ORIGINAL ARTICLE

FUNCTIONAL PERFORMANCE AND KNEE LAXITY IN NORMAL INDIVIDUALS AND IN INDIVIDUALS SUBMITTED TO ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Objectives: The aim of this study was to analyze the correlation between deficits in the isokinetic peak torque of the knee extensors and flexors with hop tests, postoperative knee laxity and functional scores in normal and ACL- reconstructed subjects with patellar tendon and hamstring tendon autografts. Methods: Sixty male subjects were enrolled and subdivided into three groups: Twenty subjects without knee injuries (GC group) and two groups of 20 subjects submitted to ACL reconstruction with patellar tendon (GTP group) and hamstrings autograft (GTF group). Results: The results showed significant correlation between knee extensors peak torque and performance in the hop tests for GTF and GC groups. There are no significantly correlations between post op knee laxity and Lysholm score compared with the hop tests and peak torque deficits. Concerning the differences between groups, the GTP group showed greater peak torque deficits in knee extensors, worst Lysholm scores and higher percentage of individuals with lower limb symmetry index (ISM) < 90% in both hop tests when compared to the other two groups. Conclusion: It is not recommendable to use only one measurement instrument for the functional evaluation of ACL-reconstructed patients, because significant correlation between peak torque, subject's functional score, knee laxity and hop tests were not observed in all groups.

Keywords – Anterior cruciate ligament; Knee; Retrospective study

INTRODUCTION

Anterior cruciate ligament (ACL) injury or rupture in athletes or physically active individuals is very common in clinical practice. Epidemiological studies show an incidence of approximately 80,000 injuries per year[1]. Influenced by these factors, there has been a tremendous growth in the number of papers published in the last 15 years, with research focusing on ACL anatomy, biomechanics, reconstructive surgery, and rehabilitation techniques. The progress of research in the field of orthopedics has significantly decreased the time required to return to sport for athletes who have undergone ACL reconstruction[2]. This reduction in the time required to return to sport is mainly due to advances in surgical techniques, primarily with the use of arthroscopy, providing less invasive techniques and reducing postoperative complications such as arthrofibrosis, and with improved techniques for graft fixation, allowing for the early mobilization of the knee joint followed by the use of accelerated rehabilitation[3]. As ACL injury occurs mostly in physically active individuals, a frequent

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asked question is directed to orthopedic surgeons and physiotherapists involved in the specialty: "When will I be able to return to sport after surgery?"

Current literature reveals no consensus on the ideal time to return to sport, since there is a wide variety of published works demonstrating return to sport in the extremely early stages, six weeks[4], or in the later stages, starting from nine months[5]. Even with this discrepancy in the literature, all authors who have published about protocols for determining the time required to return to sport use specific functional assessments for the decision-making.

To safely return to competitive sports or unrestricted physical activity after ACL reconstruction, objective and subjective criteria related to the clinical stability of the knee[6], range of motion[7], hypotrophy of thigh muscles[8], numerical questionnaires regarding function[9], functional tests involving single-legged hops and agility tests[10], and assessments of muscle performance[11] are necessary. The assessment of muscle performance, specifically the knee extensors and flexors, can be accomplished by isotonic, isokinetic, or isometric tests by performing concentric, eccentric, or isometric contractions[12]. Among all the previously mentioned alternatives, the evaluation of muscle deficits, characterized by a significant muscle performance difference between the injured or dominant limb and the contralateral or healthy side is done through a computerized isokinetic dynamometer, considered the most appropriate for data collection due to its objectivity, reproducibility, and safety during assessments[13]. In addition, studies using isokinetic dynamometers provide references for the progression of the phases of postoperative rehabilitation[14] and the criteria for unrestricted return to sport[15]. However, research on the criteria for returning to sport has generated great controversy in the literature about the validity of isokinetic dynamometers correlations with different functional tests that simulate sports movements[16,17]. Several studies observed a significant correlation between peak torque and performance in single-legged hop tests and function questionnaires[16,18]. However, other researchers argue that isokinetic dynamometers are physical exams conducted in an open kinetic chain that therefore bear important differences in relation to sport movements, and that single-legged hop tests would better reproduce the functional deficits found[19].

Therefore, this paper has the following objectives:

1) To investigate the correlation between deficits found in isokinetic peak torque with deficits found in single-legged hop tests, the Lysholm questionnaire, and postoperative ligament laxity in individuals who underwent ACL reconstruction.

2) Analyze the muscular deficits of the extensor and flexor of the knee through isokinetic peak torque in normal subjects and patients who underwent ACL reconstruction with patellar tendon and flexor tendons (semitendinosus and gracilis) autografts.

3) Evaluate the deficits found in two types of single-legged hop in normal subjects and patients who underwent ACL reconstruction with patellar tendon and flexor tendons (semitendinosus and gracilis) autografts.

METHODS

Sixty individuals aged between 18 and 45 years were verbally invited. The volunteers were divided into three groups. The first was called the control group (CG), consisting of 20 volunteers with no history of knee injury. The second group, called the patellar tendon group (PTG) was composed of 20 volunteers who underwent anterior cruciate ligament reconstruction with patellar tendon autograft. The third group consisted of 20 volunteers who underwent anterior cruciate ligament reconstruction with flexor tendons (semitendinosus and gracilis) autograft, which was named the flexor tendons group (FTG). All volunteers in the PTG and FTG groups were recruited after completing a minimum of six postoperative months. This was a retrospective study. All members of the three groups participated in noncompetitive recreational sports. The surgical procedures were performed by orthopedic surgeons from the knee surgery group of the Hospital Municipal Celso Pierro, Pontifícia Universidade Católica de Campinas. The general characteristics of the participants of the three groups and the details of the postoperative status of the PTG and FTG are described in Table 1. The inclusion criteria for the CG were the absence of previous history of knee injury of any kind, absence of neuromuscular disorders, and a difference of less than 3mm of ligament laxity between the knees measured by a KT 1000. The inclusion criteria for the PTG and FTG were the completion of six postoperative months,

Table 1 – General characteristics and postoperative status of the volunteers distributed in three groups analyzed, CG, PTG, and FTG.

Variable	CG	PTG	FTG
Sample (N)	20	20	20
Age (years)	24.95 (5.18)	32.6 (7.76)	27.55 (6.88)
Height (cm)	175.1 (7.35)	176.2 (8.48)	179.5 (8.99)
Weight (kg)	75.8 (8.7)	85.5 (14.3)	79.9 (8.7)
Flexion ROM – ND and I	143.5 (3.5)	137.6 (7.46)	136.9 (3.9)
Flexion ROM – D and I	143.5 (3.5)	137.5 (6.6)	137.8 (3.9)
Extension ROM – ND and I	-0.2 (3.49)	-1.2 (4.6)	-0.15 (2.15)
Extension ROM – D and I	-0.1 (3.17)	1.2 (4.07)	1.25 (4.7)
Perimetry (at 15 cm)	0.8 (0.6)	1.42 (1.1)	1.35 (1.3)
Tegner scale	5.5	6.2	6.7
Femoral fixation	**********	Interference 20\20	Endobutton 5\20 Transverse 8\20 Interference 7\20
Tibial fixation	**********	Interference 20\20	CS + MW 10\20 Int + Blount 2\20 Interference 8\20
PO Time (months)	**********	8.5 (5.45)	8.5 (4.00)
Superv Rehabilitation	**********	10\20	15\20
Guid Rehabilitation	**********	10\20	5\20

Legend: ROM = range of motion; ND and I = non-dominant and injured side; D and I = dominant and injured; superv = supervised; guid = guided; CS + MW = cortical screw + metal washer; int + Blount = interference screw + Blount staple; CG = control group, PTG = patellar tendon group; FTG = flexor tendons group.
Source: FMRP-USP

the absence of inflammatory signs, normal gait, absence of neuromuscular disorders, and no complaints of instability in the activities of daily living. Exclusion criteria for all groups were: history of bilateral ligament injuries, prior ligament reconstruction surgery of any kind in the knee, fractures of any kind in the lower limbs, combined ligament ruptures, advanced osteoarthritis in the tibiofemoral or patellofemoral joints with obvious deviation from the joint axis.

All volunteers received detailed written instructions on how the test would be performed and signed an informed consent form agreeing to participate in the study. The project was approved by the Ethics Committee of the Hospital das Clínicas, School of Medicine, Ribeirão Preto, Universidade de São Paulo, number 7375/2007.

The validated Portuguese language version of the Lysholm subjective evaluation[20] was used to functionally characterize the sample. The Tegner and Lysholm scales were used to assess the sports level of volunteers in the three groups[21].

The KT 1000 arthrometer (MEDmetric, San Diego, CA, USA) was used to assess all groups. In CG, the equipment determined the study participants' criteria for inclusion and exclusion. In the PTG and FTG, the KT 1000 was used to determine the clinical stability of the operated knee.

A computerized isokinetic dynamometer (Biodex Multi-joint System 3 Pro) belonging to the Orthopedics and Traumatology Assessment and Intervention Laboratory (LAIOT, Laboratório de Avaliação e Intervenção em Ortopedia e Traumatologia), from the Physiotherapy postgraduate course of the Universidade Federal de São Carlos (UFSCar) was used to collect the isokinetic peak torque.

Procedures

Initially, all participants underwent a clinical evaluation. During this evaluation, in addition to the collection of personal data, the volunteers underwent physical examination, which included assessment of the passive range of motion (ROM), perimetry of the upper thighs, and completion of the Lysholm and Tegner questionnaire. After clinical evaluation, volunteers underwent arthrometric examination (KT 1000) using the manual maximum test (MMT). Three MMTs were performed and the highest value was recorded in the clinical evaluation form (Figure 1A). For the PTG and FTG, the uninjured knee was always tested first, and in the control group, the nondominant knee. All arthrometric examinations were performed by the first author of this study, and the test-retest reliability of the examiner has previously been published[22]. After the manual maximum test, all volunteers performed a five minute warm-up on a stationary bicycle, followed by three 30-second series of traditional quadriceps and hamstring stretches.

After warming up, patients were positioned in the seat of the isokinetic dynamometer and stabilized on their torso, pelvis, and hip by restraining straps to avoid compensation during the examination (Figure 1B). Volunteers were instructed to hold their arms across their chest to isolate the extension and flexion moments of the knee.

A protocol with two speeds, 60°/s and 180°/s, was developed to evaluate the isokinetic torque. At

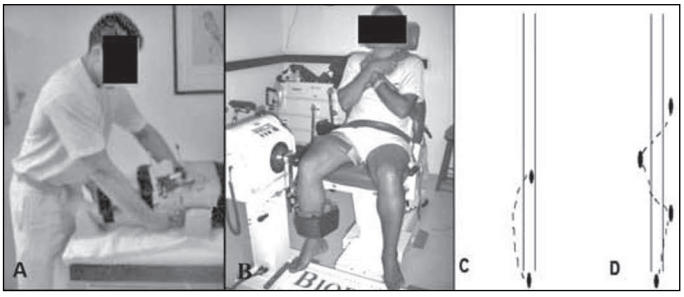


Figure 1 – A) Manual maximum test using the KT 1000, B) positioning of the volunteers* to collect the isokinetic peak torque of the knee extensors and flexors, C) single-legged hop test for distance, and D) single-legged triple hop test for distance (adapted from the original by Noyes et al).

60°/s, the volunteers performed two series of five movements of knee extension and flexion, and at 180°/s, two sets of 15 repetitions. Both speeds were performed with the knees traveling the fastest and strongest possible between the angles of 0° and 90°, with intervals of 90 seconds between the series. The first series was used to familiarize the patient with the isokinetic test. During testing, the patient received constant verbal commands to perform the examination. The examination for all tests was initiated with the non-dominant leg in the CG and the contralateral leg in PTG and FTG. Differences greater than 15% between the injured side and the contralateral side were considered significant deficits in the PTG and FTG and in the non-dominant side compared with the dominant side in the CG. The reference value of 15% was based on a study by Kvist et al.(23), which provides recommendations related to the maximum acceptable deficit for returning to unrestricted athletic activity after ACL reconstruction.

Single-legged hop tests

For the single-legged hop tests evaluation, the order of execution of the two single-legged hop tests was randomized by asking the patients to choose between two small envelopes containing either the single-legged hop test for distance or the single-legged triple hop test for distance. Two 6-m long pieces of adhesive tape were placed in the ground 15 cm apart in order to perfom the jumps.

After the order of the jumps was chosen, verbal instructions were given about the correct way to execute the test. The objective of the single-legged hop test for distance is to jump as far as possible with only one limb and to land with the same limb (Figure 1C). The purpose of the single-legged triple hop test for distance is to perform three jumps in a zigzag pattern as far as possible, crossing the two parallel lines, with only one of the lower limbs (Figure 1D). After the instructions were given, volunteers were positioned at the beginning of the tape placed on the ground for reference and guidance. Volunteers were allowed the support of only one leg to start the test. The subjects were instructed to leave the arms positioned freely while executing the test.

No period of familiarization with the test was performed in order to better observe the differences between the groups.

To obtain the deficits presented by the volunteers to perform the two types of jump, the study by Noyes et al.(24) was used as reference, which used the following equation:

$$\text{LLIS} = \frac{\text{non-dominant side distance X 100}}{\text{dominant side distance}}$$

CG

$$\text{LISM} = \frac{\text{injured limb distance X 100}}{\text{contralateral limb distance}}$$

PTG and FTG

LLIS – lower limbs index of symmetry, CG – control group, PTG – patellar tendon group, FTG – flexor tendons group

Where LLIS means the lower limbs index of symmetry, to demonstrate any significant deficit between the limbs, the injured side or the knee with the lowest score in the control group must demonstrate less than 90% distance of the value of the contralateral side[25].

STATISTICAL ANALYSIS

For intergroup comparisons of the CG, PTG, and FTG on the isometric, isokinetic, and arthrometric tests and the Lysholm questionnaire, we used analysis of variance (ANOVA) with the Bonferroni *post hoc* test with $p < 0.05$. The Pearson correlation coefficient was used to calculate the correlation between peak torque deficits in isometric and isokinetic tests and jumping performance, ligament laxity, and Lysholm questionnaire scores within groups. For comparison between individuals in the FTG and PTG who had anterior tibial translation greater than 3 mm between the knees, as well as the comparison of these individuals on hop tests, we used the Student's t-test for independent samples, with $p < 0.05$.

Additionally, a quantitative comparison was performed of the percentage of individuals in the three groups who showed a deficit in extensor torque greater than 15% between the knees in the two angular velocities, in which case there would not be adequate symmetry between the limbs in terms of the return to sport criterion; and a comparison in relation to the percentage of individuals in the three groups whose LLIS was < 90% in the two types of single-legged hop tests, which would not be appropriate symmetry between limbs in terms of the return to sport criterion. We calculated logistic regression with the group (three groups) as its independent variable and each test (extensor torque, flexor torque, and single-legged hop tests) as the response variable, with $p < 0.05$.

RESULTS

Descriptive data on the characteristics of the study participants regarding age, weight and height can be observed in Table 1. Postoperative status values between the PTG and FTG, showing similar values for the flexion and extension ROM, perimetry, and mean time after surgery (8.5 months) can also be observed, due mainly to the fact that participants of the PTG and the FTG were recruited in chronological order by consulting the database of surgeries performed in the Hospital e Maternidade Celso Pierro – Pontifícia Universidade Católica de Campinas (HMCP-PUCC), since this study was done in a retrospective format. An important aspect of this study was the intention to include patients as close to the minimum discharge time commonly used in the literature, between six and nine months. Eighty percent (16/20) of the subjects in the PTG were at that stage and 85% (17/20) of those in the FTG. In the PTG, the associated lesions observed were tibiofemoral chondral lesions + medial meniscus (1/20), medial meniscus injury (4/20), and medial and lateral meniscus injury (1/20). In the FTG, there were chondral lesions + medial meniscus (2/20), tibiofemoral chondral lesions (1/20), and medial meniscus injuries (4/20). The level of sports participation for individuals in the three groups remained between 5.5 to 6.7 on the Tegner scale.

Arthrometry and Lysholm questionnaire

In the evaluation of intergroup ligament laxity, the CG showed anterior tibial translation (ATT) values between knees that were significantly lower ($p < 0.001$) than the PTG and the FTG (Table 2). There were no statistically significant differences between the PTG and the FTG (Table 2). In the functional assessment using the Lysholm questionnaire, there were statistically significant differences among groups; the CG showed significantly higher scores than the PTG and the FTG ($p < 0.001$) (Table 2). Comparing the PTG and the FTG, the latter had a significantly higher score than the former ($p < 0.001$).

Table 2 – Comparison between groups regarding the mean (SD) of the index of symmetry (LLIS) values for the single-legged hop tests, ligament laxity, and Lysholm questionnaire using analysis of variance ANOVA with the Bonferroni post hoc test.

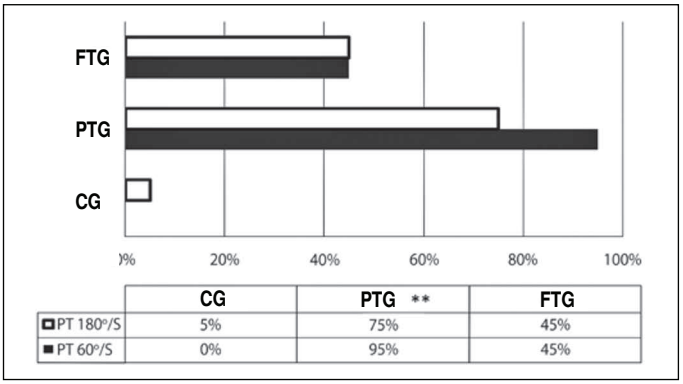
Hop test	CG N = 20	(sd)	PTG N = 20	(sd)	FTG N = 20	(sd)
Single-legged hop	94.62*	(3.63)	78.35	(12.55)	86.15	(18.51)
Single-legged triple hop	97.11*	(2.33)	80.46	(10.28)	86.93	(16.20)
KT 1000 (mm)	0.7**	(0.49)	2.94	(2.26)	2.89	(1.98)
Lysholm	100*	(.0)	87.4†	(12.9)	93.8	(6.14)

Legend: CG – control group; PTG – patellar tendon group, FTG – flexor tendons group;
* Control group with significantly higher values than those of the PTG and the FTG ($p < 0.001$)
** Control group with significantly lower values than those of the PTG and the FTG ($p < 0.001$)
† PTG with significantly lower values than those of the CG and the FTG ($p < 0.001$)
Source: FMRP-USP

Isokinetic peak torque

In the intergroup analysis, the extensor torque deficits found in the CG were significantly lower ($p < 0.001$) in isokinetic peak torque at 60°/s (7.71 ± 4.21) and 180°/s (5.85 ± 3.89) than the PTG (32.30 ± 14.30), (22.63 ± 10.61), and the FTG (18.70 ± 17.79) and (15.83 ± 15.26), respectively. In the comparison between the PTG and the FTG, the former showed significantly ($p < 0.001$) larger deficits in the two strength tests, (32.30 ± 14.30) on the isokinetic test at 60°/s vs. (18.70 ± 17.79) in the FTG. A quantitative comparison in the percentage of individuals in the three groups can be seen in Chart 1, showing an extensor torque deficit greater than 15% between the knees on the two angular velocities; in terms of return to sport criterion, this would not be appropriate symmetry between the limbs.

The PTG had a significantly higher number of individuals within this parameter than the CG at the 60°/s and 180°/s test speed ($p = 0.02$) and the FTG at 60°/s ($p = 0.01$) and 180°/s ($p = 0.05$). In the analysis of flexor peak torque deficits, the CG had deficits of (5.05 ± 5.13) in the isokinetic test at 60°/s and (6.09 ± 3.85) at 180°/s. Deficits of (4.0 ± 12.22) were observed in the PTG's isokinetic test at 60°/s and (2.51 ± 13.49) at 180°/s. The FTG had isokinetic deficits of (8.99 ± 10.01) at 60°/s and (7.20 ± 9.85) at 180°/s. There was no statistically significant difference be-

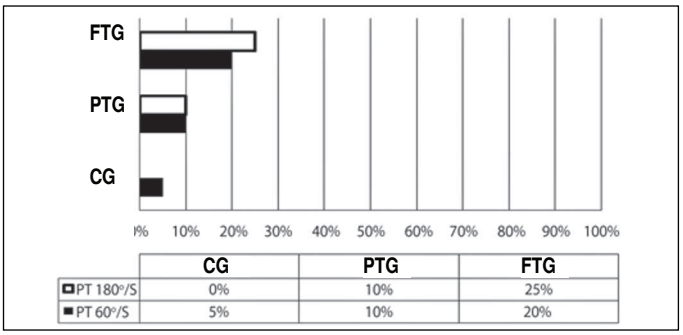


	CG	PTG **	FTG
PT 180°/S	5%	75%	45%
PT 60°/S	0%	95%	45%

Chart 1 – Comparison between groups of the percentage of patients who showed extensor torque deficits between the knees *greater* than 15% in isokinetic peak torque at 60°/s (PT 60°/s) and 180°/s (PT 180°/s)

Legend: * CG x PTG PT 180°/s (p = 0.04) and CG x FTG PT 180°/s (p = 0.01); CG x PTG PT 60°/s and CG x FTG PT 60°/s (p = 0.02) ** PTG x FTG PT 180°/s (p = 0.05) and PTG x FTG PT 60°/s (p = 0.01)
Source: FMRP-USP

tween the three groups studied (p > 0.05). The quantitative analysis between the groups regarding flexor torque showed no statistically significant difference between the percentage of subjects who had a deficit > 15% between the knees (Chart 2).



	CG	PTG	FTG
PT 180°/S	0%	10%	25%
PT 60°/S	5%	10%	20%

Chart 2 – Comparison between groups of the percentage of patients who showed flexor torque deficits greater than 15% between the knees in isokinetic peak torque at 60°/s (PT 60°/s) and 180°/s (PT 180°/s).

Single-legged hop tests

In the intergroup evaluation using ANOVA, statistically significant differences were found in the performance of the two single-legged hop tests (single-legged hop for distance and single-legged triple hop for distance) with a significantly higher average lower limbs index of symmetry (LLIS) in the CG compared to the FTG and the PTG (p < 0.001) (Table 2). The PTG showed lower mean LLIS values than those of the CG and the FTG, however, no significant differences between the PTG and the FTG in both hop tests (Table 2). Chart 3 shows the intergroup comparison of the number of individuals within each group that showed an LLIS value less than 90%. A significantly greater number of individuals in the PTG did not achieve optimal LLIS values (≥ 90%) for return to sport when compared with those of the CG and the FTG in the single-legged hop and single-legged triple hop tests (Chart 3).

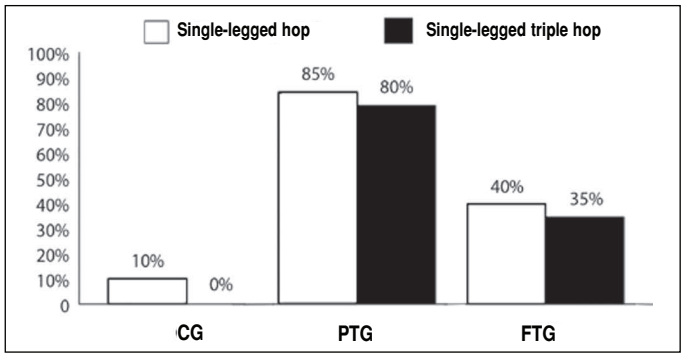


Chart 3 – Intergroup comparison of the percentage of individuals who demonstrated a lower limbs index of symmetry (LLIS) of less than 90% in the single-legged hop tests. CG (N = 20), PTG (N = 20), and FTG (N = 20).

Source: FMRP-USP
Legend: * CG x PTG single-legged hop (p < 0.001) and CG x FTG single-legged hop (p < 0.04); CG x PTG single-legged hop and single-legged triple hop (p < 0.02)
** PTG x FTG single-legged hop (p = 0.06) and single-legged triple hop (p = 0.06)
Source: FMRP-USP

Correlation between peak torque, hop tests, ligament laxity, and Lysholm questionnaire

In the intragroup analysis of the correlation between flexor peak torque and ligament laxity measured by the KT 1000, we found no statistically significant correlation in most of the strength tests used (Table 3). A significant, though moderate, negative correlation was observed only in the PTG between the deficit in flexor peak torque in isokinetic test at 60°/s and ligament laxity (r = -0.49, p = 0.03). In the other groups and tests, there was no significant correlation between flexor peak torque, hop tests, and the scores from the Lysholm questionnaire (Table 3).

In the intragroup analysis of the correlation between extensor peak torque deficits and ligament laxity, no significant correlation was found in any group (Table 4).

The same situation was observed when comparing extensor peak torque and scores from the Lysholm questionnaire – no significant correlations were observed between the groups (Table 4). The assessment of deficits in extensor peak torque with performance on hop tests found statistically significant negative correlations between extensor peak torque in isokinetic test at 60°/s and the single-legged hop test in the CG (r = -0,53, p < 0.02). There was no significant correlation between deficits in extensor peak torque

Table 3 – Pearson correlation coefficient between the deficit of flexor isokinetic peak torque at 60°/s (PT 60°/s) and 180°/s (PT 180°/s) and single-legged hop, ligament laxity, and Lysholm questionnaire in the CG (n = 20), PTG (n = 20), and FTG (n = 20).

Test	CG (r)	p	PTG (r)	p	FTG (r)	p
PT 60º/s x single-legged hop	-0.31	0.19	0.06	0.81	-0.28	0.23
PT 180°/s x single-legged hop	0.08	0.75	0.06	0.82	-0.07	0.77
PT 60º/s x single-legged triple hop	0.12	0.61	-0.04	0.86	-0.31	0.18
PT 180°/s x single-legged triple hop	0.10	0.66	-0.06	0.82	-0.22	0.35
PT 60°/s x KT 1000 man max	0.32	0.17	-0.49	0.03	-0.14	0.57
PT 180°/s x KT 1000 man max	0.19	0.41	0.02	0.94	-0.24	0.31
PT 60°/s x Lysholm	Const var		0.28	0.26	0.07	0.78
PT 180°/s x Lysholm	Const var		-0.07	0.79	-0.10	0.68

Legend: CG – control group; PTG – patellar tendon group, FTG – flexor tendons group; Const var – constant variable * statistically significant correlation ($p < 0.05$)
Source: FMRP-USP

Table 4 – Pearson correlation coefficient between deficits in extensor isokinetic peak torque at 60°/s (PT 60°/s) and 180°/s (PT 180°/s) and hop tests, ligament laxity, and Lysholm questionnaire in the CG (n = 20), PTG (n = 20), and FTG (n = 20).

Test	CG (r)	p	PTG (r)	p	FTG (r)	p
PT 60º/s x single-legged hop	-0.53	0.02*	-0.43	0.06	-0.90	< 0.001*
PT 180°/s x single-legged hop	0.03	0.90	-0.34	0.14	-0.87	< 0.001*
PT 60º/s x single-legged triple hop	-0.18	0.46	-0.21	0.38	-0.78	< 0.001*
PT 180°/s x single-legged triple hop	-0.04	0.86	-0.32	0.17	-0.78	< 0.001*
PT 60°/s x KT 1000 man max	0.33	0.16	-0.06	0.82	0.12	0.62
PT 180°/s x KT 1000 man max	-.18	0.44	0.05	0.85	0.25	0.29
PT 60°/s x Lysholm	Const var	Const var	-0.34	0.14	-0.26	0.27
PT 180°/s x Lysholm	Const var	Const var	-0.28	0.23	-0.37	0.11

CG – control group; PTG – patellar tendon group, FTG – flexor tendons group; Const var – constant variable * statistically significant correlation ($p < 0.05$).
Source: FMRP-USP.

with performance on hop tests in the PTG. In the FTG, there were statistically significant negative correlations between deficits in extensor peak torque at 60°/s and the single-legged hop for distance ($r = -0.90$, $p < 0.001$) and crossing triple hop for distance ($r = -0.78$, $p < 0.001$), and between extensor peak torque at 180°/s and single-legged hop for distance ($r = -0.87$, $p < 0.001$) and triple hop for distance ($r = -0.78$, $p < 0.001$).

DISCUSSION

The results of this study showed that individuals in the PTG presented greater deficits in extensor peak torque compared with the CG and the FTG. The difference was statistically significant only in the isokinetic test at 60°/s ($p < 0.001$).

PTG's inferior performance is also demonstrated by the greater percentage of subjects in the PTG with deficits > 15%. This result is in agreement with other authors who have demonstrated greater extensor deficits in the short-term in patients undergoing surgical reconstruction techniques using the patellar tendon[26,27]. However, both groups of patients who underwent reconstruction had significant extensor deficits compared with the control group. Therefore, the extensor peak torque deficit is not solely dependent on the type of graft or morbidity at the graft removal site, but seems to be directly influenced by factors related to the arthrogenic inhibition of the quadriceps[22,28]. This inhibition would be caused by the destruction of the mechanoreceptors located in the anterior cruciate ligament that was sectioned with surgery or injury. In addition to this inhibition and the consequent atrophy of the fibers of the quadriceps, there is the facilitation of hamstring activity to consequent dynamic stabilization of the knee[29]. This theory of the pattern of motor control facilitating the activity of the hamstrings is observed in studies that investigated the flexor torque deficits postoperatively in patients undergoing ACL reconstruction using both types of graft, which found no differences between groups[30,31], and corroborated the findings of our study, which showed no significant differences between the CG, the PTG, and the FTG in the deficits found in the knee flexor. However, these results contrast with those of other authors who observed significant flexor torque deficits in patients undergoing ACL reconstruction with flexor tendons[26,32].

One explanation for the significant flexor torque deficits found in patients using flexor tendons is due to the simultaneous removal of the semitendinosus and gracilis tendons, causing morbidity at the graft removal site[33]. A larger number of studies should be performed to clarify whether the facilitation of the hamstrings caused by the change in motor control favors the production of force, despite the removal of the semitendinosus and gracilis.

The better extensor peak torque performance of the FTG was correlated negatively with the two single-legged hop tests. This negative correlation would indicate that the smaller the deficits found in extensor torque in this group, the higher the lower limbs index of symmetry (LLIS). There was no statistically significant difference in the average LLIS between

the FTG and the PTG in both of the single-legged hop tests, in agreement with several studies that used single-legged hop tests to compare these two surgical techniques[34,35]. However, an important fact with great clinical relevance is that a *lower* percentage of participants within the FTG did not obtain the LLIS necessary to return to sport, and the group as a whole demonstrated better performance in the single-legged hop tests than the PTG. Eriksson et al.[36] analyzed the functional performance of 107 patients who underwent ACL reconstruction with a patellar tendon autograft (n = 57) or a flexor tendon autograft (n = 50) with a mean of 6.5 postoperative months. The results showed better performance on the single-legged hop tests in the flexor tendons group ($p < 0.01$). The authors attribute these differences to the larger deficit in extensor torque found in the group of individuals who used the autologous patellar tendon as a graft, which was observed in our present work. Similarly to what happened to the extensor peak torque, both groups that underwent reconstruction showed lower LLIS values than the CG. Similar to the FTG, there was a significant negative correlation between the extensor peak torque deficit in isokinetic test at 60°/s and the single-legged hop for distance in the CG.

These results corroborate studies that showed a significant correlation between extensor peak torque and performance on functional tests[7,10,16,18,24]. Similar to the findings of Wilk et al., a significant correlation between the flexor peak torque deficit and the hop tests was not observed in this study[18]. Despite the great importance of the hamstrings in providing joint stability and working as an antagonist to slow movement[37], the quadriceps may have played a more active role in jumping and landing from jumps, correlating with extensor torque into two groups, the CG and the FTG.

In the evaluation of the groups using the Lysholm questionnaire, the PTG score was significantly lower than the FTG and the CG, in contrast with studies that used function questionnaires to distinguish functional performance between techniques that used the patellar tendon and the flexor tendons and found no significant differences[38,39]. The lowest values in the Lysholm questionnaire associated with isokinetic extensor torque deficits at 60°/s in the PTG reflect lower functional performance compared to the FTG in this study.

Besides studying the correlation between deficits in the peak torque and the hop test, another parameter that was evaluated was the correlation between postoperative ligament laxity and the peak torque of knee extensors and flexors. The results showed only a weak correlation between peak torque deficits and ligament laxity as measured by the KT 1000 in the CG, the PTG, and the FTG for both muscle groups analyzed (extensors and flexors). The lack of a relationship between ligament laxity and peak torque found in this study corroborates previously published studies[10,22,40]. Sekiya et al. did not find a significant correlation between the different levels of extensor torque deficits, ligament laxity, and performance on hop tests in patients with ACL reconstruction[10]. Ergün et al. found no relationship between ligament laxity and isokinetic peak torque in the evaluation of 44 soccer players with no history of ACL injury[40].

Vasconcelos et al. analyzed the anterior tibial translation, isometric peak torque, and electromyographic activity in subjects with ACL insufficiency and control subjects[22]. Although the anterior tibial translation was significantly higher in patients with ACL insufficiency, there were no differences in the peak torque and quadriceps EMG activity between the groups. The lack of correlation between the deficit in peak torque and postoperative ligament laxity found in this study and in patients with ACL insufficiency in the study by Vasconcelos et al. may be related to the task required during isometric and isokinetic testing, which is not similar to movements that produce instability, that is, rotational movements[22].

Limitations of the study

The main objective of this study was the correlation of different clinical and functional assessment tools in the three groups of subjects included in the study. As can be seen in Table 1, different types of graft fixation have been used for ACL reconstruction in the FTG. This is due to the personal preference of the surgeons of the orthopedic department in which patients were recruited. However, we did not observe differences in relation to the ROM and ligament laxity between the PTG and the FTG; this demonstrates that the surgical techniques were appropriate, as arthrofibrosis and excessive postoperative ligament laxity > 10 mm[41] are factors that are directly related to surgical technique failure in ACL reconstruction[42,43]. However, conclusions about the advantages of the flexor tendon graft over the patellar tendon graft are limited according to the methodology used in this retrospective study.

CONCLUSIONS

According to the methodology used in this study, deficits in extensor peak torque present significant correlations with single-legged hop tests. This result was observed in two groups, CG and FTG.

In the functional evaluation of patients undergoing ACL reconstruction, it is not advisable to use only one measuring instrument, for a significant correlation between peak torque deficits, function questionnaires, ligament laxity, and single-legged hop tests was not found in all groups, always requiring the combination of all these parameters presented here.

If the parameters of extensor peak torque deficits and the lower limbs index of symmetry (LLIS) for the single-legged hop tests were used as a criterion for unrestricted return to sports, that is, medical discharge, a considerable percentage of patients who underwent ACL reconstruction with either surgical technique would not be released, even with the minimum time of six months after surgery completed, since they demonstrated significant deficits in both tests.

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