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Effect of an accelerated ACL rehabilitation protocol on knee proprioception and muscle strength after anterior cruciate ligament reconstruction

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Objective: to evaluate knee joint position sense (JPS) and muscle strength following an accelerated rehabilitation protocol after ACL reconstruction and compare it with the contralateral non-injured leg and with an age-matched non-injured control group. ***Design:*** Seven subjects (age: 26.6±4.8 years) submitted to ACL reconstruction (ACL group) using a patellar tendon auto-graft (bone-tendon-bone) and nine healthy subjects (age: 26.8±3.8 years) participated in this cross-sectional study. JPS was evaluated using a technique of open-kinetic chain and active knee positioning. Knee extensors and flexors muscle strength was evaluated in an isokinetic dynamometer at 180º/s (3.14 $rad.s^{-1}$) and 60º/s (1.05 $rad.s^{-1}$). ***Results:*** The ACL group showed better knee JPS in the uninjured knee than in the reconstructed knee in absolute (2.17º±2.69º vs. 5.98º±2.64º, $p<0.05$), relative (2.17º±2.69º vs. 5.98º±2.64º, $p<0.05$), and variable angular errors (2.38±1.15º vs. 2.01±1.64, $p<0.05$). The reconstructed knee also exhibited inferior JPS compared to both limbs of the control group. No significant differences in quadriceps and hamstrings muscle strength were observed. Significant contralateral differences between ACL and control group were found for knee extensors at 60º/s (33.6±18.0% vs. 5.9±7.1%, $p<0.05$) and 80º/s (20.2±13.5% vs. 5.8±3.9%, $p<0.05$), and knee flexors at 60º/s (16.2±6.4% vs. 8.5±5.0%, $p<0.05$). ***Conclusion:*** Our findings indicate that JPS and muscle function are still impaired after an accelerated rehabilitation protocol for ACL reconstruction surgery, suggesting that these individuals are still predisposed to further muscle or proprioceptive related knee injury.

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Key Words: anterior cruciate ligament; muscle function; proprioception; peak torque

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INTRODUCTION

The anterior cruciate ligament (ACL) injury is more frequent in athletes, particularly in females (33), usually causes long lay-off from sports activities, and is associated with an increased risk of recurrent knee injury (28, 32). ACL injuries are associated with elevated costs, including the direct costs associated with surgery and the rehabilitation process (9). However, the risk of an ACL injury in the general population is quite low; a recent population-based study conducted in New Zealand reported an ACL reported an incidence rate of ACL injury of 36.9 per 100,000 person-years (9).The ACL rupture induces changes in the kinematics of the knee joint, instability, and proprioception impairment (1). ACL rupture is usually treated with ACL reconstruction, which aims to reconstruct a mechanically strong ligament, thus restoring knee kinematics and joint stability and, therefore, avoiding long term osteoarthritis (31). The ACL may have two complementary functions: mechanical and proprioceptive (sensory) (7). Histological studies have shown that several mechanoreceptors such as Ruffini endings, Pacinian corpuscles, and Golgi tendon organs are present in the ACL (6, 11, 29, 30). It has been

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suggested that sensory information from the ACL assists in providing functional stability to the knee joint by providing paramount information to ensure adequate neuromuscular control (24). Thus, it is not surprising that several previous studies have reported proprioception deficits following ACL rupture (2, 4).

Proprioception is defined as the afferent information from different areas of the body that contribute to joint stability and postural and motor control (24), or, in other words, the sum of the neural input to the central nervous system from the afferent receptors located in the ligaments, muscles, joint capsules, tendons, and skin. Visual, cognitive, and spatial abilities also contribute significantly to the construction of proprioception. Proprioception is a sensory modality that classically involves the perception of movement, resistance, and joint positions (14).

The ACL reconstruction is followed by a physiotherapy rehabilitation program, which determines the speed and safety at which a subject regains the pre-injury level of function (31). Two types of intervention could be designed: a more conservative rehabilitation program aiming for a return to intense physical activities in 9 to 12 months and an accelerated rehabilitation program aiming for a return to intense physical activities within six months (31). Important advantages are cited for the latter, namely, lower costs, earlier return to sports, earlier graft healing, earlier recovery of range of motion, knee function, and muscle strength, and fewer complications like arthrofibrosis (31). An accelerated rehabilitation program typically lasts 16 to 22 weeks and aims to restore pre-injury levels of function, muscle strength, proprioception, neuromuscular control, and joint stability (31). The majority of the studies conducted to assess the knee proprioception following ACL reconstruction compare the reconstructed knee with the contralateral knee. Hypothesizing that the uninjured knee could be affected by both the ACL injury and the rehabilitation process, we believe that to clearly ascertain whether or not the proprioception and muscle strength has recovered following ACL reconstruction, a comparison with a non-injured control group is crucial. In this sense, the main purpose of this study was to evaluate knee joint position sense (JPS) and muscle strength following an accelerated rehabilitation protocol after ACL reconstruction and compare them with the contralateral non-injured leg, and with an age-matched non-injured control group.

MATERIAL AND METHODS

Study design

We designed a descriptive, cross-sectional study comparing JPS and knee muscle strength among healthy subjects and subjects submitted to an ACL reconstruction followed by an accelerated rehabilitation program. JPS and strength measures were obtained in both lower limbs; proprioceptive measures were obtained prior to the isokinetic strength evaluation. Before the measurement of muscle strength and JPS, all subjects were familiarized with the use of the isokinetic dynamometer and JPS testing procedures to reduce possible influences of learning on the outcomes. All the evaluation procedures were conducted by the same examiner, who was not blinded to the study design. The main outcomes for muscle function were peak torque, hamstrings/quadriceps ratio (H/Q ratio), and contralateral strength differences; outcomes for knee JPS were absolute, relative, and variable angular errors.

Subjects

Seventeen subjects—14 men and three women—participated in this study. Seven subjects (six males and one female) had history of ACL injury (four in the left and three in the right knee) and were submitted to ACL reconstruction using a patellar tendon auto-graft (bone-tendon-bone). These subjects comprised the ACL group (mean age: 26.6 ± 4.8 years; mean weight: 79.9 ± 10.1 kg; mean height: 176 ± 5 cm; mean BMI: 25.8 ± 3 kg/m^2). In all these subjects but one, the dominant lower limb was the right lower limb. The nine non-injured subjects (seven males and two females) comprised the control group (mean age: 26.8 ± 3.8 years; mean weight: 77.9 ± 9.6 kg; mean height: 176 ± 4 cm; mean BMI: 25.2 ± 2.8 kg/m^2). The dominant lower limb in the subjects who comprised the control group was the right limb for seven subjects and the left for two.

The subjects in the ACL group were recruited consecutively from a local hospital after finishing an accelerated physiotherapy rehabilitation program, which lasted for five months after the ACL reconstruction surgery. In general, the physical therapy intervention lasted 22 weeks, with three sessions per week (25, 31); they were held in the same setting and all the patients completed the same rehabilitation program under the supervision of the same physiotherapist (who had 10 years of professional experience). According to the evidence-based recommendations (25, 31), the physiotherapy protocol following ACL reconstruction included education (about surgery, complications, postsurgical exercises, walking with crutches, and the rehabilitation program), cryotherapy, electrotherapy (i.e., transcutaneous electrical nerve stimulation and muscle stimulation), joint mobility exercises (active, active assisted, and resisted), strength training (isometric, concentric, eccentric; open kinetic chain, closed kinetic chain), gait re-education, and neuromuscular and proprioceptive training. The above-mentioned treatment interventions were selected for each rehabilitation phase according to its goals: reduction of pain, swelling, and inflammation and regaining range of motion, strength, and neuromuscular control.

The subjects in the non-injured control group were selected by convenience sampling in the same geographic area.

The inclusion criteria for the ACL group were: young adults, normal knee range of motion [i.e at least 135º of knee flexion (26)], normal contralateral knee, isolated rupture of ACL, and same surgery (bone-tendon-bone). The control group followed the same criteria with the exception of the ACL injury and surgery. Participants were excluded according to the following criteria: athletes, history of other lower limb injuries within the previous six months, vestibular or neuromuscular disorders, and knee pain or infusion. The Local Ethics Committee approved the study, all participants provided written informed consent, and all procedures were conducted according to the Declaration of Helsinki.

Evaluation of proprioception (JPS)

JPS, defined clinically as the ability to reproduce joint angles, is one component of proprioception. In the present study, JPS was evaluated using a technique of open-kinetic chain and active knee positioning as previously described (22). The subjects were seated in a comfortable position, with the legs hanging freely, and blindfolded to block visual input. Four reflective markers were fixed with double-sided adhesive tape to the skin of the lateral thigh and leg over the apex of the greater trochanter, iliotibial tract level with the posterior crease of the knee when flexed to 80º, neck of the fibula and prominence of the lateral malleolus. This marker position facilitates computer measurements of videotaped knee joint test and response positions (3). One test position was investigated, prior to the strength assessment, as follows: Passive positioning by the examiner was performed by slowly extending the knee (at approximately 10º/s) from the starting position of 90º of flexion to a flexion angle between 40º and 60º, as suggested (19); then, the subjects maintained the position actively for five seconds, without manual contact from the examiner, to identify and memorize the test position; after that, the examiner replaced the leg to the starting position; finally, the subjects were instructed (given the command ‘‘reposition’’) to actively reproduce the target angle to the best of their ability and to hold the position for three seconds before returning to the initial position. Each subject performed three consecutive trials. The target angle was randomly selected from 40º to 60º. The target and the response positions were recorded with a video camera. The tripod-mounted video camera was positioned at 5 meters from the subject, at the same level of the knee joint, and then manually focused on the field of view. The camera recorded the leg movements in the sagittal plane. The same video camera was used over the experimental period. Natural vertical and horizontal lines in the videotaped environment were aligned parallel to the horizontal and vertical edges of the viewfinder so as to minimize camera tilt. Knee angles were determined by computer analysis of the videotaped images of the joint using the two-dimensional automatic digitizing module of the Ariel Performance Analysis System software (Ariel Dynamics, CA, USA). Each test or response position was determined as the average of seven consecutive knee angles digitized at 50 Hz from the videotaped view of each position. Knee JPS was reported as: (i) the absolute angular error (defined as the absolute difference between the test position and the position reproduced by the subject), which represents accuracy without directional bias; (ii) the relative angular error (the signed arithmetic difference between a test and response position), which represents accuracy with directional bias; and (iii) the variable angular error (commonly represented by the standard deviation from the mean of a set of response errors) was determined as the standard deviation from the mean of the relative errors. This method of JPS assessment demonstrated good to excellent test–retest reliability with intra-class correlation coefficient = 0.92, ranging from 0.71 to 0.98 (23).

Evaluation of muscle strength

Maximal gravity corrected concentric peak torques of knee extensors and flexors were measured during isokinetic knee joint movement at angular velocities of 180º/s (3.14 rad.s^{-1}) and 60º/s (1.05 rad.s^{-1}) with an isokinetic dynamometer (Biodex System 4, NY, USA). Subject positioning and joint alignment was performed according to the manufacturer’s instructions. In brief, subjects were seated on the dynamometer chair at 85º inclination (external angle from the horizontal) with stabilization straps at the trunk, abdomen and thigh to prevent inappropriate movements. The tested knee was positioned at 90º of flexion (0º = fully extended knee) and the axis of the dynamometer lever arm was aligned with the distal point of the lateral femoral condyle. Subjects were also instructed to hold their arms comfortably across their chests during exercise to further isolate knee joint flexion and extension movements. Before the strength evaluation, the subjects performed a warm-up consisting of five minutes of cycling on a mechanically braked cycle ergometer (Monark E-824, Vansbro, Sweden) with a fixed load corresponding to 2% of body weight. The subjects also performed a specific sub-maximal warm-up protocol on the isokinetic dynamometer consisting of nine

Table 1. Joint position sense data in both groups

	ACL Group		*Control Group*	
Joint position sense	***Reconstructed***	***Uninjured***	***Right Limb***	***Left limb***
Absolute Error (º)	5.98 ± 2.65*	2.17 ± 2.70	2.23 ± 1.25	2.45 ± 1.30
Contralateral Dif. (º)	4.19 ± 2.91**		0.62 ± 0.53	
Relative Error (º)	5.98 ± 2.65*	2.17 ± 2.70	2.23 ± 1.25	2.45 ± 1.30
Contralateral Dif. (º)	4.19 ± 2.91**		0.62 ± 0.53	
Variable Error (º)	2.38 ± 1.15*	2.01 ± 1.64	1.76 ± 0.81	2.97 ± 0.82
Contralateral Dif. (º)	1.59 ± 1.23		1.67 ± 0.59	

ACL: anterior cruciate ligament; Contralateral Dif.: contralateral difference; * Significantly different from uninjured limb and from both limbs of control group, P<0.01; ** Significantly different from the control group, P<0.01

submaximal concentric contractions of the knee extensors and flexors, immediately followed by one maximal contraction at the test speed on the isokinetic dynamometer in order to familiarize themselves with the isokinetic device and test procedures. After the warm-up, subjects rested for 30 seconds before a strength assessment, which consisted of three maximal concentric contractions at each angular velocity. A standardized verbal encouragement was given to all the subjects, motivating them for working maximally. The highest peak torque score obtained in the three repetitions was recorded for further analysis.

Statistical analysis

Data were analyzed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) statistical software. Exploratory data analysis and Shapiro-Wilk tests were performed to determine the normality of the data distribution and to identify outliers. Since the conditions for using parametric tests were fulfilled, data are described using the mean and standard deviation. Analysis of JPS acuity, knee muscle peak torque, and H/Q ratio was performed with an anova with no interactions, followed by a Bonferroni *post hoc* test if the ANOVA was significant. Independent t-tests were used to compare the contralateral differences between the ACL and control group. Statistical significance was set at α=0.05 for all statistical comparisons.

RESULTS

All 16 participants successfully completed the experimental setup. The ACL group showed better knee JPS in the uninjured leg in comparison with the reconstructed leg, which also presented inferior knee JPS than both limbs of the control group (Table 1). In the control group, no differences were found between the right and left limbs (Table 1). In all the subjects, the relative error showed a directional bias into the extension movement. Given the start position at 90º of flexion and the desired movement of the knee extension, the subjects have clearly reproduced more flexed knee angles than the target angle.

No differences in the quadriceps and hamstrings peak torque were found between groups and limbs within each group, at both angular velocities (Table 2).

The H/Q ratio in the reconstructed knee was significantly higher than that observed in the uninjured leg and in the control group, at both angular velocities (Table 2).

Concerning contralateral strength differences, the ACL group showed significantly higher contralateral difference for both quadriceps and hamstrings at 60º/s and quadriceps at 180º/s when compared with the control group.

DISCUSSION

The main findings of the present study indicate that following an accelerated rehabilitation protocol the subjects exhibited impaired knee proprioception and higher contralateral differences in quadriceps and hamstrings muscle strength.

The present study compared JPS and muscle strength between the reconstructed knee and the contralateral uninjured leg, and also with an aged-matched control group. This kind of study design differs from the majority of the previous studies (1, 10, 13), which compared only the uninjured leg (as the control leg) with the reconstructed knee. Regarding muscle strength, we used not only peak torque values but also contralateral differences. To assess JPS we chose active testing instead of passive testing, since active testing is more functional than passive testing (3) and active reproduction of joint position was found to be more accurate than passive reproduction (21).

Table 2. Muscle strength data in both groups.

	ACL Group		***Control Group***	
Muscle Strength	***Reconstructed***	***Uninjured***	***Right Limb***	***Left limb***
PT@60º Q (Nm)	160.1 ± 42.6	210.4 ± 46.2	172.1 ± 47.7	163.0 ± 35.5
Contralateral Dif. Q (%)	33.6 ± 18.0**		5.9 ± 7.1	
PT@60º H (Nm)	113.5 ± 35.6	122.2 ± 31.4	97.2 ± 31.1	89.3 ± 21.0
Contralateral Dif. H (%)	16.2 ± 6.4 **		8.5 ± 5.0	
Ratio H/Q @60º(%)	70.5 ± 10.3*	57.9 ± 5.9	56.3 ± 6.5	54.3 ± 7.0
PT@180º Q (Nm)	123.3 ± 31.4	147.5 ± 38.9	114.4 ± 31.0	114.6 ± 33.0
Contralateral Dif. Q (%)	20.2 ± 13.5 **		5.8 ± 3.9	
PT@180º H (Nm)	87.0 ± 23.3	89.6 ± 26.9	67.4 ± 21.5	65.2 ± 20.4
Contralateral Dif. H (%)	10.4 ± 6.1		8.3 ± 6.8	
Ratio H/Q @180º(%)	71.5 ± 6.4*	61.0 ± 10.4	58.8 ± 9.0	56.7 ± 7.6

ACL: anterior cruciate ligament; Contralateral Dif.: contralateral difference; H: hamstrings; PT: peak torque; Q: quadriceps; * Significantly different from reconstructed knee and from both limbs of control group, $P<0.05$; ** Significantly different from the control group, $P<0.001$

Furthermore, it was reported that active muscle contractions produce a more precise sensation of limb position (20). Active ipsilateral matching was chosen as it is a widely accepted and used method for measuring JPS (15).

The presented accelerated rehabilitation protocol following patellar tendon auto-graft ACL reconstruction does not fully recover the accuracy of knee proprioception in comparison with the contralateral leg and an aged-match control group. A comparison of our results with the literature is difficult, as knee proprioception following ACL reconstruction has been assessed using different methods and at different time points after knee surgery (1, 8, 10, 27). For instance, our results are in agreement with those reported by Lephart et al. (13) and MacDonald et al. (16), who observed proprioceptive deficits in subjects after ACL reconstruction and exercise rehabilitation. However, Lephart et al. (13) assessed proprioception by measuring sense of motion instead of sense of position and at 11 to 26 months post-ACL reconstruction. Conversely, our results contrast with those reporting that after ACL reconstruction and rehabilitation JPS returns to normal (1, 8).

Similar to our results were those of several authors (12, 18, 34) who found appreciable strength deficits after ACL reconstruction with autologous bone-tendon-bone graft. For instance, Kobayashi et al. (12) reported contralateral knee extensors strength deficits and/or recreational intense physical exercise (31). In fact, one of the criteria to define the readiness to at 60°/s of approximately 37% at six months after injury and of 30% at 180°/s. Likewise, for knee flexors a 10% contralateral difference at an angular velocity of 60°/s was also described. Niga et al. (18) measured the extensor muscle strength periodically at three, six, nine, 12, 15, and 18 months after surgery and reported a difference inferior to 20% only at 18 months. In fact, contralateral extensors muscle strength differences of 32% after one year (34) were reported.

We also observed that H/Q ratio in the reconstructed leg was significantly higher than that observed in the uninjured leg. The type of ACL reconstruction that pronouncedly affects quadriceps strength rather than hamstrings strength might explain the difference in the H/Q ratio. At 180º/s the difference in the H/Q ratio is less pronounced, which could be explained by the angular velocity at which the assessment was performed, as at higher velocities there is a greater influence of muscle coordination rather than strength (17).

Usually, patients are not advised to return to intense recreational/sports activities within six months of surgery, a time point after which it has been suggested that proprioceptive impairment no longer exists (5). The subjects in the present study presented proprioceptive deficits and muscle strength imbalance (contralateral differences and antagonist/agonist ratio), suggesting that following an accelerated rehabilitation protocol the subjects still presented an increased risk of injury and were not ready to return to occupational perform intense physical activity is to have at least 85% of the quadriceps and hamstring strength of the contralateral side (31), which was not fulfilled in our subjects.

The present study has some limitations that should be mentioned. First, the small number of subjects limits the ability to make generalized clinical conclusions. However, a very strict inclusion criterion, which excluded subjects who'd undergone different surgical procedures or had different associated injuries such as meniscal tears or cartilage damage, was an important factor restricting the recruitment of the subjects. Future studies enrolling a larger sample are clearly needed to confirm our findings. The absence of preoperative and early postoperative assessment of JPS and muscle strength may also be considered a limitation, given that it would provide information concerning the influence of the surgery and the rehabilitation process on proprioception and muscle strength.

In conclusion, the results of the present study suggest that knee proprioception and muscle strength are still impaired after ACL reconstruction surgery and an accelerated rehabilitation protocol. Consequently, clinicians should be cautious when returning individuals to tasks requiring high demands of the components of proprioception and/or muscle strength within six months of ACL surgery.

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