHOU, 2000). However, CE in different frequencies have never been tested in ACL reconstructed patients before; thus, definite conclusion cannot be made. Further research should explore different exercise frequencies in CE for this patient's population.

Irrespective of these study significant results, the interesting feature was that the enhancement of quadriceps strength was bigger, at the two experimental groups at both angles, in comparison with the control group in ACL reconstructed patients.

Consequently, the results of this study suggest that CEE when used as an additional rehabilitation, at a sequence of 3d/w, to ACL traditional rehabilitation program could be beneficial exercise for quadriceps strength enhancement, in the early phase of ACL reconstruction.

#### Limitations

Due to our small sample we did not determine the effectiveness of CEE after the ACL reconstruction for the dominance and non-dominance limb. Future studies are needed to clarify this notion.

#### Conclusion

Contralateral eccentric exercise is useful mechanism in strengthening the quadriceps muscle of an ACL reconstructed knee by training the uninjured knee, at knee angles that related with the ACL strains level.

These findings have important clinical implications for training athletes and for

rehabilitation following injury. Because of no related studies based on the effects of CEE in patients', further research is needed to support the clinical implications of CE by utilizing specific patient subgroups and by exploring several parameters such as, the type of exercise, the duration, the frequency and the long effects of CE, as an additional rehabilitation program.

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