

Males still have limb asymmetries in multijoint movement tasks more than 2 years following anterior cruciate ligament reconstruction

Raquel Castanharo · Bruno S. da Luz ·
Alexandre C. Bitar · Caio O. D'Elia ·
Wagner Castropil · Marcos Duarte

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Abstract

Background More than 2 years after undergoing anterior cruciate ligament (ACL) reconstruction, women still present bilateral asymmetries during multijoint movement tasks. Given the well-known ACL-injury gender bias, the goal of this study was to investigate whether males also present such asymmetries more than 2 years after undergoing ACL reconstruction.

Methods This study involved 12 participants submitted to ACL reconstruction in the ACL group and 17 healthy participants in the control group. The mean postoperative period was 37 months. The participants executed bilateral countermovement jumps and load squat tasks. The kinematics and ground reaction forces on each lower limb and pelvis were recorded, and used to compute bilateral peak vertical ground reaction forces, peak knee and hip joint powers in the sagittal plane, and the ratio between these powers.

Results For the jump task, the groups had the same performance in the jump height, but for the ACL group the peak knee joint power on the operated side was 13% lower than on the non-operated side ($p = 0.02$). For the squat task, the hip-knee joint power ratio on the operated side of the ACL group was 31% greater than on the non-operated side ($p = 0.02$).

Conclusions The ACL group presented a deficit in the operated knee that had its energy generation over time (joint power) partially substituted by the hip joint power of the same side. The fact that, even after more than 2 years following the ACL reconstruction and returning to regular activity, the ACL group still had neuromuscular asymmetries suggests a need for improvement in the ACL reconstruction surgery procedures and/or rehabilitation protocols.

Introduction

Injury of the anterior cruciate ligament (ACL) is quite prevalent in many sports activities [1]. Several studies have shown that individuals who submit to ACL reconstruction (ACLR) and rehabilitation and then return to their normal physical activities will, after a period of approximately 1 year, still show neuromuscular deficits in the involved limb compared with the noninvolved limb, and when compared with control individuals during multijoint movement tasks such as squatting, jumping and walking [2–4].

After a long postoperative period (a few years), rehabilitation and a return to regular activities, individuals who have undergone an ACLR would be expected to no longer exhibit neuromuscular limb asymmetry when performing multijoint movement tasks [5]. Surprisingly, this question has been scarcely investigated, and the only study published on the topic found the opposite result. Paterno and colleagues [6] observed neuromuscular deficits of the operated limb in female athletes on average 27 months following their ACLR who had returned to their regular physical activities.

R. Castanharo · B. S. da Luz · M. Duarte (✉)
Neuroscience and Behavior Graduate Program,
University of São Paulo, Av. Prof. Mello de Moraes,
65, São Paulo, SP 05508-030, Brazil
e-mail: duartexyz@gmail.com
URL: <http://demotu.org/>

A. C. Bitar · C. O. D'Elia · W. Castropil
Instituto Vita, São Paulo, Brazil

It is known that females present an approximately three times greater incidence of ACL injury in sporting events than men [1] and a higher (7.8%) ACL re-injury incidence to the contralateral knee after reconstruction. These women, however, do not incur more injuries to the reconstructed knee than men [7]. Based on these results, it is possible that males may present a different behavior than that observed for females. Consequently, the goal of this study was to investigate bilateral lower limb asymmetries during multijoint movement tasks performed by males more than 2 years after undergoing an ACLR.

Methods

This study was approved by the Ethics Committee at our university, and informed consent was obtained from each participant. Twenty-nine male volunteers took part in the study; 12 participants had undergone an ACL reconstruction and were placed in the ACL group (mean age 28 ± 8 years, height 1.76 ± 0.05 m, and body weight 84 ± 10 kg), and 17 healthy participants constituted the control group (age 26 ± 4 years, height 1.80 ± 0.07 m, and body weight 82 ± 7 kg). None of these variables were significantly different between the groups ($p > 0.17$). For the participants in the ACL group, the mean postoperative time was 37 ± 9 months. The same medical team had operated on all participants, using a unilateral semitendinosus-gracilis tendon autograft, with no more than 25% of the meniscus removed, and each participant had followed up his surgery with a complete physiotherapeutic rehabilitation process. In general format, the rehabilitation protocol was applied 3 days a week for 6 months and consisted of the full recovery of the range of motion, force training with closed kinetic chain exercises, electrostimulation of the quadriceps, isotonic exercises, and proprioceptive training.

The inclusion criteria for both groups required the participants to engage in a recreational sports activity at least twice a week, and the postoperative time for the participants in the ACL group had to be at least 2 years. The exclusion criteria for the ACL group were any other surgeries on the lower limbs (including ACL surgery on the same knee or on the other knee) and chondral lesion degrees III and IV evaluated using the Outerbridge classification. The Lisholm Knee Questionnaire and the 2000 IKDC Subjective Knee Evaluation Form were used for the ACL group in order to evaluate their knee symptoms and functionality. The ACL group presented a median of 95 (25–75th percentiles of 91–100) on the Lisholm Questionnaire and a median of 95 (25–75th percentiles of 93–98) on the IKDC Form. To determine the dominant lower limb, the participants were asked, “With which leg do you normally kick a ball?”

The participants were asked to execute bilateral countermovement jumps and load squat tasks as illustrated in Fig. 1. They were instructed to perform the countermovement jump as high as possible, with their arms crossed across their chests. The squat was performed with a load of 20% of their body mass at a depth of 90° of knee flexion. Both bilateral tasks were performed with the participants standing with each foot on a different force plate in order to allow a separate kinetic analysis of each lower limb. Six trials of each task were analyzed.

The kinematics of the participants were registered with a three-dimensional motion analysis system (Vicon 460, Oxford Metrics, Oxford, UK) operating at 120 Hz, and the ground reaction forces were measured with two force plates (OR6-2000, AMTI Inc., Watertown, MA) embedded in the floor and operating at 1,080 Hz. We modeled the lower limbs and pelvis as rigid segments and described their movements using retroreflective markers placed in the sacrum and the following anatomical points bilaterally:

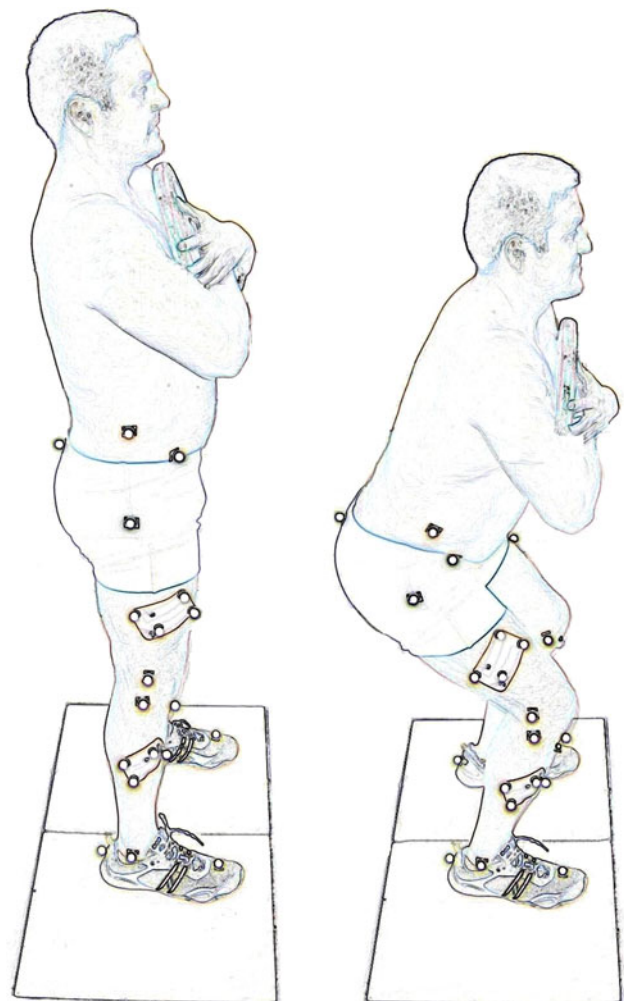


Fig. 1 Illustration of two phases of the load squat task performed by the subjects and the markers' placement

iliac crest, anterior superior iliac spine, femoral greater trochanter, medial and lateral femoral epicondyle, head of fibula, tibial tuberosity, medial and lateral malleolus, posterior prominence of calcaneus, and head of II metatarsi.

We analyzed the movement at the anatomical sagittal (flexion/extension) plane, and we computed the net internal moment and power of the ankle, knee, and hip joints employing an inverse dynamics procedure using Visual3D software (version 4.0, C-motion Inc., Rockville, MD). Joint power was calculated as the product between the moment and angular velocity of the joint. To evaluate the asymmetry between lower limbs, we analyzed the peak vertical ground reaction force (GRFv) during the impulsion and landing phases of the jump, and for both jumps (impulsion phase) and squats (ascending phase), the peak knee and hip joint powers and the hip-knee power ratio were analyzed. A positive power indicates that energy (power is equal to energy variation divided by time interval) is being generated, and negative power indicates that energy is being absorbed on the joint. For the investigated events, all power values were positive, i.e., energy is being generated at the hip and knee joints during the jump impulsion phase and the squat ascending phase. The hip-knee power ratio was calculated as the peak value of the hip joint power divided by the peak value of the knee joint power at the same side. A value of less than 1 indicates increased knee extensor power compared with hip extensor power, while a value greater than 1 indicates increased hip extensor power compared with knee extensor power. Due to problems with the data collection, the analysis of the squat task was performed for only 9 participants in the ACL group and 15 participants in the control group. All data analyses were performed using the Visual3D and Matlab (version 7.0, Mathworks Inc., Natick, MA) software packages. One-way ANOVA with a factor group (control vs. ACL) was conducted for the jump height variable. To be able to examine the participants of the ACL group according to the factor side of an ACLR, we first verified whether there was any effect of side dominance on the dependent measures for this group. For such, the ACL group data were classified according to the factor side (dominant versus non-dominant), and a dependent *t* test was used to determine any difference for the dependent measures. This analysis did not show any effect of the factor side dominance for the ACL group (all *ps* > 0.05). For this reason, two-way ANOVAs with the factor group (control vs. ACL) and the factor side (control, dominant versus non-dominant side; ACL, operated versus non-operated limb), considered as repeated measure, were employed for the dependent measures. The Sidak test was employed for post-hoc comparisons. A significance level of 0.05 was used for all statistical tests.

Results

Figure 2 shows exemplary time series of the GRFv and joint power variables during the jump and squat tasks for one subject. Table 1 shows the mean and standard deviation values for all participants and the effect statistics for

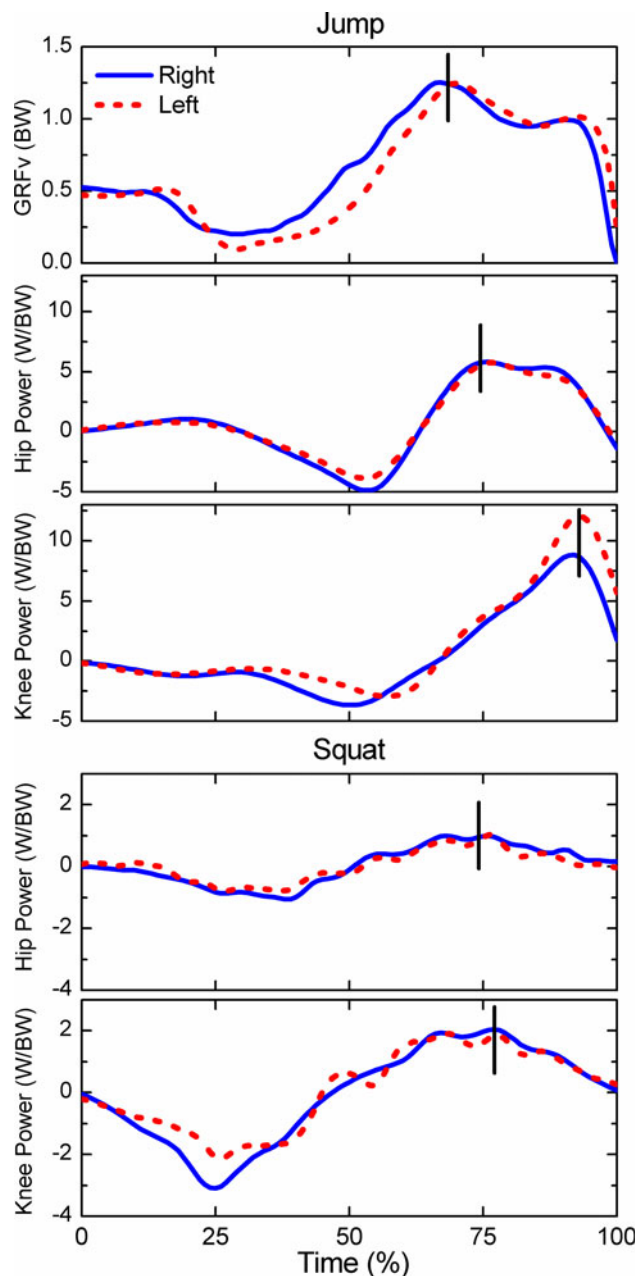


Fig. 2 Exemplary time series of the vertical ground reaction force (GRFv) and hip and knee joint power during the jump and squat tasks for the right and left limbs of one subject of the ACL group. The vertical lines show the instant where the variables in Table 1 were measured. For the jump task, only the impulsion phase is shown (0% indicates the movement start and 100% indicates the takeoff instant). For the squat task, both descent (0–50%) and ascent (50–100%) phases are shown. BW body weight

Table 1 Mean and standard deviation (SD) values for the jump height, peak vertical ground reaction force (GRFv), and peak hip and knee joint power variables during the countermovement jump and squat tasks for the different lower limb sides of the control and ACL groups, and the *p* values for the statistical comparisons

Task	Variable	Control mean \pm SD		ACL mean \pm SD		<i>p</i> values		
		Dominant Non-dominant	Operated Non-operated	Group	Side	Group \times side Control ACL		
JUMP	Height (cm)	30 \pm 4	27 \pm 6	0.12	–	–		
	Peak GRFv impulsion (BW)	1.2 \pm 0.2	1.1 \pm 0.2	0.4	0.7	0.06		
		1.1 \pm 0.2	1.1 \pm 0.2			0.2		
	Peak GRFv landing (BW)	2.6 \pm 0.7	2.4 \pm 0.5	0.8	0.5	0.2		
		2.4 \pm 0.7	2.4 \pm 0.6			0.7		
	Peak hip power (W/BW)	5.4 \pm 1.2	5.4 \pm 1.5	0.5	0.6	0.1		
		5.7 \pm 1.2	5.1 \pm 1.9			0.09		
	Peak knee power (W/BW)	10.3 \pm 1.5	8.7 \pm 2.9 ^a	0.4	0.3	0.1		
9.7 \pm 1.8		10.0 \pm 2.9 ^a			0.02			
Hip-knee power ratio	0.54 \pm 0.11	0.60 \pm 0.14	0.9	0.6	0.1			
	0.61 \pm 0.19	0.55 \pm 0.27			0.4			
SQUAT	Peak hip power (W/BW)	1.0 \pm 0.5	1.1 \pm 0.4	0.7	0.6	0.8		
		1.0 \pm 0.5	1.0 \pm 0.5			0.6		
	Peak knee power (W/BW)	2.0 \pm 0.6	2.0 \pm 0.6	0.8	0.2	0.9		
		2.0 \pm 0.6	2.2 \pm 0.4			0.1		
	Hip-knee power ratio	0.56 \pm 0.40	0.63 \pm 0.36 ^a	0.9	0.03	0.8		
0.55 \pm 0.38		0.48 \pm 0.21 ^a			0.02			

BW body weight

^a Interaction effect group \times side for the ACL group, *p* < 0.05

the jump height, peak GRFv, and peak hip and knee joint power during the jumping and squatting tasks (for all subjects, the within-subject variation was very small and it is not reported). For the jump task, the groups had the same performance in the jump height, but there was an interaction effect between the factors group and side (for the ACL group, the peak knee joint power on the operated side was 13% lower than on the non-operated side). Regarding the squat task, there was a main effect of the factor side for the hip-knee power ratio variable (the hip-knee joint power ratio on the dominant/operated side was 15% greater than on the non-dominant/non-operated side) and an interaction effect between the factors group and side (for the ACL group, the hip-knee joint power ratio on the operated side was 31% greater than on the non-operated side).

Discussion

Our goal was to describe lower limb asymmetries during multijoint movement tasks performed by males who had undergone an ACLR at least 2 years ago and who have returned to regular activities. We observed neuromuscular asymmetries in the ACL group when performing jumps and squatting tasks; however, there was no difference in

performance between the ACL and the control groups, as evidenced by the lack of group difference in jump heights. More specifically, we observed significant lower peak knee joint power and a higher hip-knee power ratio for the operated knees during multijoint movement tasks.

Our results agree with the findings of Paterno and colleagues [6], who observed neuromuscular asymmetries in female athletes who had on average 27 months following ACLR and had returned to their regular physical activities. Paterno and colleagues [6] observed that during the landing and takeoff phases of drop jump by female athletes with an ACLR, the peaks of the GRFv of the involved side were higher than the respective values for the non-involved side, and overall these values were higher than those of the control group. However, we did not observe asymmetries when we looked at the vertical component of the ground reaction force as Paterno and colleagues [6] observed; we only saw asymmetries in the joint power variables. We also did not observe differences between groups with respect to these variables. Of note, Paterno and colleagues [6], by looking at only the ground reaction forces during landing and jumping, were not able to describe in more detail the neuromuscular changes those participants developed after a long postoperative period. Our results specifically point to a deficit in the operated knee that had its mechanical joint

power (energy generation) partially substituted by the hip joint power of the same side.

One may wonder how it is possible that the ratios between the peak values of the hip and knee joint powers are different between sides if each joint power when compared side-to-side is not different. We can explain this result because (1) the hip and knee powers varied by a small quantity in opposite directions on the operated side (the hip power increased while the knee power decreased) and, consequently, the ratio amplified these variations; and (2) by calculating a ratio of two variables of the same side and subject we decreased the variations within the subject (between sides) and between the subjects, allowing smaller changes to be detected.

This strategy of demanding higher energy generation or higher joint moment production at the hip relative to the knee of the operated side in comparison with the hip and knee on the non-operated side is similar to the one developed in the short term (approximately 1 year) after an ACLR [8]. The fact that both females and males present long-term deficits after an ACLR suggests that this deficit is not gender specific. Similar side asymmetries have been observed in a variety of tasks and with different variables of analysis such as plantar pressure during squats [9], joint moment during vertical jumps [8], ground reaction force [6], and work [10] during drop jumps, and joint moment during lateral step up [8]. However, the asymmetry is not always repeatable across studies for the same task and variables of analysis. For example, while we did not observe asymmetry in the ground reaction force during a vertical jump, which is a result that agrees with the study of Decker and colleagues [10], who investigated drop jumps, Paterno and colleagues [6] found asymmetry in the GRF during the drop jumps. The reason for this inconsistency across studies is unclear.

These results indicate that individuals who have undergone an ACLR need special care in terms of rehabilitation and training even after a long term because they still have neuromuscular asymmetry. Particular attention should be devoted to the operated knee and hip joint of the same side even after more than 2 years of postoperative time because the observed asymmetry consisted of a partial substitution of the operated knee function by the hip. Although females present a higher incidence of ACL injury, this long-term neuromuscular asymmetry after an ACLR is gender independent, and so both male and female individuals need special care.

The fact that the participants, even after more than 2 years after undergoing an ACLR and returning to regular

activities, still have neuromuscular asymmetries suggests a need for improvement in the ACLR surgery procedures and/or rehabilitation protocols. It seems that, whenever it is possible for the nervous system to substitute for the operated knee's function, it will do so. An idea might be to develop a way of impeding the nervous system from developing this substitution strategy by artificially and momentarily impairing the hip joint of the operated side or to momentarily impair the non-operated knee to avoid the development of asymmetry.

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Conflict of interest The authors declare that there is no conflict of interest related to this article.

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