Original article (full paper)

Effects of isokinetic eccentric training on knee extensor and flexor torque and on gait of individuals with long term ACL reconstruction: A controlled clinical trial

Heleodório Honorato dos Santos
Federal University of Paraíba, João Pessoa, Brazil

Catarina de Oliveira Sousa
Federal University of Rio Grande do Norte, Natal, Brazil

José Angelo Barela
Ana Maria Forti Barela
Cruzeiro do Sul University, São Paulo, Brazil

Tania de Fatima Salvini
Federal University of São Carlos, São Carlos, Brazil

Abstract—This study investigated the effects of the isokinetic eccentric training (IET) on the knee extensor and flexor torque and kinematic gait parameters in individuals with ACL reconstruction. Sixteen men with ACL reconstructed (ACLr) whose torque and the gait were evaluated, before and after 12 weeks of IET, was compared to a control group (14 individuals). Student *t*, MANOVA and ANOVA tests were performed with 5% of significance. The training increased the isometric, concentric at 30 and 120º/s ($p < .05$) and eccentric at 30º/s ($p < .01$) extensor torque on the affected limb (AL), and eccentric at 30 and 120º/s ($p < .01$), on the non-affected limb (NAL). In the flexors, there was an increase on the torque: isometric, concentric at 30º/s and eccentric at 30 and 120º/s ($p < .01$) in AL and in eccentric at 30 ($p < .05$) and 120º/s ($p < .01$) in NAL. With respect to the angular and spatio-temporal variables gait, there was no difference between pre-and post-training in LCAr group. Compared to control group, the cycle time, in two members, was lower in LCAr group, and stride length and cadence were higher in the AL of the LCAr ($p < .05$). Moreover, the knee flexion-extension angles (minimum and maximum) remained lower in LCAr, pre- and post-training ($p < .01$). The torque gain associated with eccentric isokinetic training did not affect the kinematic parameters of gait in patients undergoing ACL reconstruction.

Keywords: gait, exercise, muscle strength, movement, anterior cruciate ligament reconstruction

Resumo—"Efeitos do treinamento isocinético excêntrico de extensores de joelho e torque flexor na marcha de indivíduos com reconstrução do LCA: Um ensaio clínico controlado." Este estudo investigou os efeitos do treinamento isocinético excêntrico (TIE) sobre o torque extensor e flexor do joelho e parâmetros cinemáticos da marcha de indivíduos com reconstrução do LCA. Dezesseis homens com LCA reconstruído (LCAr), foram avaliados quanto ao torque e marcha, antes e após 12 semanas de TIE e comparados com um grupo controle (14 indivíduos). Testes *t Student*, MANOVA e ANOVA foram realizados com 5% de significância. O treinamento aumentou o torque extensor isométrico, concêntrico a 30 e 120º/s ($p < 0,05$) e excêntrico a 30º/s ($p < 0,01$) no membro afetado (MA), e excêntrico a 30 e 120º/s ($p < 0,01$), no membro não afetado (MNA). Nos flexores, houve um aumento no torque: isométrico, concêntrico a 30º/s e excêntrico a 30 e 120º/s ($p < 0,01$) no MA, e excêntrico a 30 ($p < 0,05$) e 120º/s ($p < 0,01$) no MNA. Com relação às variáveis espaço-temporais e angulares da marcha, não houve diferença entre as avaliações pré e pós-treino no grupo LCAr. Comparado ao controle, a duração do ciclo, nos dois membros, foi menor no LCAr, e comprimento da passada e cadência foram maiores no MA do grupo LCAr ($p < 0,05$). Além disso, os ângulos (mínimo e máximo) de flexão-extensão do joelho permaneceram menores no LCAr, pré e pós-treino ($p < 0,01$). O ganho de torque associado ao treinamento isocinético excêntrico não modificou os parâmetros cinemáticos da marcha nos indivíduos submetidos à reconstrução do LCA.

Palavras-chave: marcha, exercício, força muscular, movimento, reconstrução do ligamento cruzado anterior

Resumen—"Efectos del entrenamiento excéntrico isocinético en extensor de la rodilla y el par flexor y sobre la marcha de las personas con reconstrucción ACL: Un ensayo clínico controlado." Este estudio investigó los efectos del entrenamiento isocinético excéntrico (EIE) en el torque del extensor y del flexor de la rodilla y parámetros cinemáticos de la marcha de personas con la reconstrucción del LCA. Dieciséis hombres con LCA reconstruido (LCAr), fueron evaluados para el par y la marcha antes y después de 12 semanas de EIE y se compararon con un grupo control (14 personas). Prueba *t* Student, ANOVA y MANOVA se realizaron con 5 % de significación. La formación aumentó extensor torque isométrico, concéntrico 30 y 120°/s ($p < 0{,}05$) y la excéntrica 30°/s ($p < 0{,}01$) en el miembro afectado (MA), y la excéntrica 30 y 120°/s ($p < 0{,}01$) en el miembro no afectado (MNA). Flexor, hubo un aumento en el par motor: isométrica , concéntrica 30°/s excéntrica 30 y 120°/s ($p < 0{,}01$) en MA, excéntrico y 30 ($p < 0{,}05$) y 120°/ s ($p < 0{,}01$) en el MNA. Con respecto a las variables angulares y espacio-temporal de andar, no hubo diferencia entre pre y post-entrenamiento en grupo LCAr. En comparación con el grupo control, el tiempo de ciclo, em los dos miembros, fue menor en LCAr, y la longitud del paso y cadencia fueron mayores en el LCAr del MA ($p < 0{,}05$). Por otra parte, los ángulos de flexión-extensión de la rodilla (mínimo y máximo) se mantuvieron bajos en LCAr, pre y post-entrenamiento ($p < 0{,}01$). El aumento del torque asociado con el entrenamiento isocinético excéntrico no afectó los parámetros cinemáticos de la marcha en las personas sometidas a la reconstrucción del LCA.

Palabras-clave: marcha, ejercicio, fuerza muscular, movimiento, reconstrucción del ligamento cruzado anterior

Introduction

The anterior cruciate ligament (ACL) is the most frequently injured ligament of the knee, resulting in pain, instability and difficulty to execute several recreational and athletic activities (Ernst, Saliba, Diduch, Hurwitz, & Ball, 2000). In order to individuals to return to his/her activities, surgical reconstruction is frequently used to recover the functional and mechanical stability of the knee joint (Ernst *et al*., 2000; Ferber, Osternig, Woollacott, Wasielewski, & Lee, 2002).

Despite of the use of protocols aiming to promote the patient return to daily life and sport activities as quickly as possible, deficits above 40% in the quadriceps strength are reported up to the 6 first months of post ACL reconstruction, specially using a patellar tendon (PT) graft (Palmieri-Smith, Thomas, & Wojtys, 2008). Such deficits can still persist with mild affection up to 5 (Ageberg, Thomeé, Neeter, Silbernagel, & Roos, 2008) or 6 years (Keays, Bullock-Saxton, Keays, Newcombe, & Bullock, 2007).

In order to recover the deficit of strength in the muscles that stabilize the knee, eccentric training has been used in ACL post-surgical rehabilitation (Fogarty, Mahaffey, & Rosene, 2001) and, in comparison to isometric or concentric training, the eccentric training promotes a higher neural activation (LaStayo *et al*., 2003) and increased muscle strength (Seger & Thorstensson, 2005).

Some authors have observed proprioceptive changes after the injury (Bonfim, Grossi, Paccola, & Barela, 2008) and subsequent ACL reconstruction (Bonfim, Paccola, & Barela, 2003), which might be related to changes in the gait kinetics and kinematics of the lower limb (Knoll, Kocsis, & Kiss, 2004). Other studies have evaluated effects of treadmill and on ground gait training using self-selected velocity by the individuals during 2 (Moraiti, Stergiou, Vasiliadis, Motsis, & Georgoulis, 2010), 3 (Kurz, Stergiou, Buzzi, & Georgoulis, 2005) and 7 years post ACL reconstruction (Sanford, Zucker-Levin, Williams, Mihallko & Jacobs, 2012). They showed, relative to a control group, differences in the gait kinematics using the trajectory of the movement (Moraiti *et al*., 2010), lower amplitude of the knee flexion angle (Lyon, Liu, Hung, & Kernozek, 2011), altered dynamic phase (Kurz *et al*., 2005), and increased valgus-varus moment of the knee, especially during the support phase (Sanford *et al*., 2012).

Although many studies on gait analysis, pre- and post-ACL reconstruction have been performed, just a few ones have evaluated the effects of isokinetic eccentric strengthening program. Coury *et al*. (2006) verified that, after 9 months of ACL reconstruction, isokinetic eccentric training of the knee extensors increased the joint torque and promoted higher similarity in movements of flexion-extension, compared to a control group. However, based on electrogoniometry data, this study also showed a significant increase in the range of motion (ROM) in valgus during the gait balance phase. This valgus increase was attributed to a mechanical compensation in the joint induced by the training which could compromise the clinical indication of this type of training for these individuals.

The intriguing results observed in the study of Coury *et al*. (2006) are questionable since the reliability of the obtained measures was later disputed. Using an articulated prototype, which simulated knee movement, it was showed that the electrogoniometer was not accurate as it was previously thought and could indicate important measurement errors due to its long use (Sato, Coury, & Hansson, 2009). Besides, in misalignment conditions, during the movements of flexion-extension ≥ 60º, it was observed an increase in the measurement error of the valgus-varus movement (Roewer, Di Stasi, & Snyder-Mackler, 2011; Sato, Hansson, & Coury, 2010).

Finally, Coury *et al*. (2006) only trained the extensor of the knee group, which may have caused an imbalance of forces around the knee joint (change of the ratio hamstrings/quadriceps). Therefore, there is still a need for studies designed to better understand the effects of eccentric training on muscle strengthening and consequent gait changes in individuals after ACL reconstruction.

The hypothesis of this study was that the isokinetic eccentric training of extensor and flexor knee muscles in individuals with long post ACL reconstruction periods (>2 years) might contribute to strengthen the muscle groups involved in these movements, improving the stability of the knee, without causing undesirable gait changes. Therefore, the purpose of this study was to investigate the effects of the isokinetic eccentric training (IET) on the knee extensor and flexor torques and kinematic gait parameters in individuals with ACL reconstruction.

Methods

Sample

The individuals of the ACL reconstructed (ACLr) group were selected by the Service of Physiotherapy in Health School Center of Federal University of São Carlos (UFSCar/SP/Brazil) based upon the following inclusion criteria: age group between 20 and 50 years old; Body Mass Index (BMI) £ 28 kg/m^2; 2 to 5 years of unilateral ACL reconstruction; graft type patellar tendon; post-surgical rehabilitation $\geq$ 6 months; have returned to daily activities and sports practice; and not showing any pain or knee edema and availability to participate in the study. A total of 16 individuals were involved in all phases of the study (30.6±9.3 years; 78.1±12.1 kg; 1.75±0.1 m; BMI=25.5±3.0 kg/m^2; lesion time=50.4±34.9 months; reconstruction time=27.0±23.7 months), according to Figure 1.

The control group (CONg) was composed of 14 individuals (29.3±8.1 years old; 81.8±11.6 kg; 1.76±0.07 m; BMI=26.7±3.4 kg/m^2), with no changes, traumas or diseases in the lower limbs, whose physical characteristics paired in to individuals of ACLr group by Intra-Class Correlation (ICC/stature = 0.87; ICC/BMI = 0.90) . The individuals in the control group were enrolled only in the gait evaluation procedures in order to make possible comparison of the gait spatiotemporal variables between groups.

The study was approved by the Ethics Committee of the Institution (CEP/UFSCar - Process nº 350/2006) and registered in the Australian New Zealand Clinical Trials Registry (ANZCTR) under the number 12607000590460. Previously to any involvement in the study and all individuals signed a Consent Form, under the Resolution 196/96 of the National Council of Health Care and Helsinki of Declaration.

Dinamometry

Knee extensor and flexor torques were evaluated with an isokinetic dynamometer (*Biodex Multi-Joint System 3, NY*) 72 hours before and after the period of isokinetic training. All individuals of the ACLr were evaluated by the same examiner, always starting with the non-affected limb (NAL), followed by the affected limb (AL), as suggested by Lautamies *et al*. (2008), in the following order of activity: 1) isometric; 2) concentric in 30 and 120º/s; and 3) eccentric in 30 and 120º/s (Dvir, 2004; Keays, Bullock-Saxton, Keays, & Newcombe, 2001). Before the tests, the individuals performed 5 minutes of warming up, riding at 20 km/h (75W) a stationary bicycle, followed by a stretching program focused on the

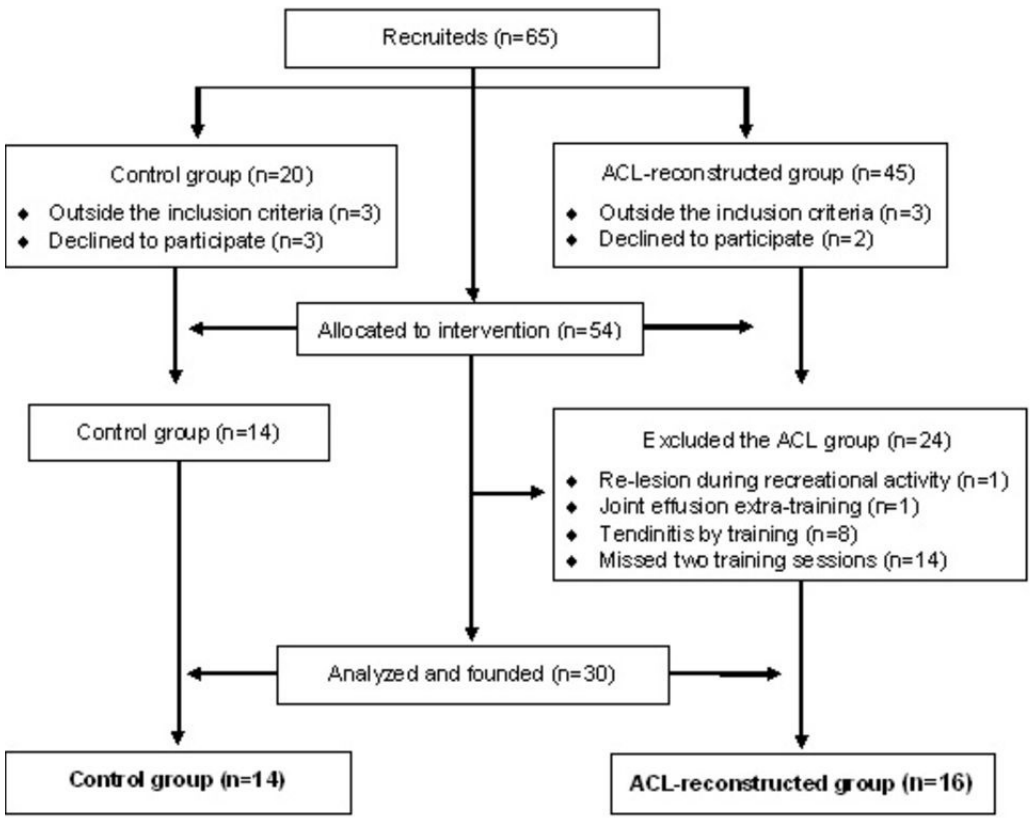

Figure 1. Flow diagram of the sample (ACL-reconstructed and control groups).

knee flexors and extensors and plantar flexors (30 s of stretching and 30 s of rest) in both limbs (Coury *et al*., 2006).

For measurement of the maximum isometric torque, the dynamometer arm was fixed in the position of 60º, for the extensors, and of 30º for the flexors (Santos *et al*., 2010). The test consisted of a series of 3 maximum voluntary isometric contractions, each one maintained for 5 s, with intervals of 1 minute between them (Judge, Moreau, & Burke, 2003). The average of the 3 peak torques was obtained for each participant (Seger & Thorstensson, 2005).

The concentric (30º/s e 120º/s) and eccentric (30º/s and 120º/s) tests consisted of a series of 5 consecutive maximal voluntary contractions, with 3 minutes of rest between the tests in an ROM of 70º (20º to 90º) (Coury *et al*., 2006). Before each test, individuals were familiarized with the equipment, which consisted of 3 sub maximum contractions of the extensors and flexors, for each mode and velocity, followed by 1 minute of resting (Croisier, Malnati, Reichard, Peretz, & Dvir, 2007).

Gait evaluation

Individuals were instructed to wear swimwear (swimming trunks or short) to facilitate the identification of the anatomical points. Then, the skin preparation was performed (tricotomy and sterilization) in order to place infra-red (IRED) markers (OPTOTRAK 3020). These markers (Figure 2A) were placed (double sided adhesive tape + hypoallergenic tape) on 9 anatomical points of the lower limb (Figure 2B), in the following order: a) sagittal plane (1 – head of the 5th metatarsus; 2 – lateral malleolus; 3 – head of the fibula; 4 – lateral epicondyle of the femur; 5 - greater trochanter of the femur); b) frontal plane (6 - intermalleolar point; 7 – anterior tibial tuberosity - ATT; 8 – 1/3 lower thigh – measure between the anterior superior iliac spine/ASIS and suprapatellar fold; and 9 - ASIS) (Bulgheroni, Bulgheroni, Andrini, Guffantti, & Giughello, 1997; Chiba, Ebihara, Tomita, Sasaki, & Butle, 2005; Knoll *et al*., 2004).

Gait preparation and evaluation were performed by individuals of the two groups (ACLr and CON), but those from the ACLr went through these procedures twice: 3 days before and 6 days after the isokinetic training period. In both cases, all the procedures were performed by the same examiner in order to minimize measurement errors.

The IRED markers (Figure 2B) were connected to the respective strobes (Figure 2A), which were placed on the participant´s waist by fixating them in the swimwear. A camera system (Figure 2 C: *Optotrak Certus* 3020 - *Northern Digital Inc., Waterloo*, *Canada*) was positioned 3.2 m from the individuals, with a height of 1.15 m, maintaining an accuracy < 0.3 mm for X and Y axis, and < 0.45 mm for Z axis (Dalal, 2012).

Gait evaluation occurred with individuals walking on a motorized treadmill (*Advanced 2, Athletic Ind.*, *Brazil*). First, participants stood upright motionless on the treadmill in order to obtain referential information in static position (32 s). Afterwards, individuals walked for 6 minutes for familiarizing (Knoll *et al*., 2004; Matsas, Taylor, & McBurney, 2000), in a pre-established velocity of 5 km/h, which is considered natural or comfortable (Van Hedel, Tomatis, & Müller, 2006). After the familiarization, 2 consecutive records were obtained, each one lasting 70 seconds. Data were collected at frequency of 100 Hz, always starting with the NAL, without individual's knowledge.

Isokinetic training

In the isokinetic training program, ACLr individuals performed 3 series of 10 maximum voluntary eccentric contractions (MVEC) of knee flexors and extensors (Coury *et al*., 2006; Dvir, 2004) in AL, in 30º/s (Croisier *et al*., 2007), with 3 minutes of resting between the series (Coury *et al*., 2006; Kraemer *et al*., 2002). This protocol was performed twice a week (with interval of 72 hours between the sessions), during 12 weeks (24 sessions).

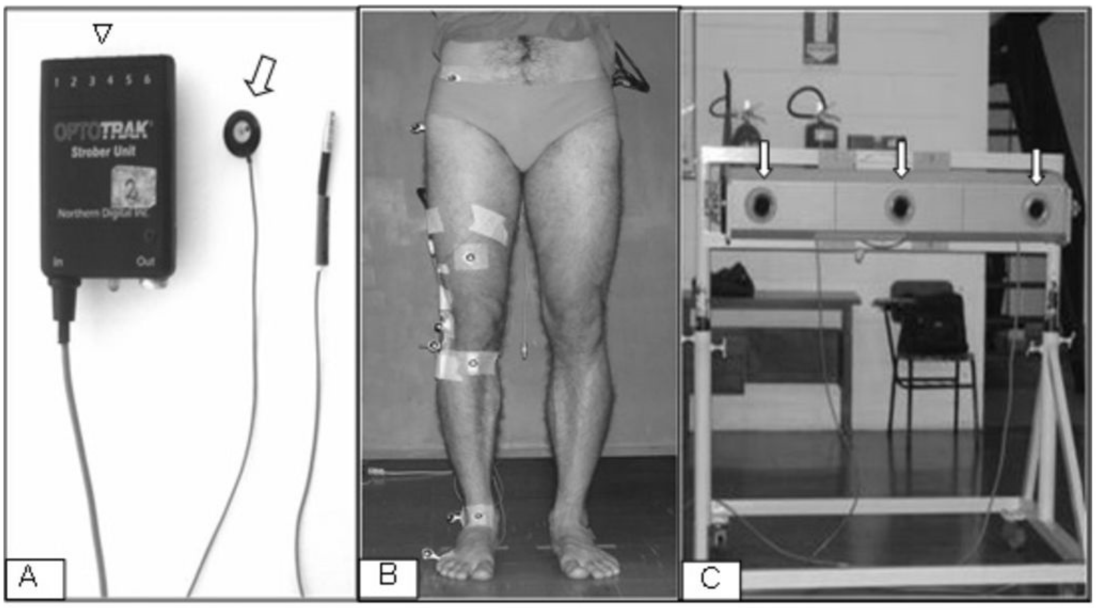

Figure 2. Optoelectronic system (Optotrak): A = active marker (arrow) and connection support (arrow head); B = positioning of the markers; C = camera set.

The individuals did not receive any other kind of physiotherapeutic intervention or attended to any other program of strength training during the period of isokinetic training. However, they were instructed to perform their daily activities as they used to do, even participating in recreational activities. The same physiotherapist orientated all the training sessions, to maintain the pattern of verbal commands ministered to the individuals during the 24 sessions of isokinetic eccentric training.

Data analysis

In the dynamometry, peak torque average (PTA) of the 5 contractions was calculated, for the knee extensors and flexors in each mode and velocity during the test. For comparison among individuals, the torque values in the pre- and post-training evaluations were standardized by each the individual's body mass.

Gait analysis was based on the tridimensional coordinates from each IRED marker. These coordinates were processed by MatLab 6.5 (*MathWorks Inc., Natick, MA, USA*) routines using windowing 30-second-period data. During this period, stride cycles were determined using the 5th metatarsal vertical velocity, and spatiotemporal variables (duration of the cycle, stride length, velocity, cadency and duration of the support phase) for each cycle. In addition, sagittal and frontal knee angle values were obtained, after disregarding the respective neutral position of each individual. Knee angles were filtered using low-pass Butterworth digital filter, 4th order and cutoff frequency of 10 Hz. Afterwards, the minimum and maximum of flexion(+)/extension(-) and valgus(+)/varus(-) for the support and balance phases were obtained for each cycle and, finally, averaged within each subject.

Statistical analysis

The descriptive (average and standard deviation) and inferential (test *t* Student – paired and independent; MANOVA and ANOVA - two-way, followed by Tukey *post-hoc* test) tests were performed using *Statistical Package for the Social Sciences* (SPSS - 15.0), after confirmation of data normality (Shapiro Wilk's) and homogeneity of variances (Levene's) considering a significance level of 5% in all comparisons.

Tests *t* Student were performed in order to obtain the PTA of the knee extensors and flexors (paired and independent) and Mann-Whitney to verify the differences between intra-limb values (pre- and post-training) and inter-limb values (affected and non-affected), respectively.

Comparison of the gait variables between ACLr x CON groups paired the members of the groups. Thus, for all gait assessments a member of the CON group was matched to a member of the ACLr group.

For the spatiotemporal variables (duration, length, stride velocity and cadency) multivariate analyses (MANOVA) were performed considering factors: 1) evaluation and limbs for ACLr; and 2) groups and limbs, in pre- and post-training evaluation. For the analysis of the variable "duration of the support phase," ANOVA tests were performed considering factors: 1) evaluation and limbs for ACLr; and 2) groups and limbs, for each evaluation (pre- and post-training).

Regarding angular variables gait in the flexion-extension and valgus-varus knee movement (minimum and maximum angle, support and balance phases) multivariate analyses (MANOVA) were performed considering factors: 1) evaluation and limbs for ACLr; and 2) groups and limbs for ACLr and CON, in pre- and post-training evaluation.

Results

Torque

Table 1 depicts peak torque pre- and post-isokinetic eccentric training of knee extensors and flexors in both affected (AL) and non-affected limb (NAL). In the pre-training, peak torque averages of the knee extensor in the AL were 14, 19, 14 and 10% lower than in the NAL in the isometric ($p < .01$), concentric

Table 1. Average Peak Torque (APT) pre and post isokinetic eccentric training of the extensors and flexors of the knee in AL and NAL.

Torque	Pre-training		Post-training		Percentage difference (%) and value of p			
					Pre-training	Post-training	Pre x Post	Pre x Post
	AL	NAL	AL	NAL	AL x NAL	AL x NAL	AL	NAL
Extensors								
Isometric	229.7±60.6	268.4±66.2	253.4±52.0	278.7±64.6	-14 (<.01)	-9 (<.05)	9 (<.05)	4 (.09)
Conc.30º/s	192.6±52.2	238.5±47.5	212.2±46.7	238.4±48.7	-19 (<.01)	-11 (<.01)	9 (<.01)	0 (.99)
Conc.120º/s	149.6±39.2	173.4±44.2	161.3±30.5	186.3±35.1	-14 (<.05)	-13 (<.01)	7 (<.05)	6 (.14)
Ecc. 30º/s	253.0±66.0	281.9±74.2	313.4±58.0	324.8±70.1	-10 (<.01)	-4 (.42)	19 (<.01)	13 (<.01)
Ecc.120º/s	234.8±79.8	253.2±93.3	263.4±59.4	311.4±72.4	- 7 (.22)	-15 (<.01)	11 (<.07)	19 (<.01)
Flexors								
Isometric	140.6±30.3	146.2±30.7	157.4±30.3	149.4±32.9	-4 (.39)	5 (.11)	11 (<.01)	2 (<.56)
Conc.30º/s	121.3±26.7	128.3±25.1	134.2±23.7	125.9±25.5	-5 (.14)	6 (.46)	10 (<.01)	-2 (<.55)
Conc.120º/s	107.6±31.7	101.6±20.7	111.4±21.6	106.1±20.0	5 (.40)	5 (.16)	3 (<.64)	4 (<.13)
Ecc.30º/s	133.6±26.2	137.9±32.7	175.9±34.8	151.3±34.0	-3 (.33)	14 (<.01)	24 (<.01)	9 (<.05)
Ecc.120º/s	139.9±26.5	138.1±30.9	172.8±30.4	156.1±29.7	1 (.68)	10 (<.01)	19 (<.01)	11 (<.01)

Note: Student *t*-test (paired = pre and post; independent = AL x NAL).

Table 2. Comparison of the values of APT between AL (post-training) and NAL (pre-training) of the knee extensors and flexors.

Contraction modes	Extensors				Flexors			
	AL Post-training	NAL Pre-training	Difference(%)	*p* value	AL Post-training	NAL Pre-training	Difference (%)	*p* value
Isometric	253.4±52.0	268.4±66.2	-6	.21	157.4±30.3	146.2±31.1	7	<.05
Conc. 30º/s	212.2±46.7	238.4±48.7	-11	<.05	134.2±23.7	128.3±25.1	4	.25
Conc. 120º/s	161.3±30.5	173.4±44.2	-7	.23	111.4±21.6	101.6±20.7	9	<.05
Ecc. 30º/s	313.4±58.0	281.9±74.2	10	<.05	175.9±34.8	137.9±32.7	21	<.01
Ecc. 120º/s	263.4±59.4	253.2±93.3	4	.55	172.8±30.4	138.6±30.3	20	<.01

Note: Student *t*-test (independent)
Legend: APT = average peak torque; AL = affected limb; NAL = non-affected limb.

at 30º/s ($p < .01$), concentric at 120º/s ($p < .05$) and eccentric at 30º/s ($p < .01$) condition, respectively. No differences were observed between limbs for the flexors.

In the post-training evaluation, percentage differences between limbs for the extensors decreased, even though they still remained higher in NAL in the isometric mode (9%; $p < .05$), concentric at 30 and 120º/s (11% and 13%; $p < .01$) and eccentric at 120º/s (15%; $p < .01$). Regarding the flexors, torque values in eccentric mode at 30º (14%; $p < .01$) and 120º/s (10%; $p < .01$) were higher for AL compared to NAL.

Comparing torque of the extensors at pre- and post-training, peak torque increased 9, 9, 7 and 19% for the AL in the isometric ($p < .05$), concentric at 30% ($p < .01$) and 120º/s ($p < .05$) and eccentric at 30º/s ($p < .01$) modes. For the NAL, peak torque increased 13 and 19%, only at 30 and 120º/s ($p < .01$), in the eccentric mode. Comparing pre- and post-training values for the flexors, peak torque increased 11, 10, 24 and 19% in AL isometric, concentric at 30º/s, and eccentric at 30 and 120º/s ($p < .01$), whereas for the NAL, peak torque increased 9 and 11% only in eccentric mode at 30% ($p < .05$) and 120º/s ($p < .01$).

Table 2 depicts comparisons between peak torque of AL post- and NAL pre-isokinetic concentric and eccentric training of knee extensors and flexors. Peak torque of AL post-training was 11% lower ($p < .05$) in eccentric mode at 30º/s and 10% higher ($p < .05$) in eccentric mode at 30º/s than of NAL. No difference was observed for isometric, concentric and eccentric at 120º/s ($p > .05$). For the flexors, peak torque increased 7, 9, 21 and 20% for the isometric ($p < .05$), concentric at 120º/s ($p < .05$) and eccentric at 30 and 120º/s ($p < .01$), compared to the pre-training values of NAL. No difference for concentric mode at 30º/s was observed.

Table 3 depicts means of time to peak torque between AL and NAL in pre- and post-training of extensor and flexors. Time to peak torque was different for the extensors of the knee in eccentric contraction mode at 120º/s ($p = .018$) for the AL and in concentric contraction mode at 30º/s ($p = .029$) for the NAL. For the flexors, differences were also identified in the eccentric contraction mode at 120º/s, for both AL ($p = .016$) and NAL ($p = .004$) limbs.

Spatiotemporal gait variables

Table 4 depicts spatiotemporal variables for both groups and limbs and in the pre- and post-training for the individuals with reconstructed ACL. For the comparison involving pre- and post-training and affected and non-affected limb of the reconstructed group, MANOVA revealed no difference between pre- and post-training limbs evaluations, *Wilks' Lambda*=0.657, $F(5,11)=1.149$, $p = .392$, *Wilks' Lambda*=0.908, $F(5,11)=0.222$, $p = .945$, and evaluation and limb interaction, *Wilks' Lambda*=0.548, $F(5,11)=1.815$, $p = .190$, indicating that stride

Table 3. Average values of time to peak torque (TPT) of the knee movements in the isokinetic dynamometer.

Contraction modes	TPT					
	Affected Limb (AL)			Non-affected Limb (NAL)		
	Pre-training	Post-training	*p* value	Pre-training	Post-training	*p* value
Extensors						
Conc.30º/s	814.38±250.81	881.25±258.87	.464†	680.00±168.44	825.63±190.61	.029†
Conc.120º/s	278.75±33.84	261.88±50.23	.274†	278.75±30.30	268.13±35.07	.366†
Ecc. 30º/s	2595.63±1083.95	2121.25±275.34	.100†	4814.38±6887.21	2373.75±857.35	.073◊
Ecc.120º/s	1105.44±503.41	776.88±152.61	.018†	816.25±271.44	810.00±174.32	.939†
Flexors						
Conc.30º/s	519.38±118.35	593.13±223.21	.252†	555.63±128.53	569.38±181.53	.955◊
Conc.120º/s	273.75±112.00	271.25±70.89	.850◊	287.50±101.49	263.75±57.26	.421†
Ecc.30º/s	1915.00±429.64	1990.00±236.42	.925◊	1845.63±354.57	1798.75±325.41	.700†
Ecc.120º/s	453.13±136.86	551.25±66.72	.016◊	438.75±127.59	551.25±63.65	.004†

Legend: † = Mann-Whitney´s test; ◊ = Student *t*-test (independent).

Table 4. Averages and standard deviations of the gait spatiotemporal variables of the ACLr and control groups.

Spatiotemporal Variables	**ACLr**		**Control**
	Pre-training	**Post-training**	
Stride duration (sec.)			
AL	1.05±0.05	1.04±0.05	1.08±0.04
NAL	1.04±0.05	1.05±0.05	1.07±0.04
Stride length (m)			
AL	1.33±0.06	1.34±0.06	1.28±0.05
NAL	1.33±0.07	1.33±0.07	1.32±0.07
Stride velocity (m/s)			
AL	1.28±0.13	1.28±0.15	1.19±0.09
NAL	1.30±0.13	1.27±0.13	1.31±0.31
Cadency (steps/minute)			
AL	114.96±5.83	115.44±5.93	110.85±4.39
NAL	115.40±5.87	114.70±5.85	113.90±6.65
Duration of the support phase (%)			
AL	59.66±1.06	59.67±1.39	59.72±2.13
NAL	59.46±1.15	59.33±0.84	60.09±1.10

Legend: AL = affected limb; NAL = non-affected limb.

duration, length, velocity and cadency for the individuals with ACL reconstruction remained the same (Table 4).

When comparing the CON and ACLr groups in the pre-training, MANOVA did not reveal any difference for group, *Wilks' Lambda*=0.816, $F(5,24)=1.079$, $p = .397$), limb, *Wilks' Lambda*=0.829, $F(5,24)=0.992$, $p = .443$, and group and limb interaction, *Wilks' Lambda*=0.790, $F(5,24)=1.274$, $p = .307$. In the post-training, MANOVA did not reveal difference for group, *Wilks' Lambda*=0.870, $F(5,24)=0,720$, $p = .615$, and limb, *Wilks' Lambda*=0.870, $F(5,24)=0.716$, $p = .618$, but revealed a group and limb interaction, *Wilks' Lambda*=0.473, $F(5,24)=5.358$, $p = .002$. Univariate analyses indicated difference for stride duration, $F(1,28)=8.053$, $p = .008$, length, $F(1,28)=5.495$, $p = .026$, and cadency, $F(1,28)=4.492$, $p = .043$. *Post-hoc* test showed that for the ACLr group, stride duration for both AL and NAL limbs was shorter than for the CON. In addition, stride length and cadency for the ACLr group in the AL were longer and higher, respectively, than in the AL of CON group.

Table 4 also depicts the support phase duration. ANOVA revealed not difference between the ACLr pre- and post-training, $F(1,15)=1.272$, $p = .277$, limb, $F(1,15)=0.197$, $p = .664$, and evaluation and limb interaction, $F(1,15)=0.117$, $p = .738$. Additional ANOVAs did not reveal any difference, in the pre-training, for group, $F(1,56)=1.442$, $p = .442$, limb, $F(1,56)=0.081$, $p = .823$, and group and limb interaction, $F(1,56)=0.621$, $p = .434$, and any difference, in the post-training, for group, $F(1,56)=2.459$, $p = .456$, limb, $F(1,56)=0.002$, $p = .972$, and group and limb interaction, $F(1,56)=0.915$; $p = .343$.

Knee angles

Table 5 depicts knee flexion-extension and valgus-varus information for both ACLr and CON groups and limbs and for the ACLr group in the pre- and post-training. For the ACLr group, MANOVA did not show any knee flexion-extension and valgus-varus difference between pre- and post-training evaluation, *Wilks' Lambda*=0.128, $F(1,15)=2.274$, $p = .222$, limb, *Wilks' Lambda*=0.300, $F(1,15)=0.777$, $p = .671$, and evaluation and limb interaction, *Wilks' Lambda*=0.342, $F(1,150=0.641$, $p = .752$.

When comparing the knee angles between the CON and the ACLr, in the pre-training, MANOVA revealed difference for group, *Wilks' Lambda*=0.279, $F(1,28)=3.670$, $p = .007$, indicating that for the ACLr group, knee flexion-extension maximum and minimum values in both supportive, $F(1,28)=9.501$, $p = .005$; $F(1,28)=23.735$, $p = .0001$, and balance phases, $F(1,28)=9.244$, $p = .005$, $F(1,28)=10.567$, $p = .003$, were lower, respectively, than for the CON group. Differently, MANOVA did not show any difference for limb, *Wilks' Lambda*=0.455, $F(1,28)=1.699$, $p = .155$, and group and limb interaction, *Wilks' Lambda*=0.628, $F(1,28)=0.839$; $p = .614$.

In the post-training, MANOVA revealed again difference for group, *Wilks' Lambda*=0.275, $F(1,28)=3.732$, $p = .007$), indicating that for the ACLr group, knee flexion-extension maximum and minimum values in both supportive, $F(1,28)=9.323$, $p = .005$, $F(1,28)=22.375$, $p = .0001$, and balance phases, $F(1,28)=10.720$, $p = .003$, $F(1,28)=12.558$, $p = .001$, were lower, respectively, than for the CON. In addition, MANOVA also revealed difference for limb, *Wilks' Lambda*=0.256, $F(1,28)=4.113$, $p = .004$, but in the follow up univariate tests these differences were not identified. Finally, MANOVA did not reveal any group and limb interaction, *Wilks' Lambda*=0.517, $F(1,28)=1.324$, $p = .290$.

Table 5. Values of angles of flexion-extension and valgus-varus of the knee in ACLr and control groups.

Groups	**Flexion-extension (º)**			
	Support		**Balance**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
ACLr_Pre				
AL	-0.38±3.37[a]	37.11±4.06[a]	-5.30±4.53[a]	55.67±4.11[a]
NAL	-1.19±4.40[b]	39.64±4.90[b]	-5.02±4.65[b]	58.49±5.02[b]
ACLr _Post				
AL	-0.17±3.25[c]	36.94±3.91[c]	-5.45±3.84[c]	54.78±4.61[c]
NAL	-0.39±2.37[d]	40.57±4.32[d]	-4.64±3.83[d]	58.48±4.51[d]
Control				
AL	3.46±3.77	45.86±5.67	-0.21±5.17	61.83±5.04
NAL	2.41±4.79	45.80±6.22	-0.74±5.39	61.92±5.91
	Valgus-varus (º)			
ACLr _Pre				
AL	-0.67±1.22	13.35±3.81	-0.50±1.31	17.83±5.97
NAL	-0.85±1.00	13.97±4.17	-0.62±1.02	19.72±5.93
ACLr _Post				
AL	-0.70±1.30	13.20±3.98	-0.85±0.76	17.55±5.87
NAL	-0.48±1.02	13.61±3.90	-0.55±1.17	18.70±5.16
Control				
AL	-1.56±2.02	2.87±3.03	0.75±1.62	18.14±4.05
NAL	-1.57±1.68	12.09±4.27	-0.97±117	18.01±6.64

Note: (a) statistic difference in the pre-training comparison of AL between ACLr and Control groups; (b) statistic difference in the pre-training comparison of NAL between ACLr and Control groups; (c) statistic difference in the post-training comparison of AL between and Control groups ACLr; (d) statistic difference in the post-training comparison of NAL between ACLr and Control groups. Legend: AL = affected limb; NAL = non-affected limb.

Discussion

Torque

The results indicated that individuals with ACL reconstruction produce lower torque with the AL, as observed in the pre-training evaluation, with the exception of the eccentric mode in 120º/s. Such lower production of torque wit the AL might be due to a dysfunction of the quadriceps muscle caused by ACL rupture. The rupture promotes a deficit of activation of the gamma motoneuron with consequent attenuation of the efferent stimulus Ia (Konishi, Fukubayashi, & Takeshita, 2002; Williams, Snyder-Mackler, Barrance, Axe, & Buchanan, 2004) associated to the atrophy and decrease of the extensor muscle strength, always present after ACL reconstruction (Grant, Mohtadi, Maitland, & Zernicke, 2005; Mattacola *et al*., 2002; Meighan, Keating, & Will, 2003). Such suggestion is even corroborated by Palmieri-Smith *et al*. (2008) who observed deficits > 30% in the quadriceps strength, depending on the mode of contraction and velocity evaluated, and that can persist through years after the surgery (Kurz *et al*., 2005; Lyon *et al*., 2011; Moraiti *et al*., 2010; Sanford *et al*., 2012). Therefore, deficits in the reconstructed knee extensor torque (10 to 19%) observed in the present study were predicted considering the lesion (50.4 ± 34.9 months) and the surgery elapsed time (27.0 ± 23.7 months). As previously suggested (Gerber et al., 2007), the strength and the trophism of the thigh muscles post ACL reconstruction are dependent of these two variables.

The results of the present study show that the isokinetic training promoted significant gain in the knee extensor torque, leading to a reduction in the difference identified before the training. Moreover, based on the mode and velocity that individuals were trained (eccentric at 30º/s), the substantial torque gain (19%) in the AL suggests a specific response to intervention, leaving the AL with a torque capability of 10% higher than in NAL, in pre-training. Similar results and effects were observed for the flexor torque, with the training also promoting substantial gain in the AL.

No study has compared torque between the pre-training of the NAL and the post-training of the AL, as performed in this study. Using the eccentric exercise to obtain a more effective strength gain, the main goal of several studies (Carroll, Riek, & Carson, 2001; Kellis & Baltzopoulos, 1998; Staron *et al*., 1994) was to match values of the reconstructed limb to the non-affected limb.

Gait

The results of the present study clearly showed that only a few differences were observed in the AL of ACL reconstructed during walking. Such result is interesting because the training protocol has promoted gain in torque production, but such gain has not been enough to promote dramatic walking temporal organization between AL and NAL. This result might be due to the control of velocity, which was maintained at 5 km/h, and also because participants walked on a treadmill that might have prevented any larger differences. It is worth to mention that the use of treadmill with controlled velocity was based on the fact that several studies (Riley, Paolini, Della Croce, Paylo, & Kerrigan, 2007; Warabi, Kato, Kiriyama, Yoshida, & Kobayashi, 2005) suggested that such strategy presents several advantages for walking examination.

Differences of the extensor torque between the AL and NAL limbs of ACL reconstructed individuals of ACLr and the discreet changes in gait observed in this study, Shi *et al*. (2010) were also observed that after ACL reconstruction and post-surgery rehabilitation. Some gait spatiotemporal (step length, velocity and cadency) and angular excursion (maximum knee flexion angle) are restored and other remain unaltered (knee flexion excursion in the support stage and flexor peak torque). Specifically, in the present study, after training, there was a decrease in the stride duration of both limbs of ACL reconstructed individuals and an increase in stride length and cadency of the AL, compared to CON group. These changes can be due to the decreased peak torque, both in the extensors and in the flexors of the knee, promoted by the isokinetic eccentric training. The movement velocities (60 and 120º/s) indicated that the higher velocity (120º/s) approximated to the velocity developed by the individuals during walking on a treadmill.

The results indicated that the training protocol adopted in this study was efficient in improving torque production of AL in individuals with ACLr, and promoting symmetry among limbs. The flexion-extension angle difference observed during the support and balance phases of walking, during the pre-training evaluation (shortest flexion and longest extension) persisted after the training protocol, when compared to CONg.

Some authors (Kurz *et al*., 2005; Shi *et al*., 2010) have suggested that these little changes in the kinematics of the knee, can be related to the loss of sensory information caused by injury and incomplete restoration of the ACL anatomy and function after the reconstruction, by surgical trauma, and by the adaptions related to the mechanism of avoiding pain, during the early stage of rehabilitation. If this is the case, our training protocol was not designed to improve such deficits and, therefore, would not promote kinematics changes and would explain the lack on changes in knee flexion-extension.

Another important aspect observed in the present study is related to the knee valgus-varus angle. We have employed similar training protocol to the one employed by Coury *et al*. (2006) who found significant differences pre and post-training for this movement using electro goniometry. This finding in the present study would be the result of a mechanical compensation induced by the load of eccentric training. The isokinetic training did not promote any change in the limbs in ACLr, neither when compared to CONg. Based on the results herein, our training protocol can be used in the post rehabilitation period in individuals as ACLr since it does not promote or lead to any undesirable compensatory change.

One possible explanation regarding the differences observed in our study and in previous one (Coury *et al*., 2006) might be related to the instruments that were used to obtain the kinematic information. For instance, some studies (Roewer *et al*., 2011; Sato *et al*., 2009; Sato *et al*., 2010) showed that there were measurement errors for the knee movement when the electro goniometry was used.

Sato *et al*. (2009), testing the reliability of measures in 6 electrogoniometers and simulating the flexion/extension and valgus/varus movement, showed that the higher the value of ROM, the higher the measurement error would be. All sensors showed an average effect of hysteresis of 1.6º and it was necessary a polynomial adjustment of 8th order, in an interval of 5º to correct, properly, an average error of 12% (amplitude from 5 to 21%). Moreover, evaluating the measurement errors within the movements of the knee are due to anatomical changes in the frontal plane—common among the individuals. Therefore, differences between pre- and post-training caused by hypertrophy of the thigh muscles can promote variations in the alignment of the electro goniometers fixed on the lateral face of the leg and thigh, which can also increase the valgus-varus error associated to the movement of flexion-extension of the knee during the gait (Roewer *et al*., 2011; Sato *et al*., 2010).

On the other hand, States and Pappas (2006) stated that the optoelectronic system used in this study (Optotrak 3020) showed excellent precision and reproducibility of measures for angles and distances (1.48 to 5.30 m) both in static conditions as in movement, therefore, achieving high reliability for the analysis of human movement.

Despite all the efforts to employ and maintain methodological rigor in the present study, some limitations can be identified. First, the examiner who performed the evaluations also participated in the isokinetic training of the individuals. Second, due to many reasons, some participants did not complete the entire training protocol and, therefore, withdraw from the study, resulting in a relatively reduced amount of the sample. Finally, the control group participants were not enrolled in the isokinetic eccentric training.

Conclusions

In general, the IET of the knee extensors and flexors, post ACL reconstruction, promoted significant gain of torque in AL, matching it with the pre-training values of NAL, without affecting the spatiotemporal (cycle length, stride length and cadence) and angular (flexion-extension and valgus-varus of the knee) variables of gait. These findings confirmed the initial hypothesis that this kind of training can be used safely to recover the muscle strength post ACL reconstruction.

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Authors' note

Heleodório Honorato dos Santos (dorioufpb@gmail.com) is affiliated with the Departament of Physical Therapy, Federal University of Paraíba, João Pessoa, PB, Brazil.

Catarina de Oliveira Sousa (cat.olivsousa@gmail.com) is affiliated with the Department of Physical Therapy, Federal University of Rio Grande do Norte, Natal, RN, Brazil.

José Angelo Barela (jose.barela@cruzeirodosul.edu.br) is affiliated with the Institute of Physical Activity and Sport Sciences, Cruzeiro do Sul University, São Paulo, and with São Paulo State University, Rio Claro, SP, Brazil.

Ana Maria Forti Barela (ana.barela@cruzeirodosul.edu.br) is affiliated with the Institute of Physical Activity and Sport Sciences, Cruzeiro do Sul University, São Paulo, SP, Brazil.

Tania de Fatima Salvini (tania@ufscar.br) is affiliated with the Departament of Physical Therapy, Federal University of São Carlos, São Carlos, SP, Brazil.

Corresponding author:

Heleodório Honorato dos Santos
Av. Mons. Odilon Coutinho, 191/402, Cabo Branco, João Pessoa 58045-120
PB, Brazil
Telephone: 55 83 9613 7900 / 8750-7708
E-mail: dorioufpb@gmail.com

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