ISOKINETIC MUSCLE PERFORMANCE AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: A CASE-CONTROL STUDY

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ABSTRACT

Background and Purpose: Knee muscle strength deficits have been reported in individuals who have undergone anterior cruciate ligament reconstruction (ACLR). Isokinetic testing is a valid way to assess muscle strength. Some isokinetic variables, including the range of motion in the phases to attain a specific velocity, load range (sustained specific velocity), time to achieve deceleration, and qualitative analysis of the torque-angle velocity relationship, may contribute to understanding recovery of these individuals after surgery. Thus, the purpose of this study was to compare the load range (LR), time to attain velocity (TTAV), deceleration time (DT) phases, total range of motion (ROM), peak torque/body mass (PT/BM), angle of peak torque (AngPT) during LR and torque-angle-velocity relationships (TAV_{3D}) between post ACLR and matched control subjects.

Study design: Case-control.

Methods: Seven men who underwent ACLR and seven matched controls were evaluated from four to six months after surgery. Testing was performed on a Biodex System 4 isokinetic dynamometer in concentric mode at 60, 120 and 300 °/s, for knee flexion and extension.

Results: Statistically significant differences were seen for extension ROM at 60 °/s where ROM was greater in the control group. PT/BM for extensors was also significantly greater in controls by 20 % compared to ACLR at 60 and 120 °/s. PT/BM for flexors was significantly greater for controls at 60 °/s (~15 %). TAV_{3D} showed differences in torque and, specifically, the control group sustained knee flexion torque for a greater range of motion when compared to the ACLR group.

Conclusion: The ACL group presented with lower ROM and PT/BM, therefore exhibiting worse muscle performance in comparison to the control group.

Level of Evidence: 3

Keywords: Anterior cruciate ligament reconstruction, isokinetic dynamometer, torque.

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The authors declare no conflicts of interest related to this work.

INTRODUCTION

The most common knee injury in young adults is anterior cruciate ligament (ACL) tears.^{1,2} Around 200,000 ACL injuries occur each year in the United States, and approximately 65 % of these injuries are treated with reconstructive surgery.³ This procedure aims to correct functional instability of the knee and allow the patient to return to sport activities.⁴ Different operative techniques may be employed with the most widely used being bone patellar tendon bone (BPTB) or hamstring tendon (HT) grafts.^{5,6}

After ACL reconstruction (ACLR), muscle weakness is often observed, with lower strength in the extensor muscles when BPTB is used and in flexor muscles when HT is the choice.⁷⁻⁹ Torque is often measured isokinetically to assess performance of the knee muscles after ACLR. Researchers have evaluated patients between five and six months after reconstruction. During this period, the torque deficit for extensors in the injured leg may be more than 10 % and last two years post ACLR.^{8,10-12}

Different measurements of muscle performance are important for return to sports and physical activity after ACLR. The most common measure of strength obtained from an isokinetic dynamometer is peak torque and can be represented as a percentage normalized to body mass.¹³ Peak torque is a good indicator of joint function and relative muscle strength in comparison to other individuals.^{14,15} Another variable is angle of peak torque that is a measure of the torque as a function of knee joint angle produced when the muscle is maximally activated during isovelocity shortening and may be a useful for planning training or rehabilitative programs.¹⁶

Another way to explore isokinetic results is to divide range of motion into three sections. The first is time to attain velocity (TTAV), the second is load range (LR) wherein specific velocity defined is sustained and finally deceleration time (DT). These outcome variables may provide additional information, such as the time for reaction and the ability to maintain the velocity, which could aid in clinical evaluation and implementation of specific rehabilitation protocols in order to optimize treatment.^{17,18}

Qualitative analysis of isokinetic output is another form of assessment that uses surface maps of the

torque-angle-velocity relationship (TAV_{3D}). It can provide a more comprehensive understanding of dynamic behavior of a muscle compared to static assessments, due to focusing on length-tension and length-velocity relationships.^{19,20} In this context, it is relevant to verify possible deficits in muscle performance and load range six months post ACLR. Thus, the purpose of this study was to compare the load range (LR), time to attain velocity (TTAV), deceleration time (DT) phases, total range of motion (ROM), peak torque/body mass (PT/BM), angle of peak torque (AngPT) during LR and torque-angle-velocity relationships (TAV_{3D}) between post ACLR and matched control subjects.

METHODS

Seven males post ACLR using hamstring tendon autograft of their dominant limb participated. Four were professional soccer players while the others were physically active, including participating in amateur soccer. Patients were excluded if they had suffered more than one ACL injury in the same knee or the contralateral limb. The matched control group was comprised of seven healthy males with no prior injuries or surgeries of their lower limbs. Five control participants were professional soccer players while the others were physically active including participation in amateur soccer. All participants read and signed an informed consent prior to testing. The Universidade Estadual de Londrina Ethics Committee approved this study and all procedures (#055/2012).

One investigator performed all isokinetic testing using the Biodex System 4® Dynamometer (Biodex Medical System Inc., Shirley, NY). Testing was performed in the concentric isokinetic mode at 60, 120 and 300 °/s, for knee flexion/extension with a sampling frequency of 100 Hz. Participants were instructed to not perform any physical activities on the day of testing. Warm-up consisted of stationary cycling for ten minutes at a speed of 30 km/h with no resistance. Subjects were then positioned on the seat of the dynamometer, and stabilized by belts around their trunk, pelvis and thighs. Hip flexion was set at 85 ° and the dynamometer axis was aligned with the lateral femoral epicondyle. The ankle pad was positioned just above the medial malleolus.²¹ All calibration and gravity correction procedures followed manufacturers' guidelines.²²

Range of motion (ROM) was limited to between 90 ° of flexion and 0 ° of extension. Extension ROM for each participant was defined in accordance with their individual limits. Three practice repetitions at each velocity were performed to ensure compliance with testing procedures. Isokinetic testing consisted of one set of five repetitions at each velocity, in random order, with a rest time of 90 seconds between sets.²⁰ Participants were instructed to perform at maximal effort during all repetitions while verbal encouragement and visual feedback were provided. For reliability purposes, a coefficient of variation less than 10 %, for each set, was considered acceptable.²³

The raw data were extracted in the Biodex software, and additional processing was performed with specific *Matlab*® algorithms. Mean values from the five repetitions were calculated for all variables at each velocity. The percentages of each phase (TTAV, LR and DT) were calculated in relation to the total ROM, as peak torque is achieved in the LR phase. PT/BM and AngPT were also calculated only during the LR phase.

To create the TAV_{3D} surface maps, the surf mathematical function from *Matlab*® was used. All five repetitions of each velocity were interpolated according to phase duration. The algorithm estimated the intrinsic geometry by considering torque (z-axis), joint angle (x-axis) and velocity (y-axis) in the same time frame. The z axis defined the map height in relation to strength intensity while the x and y axes shaped boundaries of the surface. The qualitative analysis with a TAV_{3D} surface maps improve the interpretation of the test results, it is possible to observe the interaction between torque, velocity and the range of motion. This interpretation may add to the other isokinetic test results, like the evaluation of the movement or the functional activity could add to decision

making for the treatment. Given the fact that all participants in the ACL group injured their dominant leg, comparisons were performed between the dominant leg of the control group and injured leg of the ACL group.

For comparisons of the isokinetic variables, multiple two-way analysis of variance (ANOVA) by group and velocity were used, after verification of the equality of variance errors (Levene test). Interactions were also verified. If the *F* test was statistically significant, multiple comparison post-hoc tests using Bonferroni correction were performed through a specific syntax. Significance was stipulated at 5% and all analyses were performed with SPSS version 22.0 (IBM SPSS®, Armonk, NY, USA).

RESULTS

Anthropometric characteristics are presented in Table 1, and there were no differences between groups.

ISOKINETIC PERFORMANCE

Statistically significant differences were found in extension at 60°/s, where the control group ROM was approximately 7.1% greater ($p=0.007$) than the ACL group (Table 2). PT/BM values in the control group were significantly greater for the extensor muscles at 60 and 120°/s, by 18.4% ($p=0.037$) and 21.4% ($p=0.023$) respectively. For flexion, PT/BM was significantly greater for controls at 60°/s, by 15.3% ($p=0.007$) (Table 3). The other variables were not statistically significantly different.

SURFACE MAPS

TAV_{3D} of the control group demonstrated higher torque, in vertical axes, when compared to the post ACLR group (color intensity is proportional to each surface throughout the ROM, with light grey/blue

Table 1. Anthropometric characteristics

	ACL Md (25-75%)	Control Group Md (25-75%)	<i>p</i>
Age (years)	23 (19-25)	21.8 (19-24)	0.47
Body mass (kg)	86.4 (70-102)	78.5 (76-80)	0.56
Height (cm)	181.5 (173.2-192)	180.5 (176-185)	0.89
Body mass index (kg/m ²)	25.8 (22.3-28.5)	24.1 (23.4-24.5)	0.65
Post-operative period (months)	5 (4.5-6)		
Md= Median			

Table 2. Range of motion for each isokinetic phase, between the groups.

Involved	ACL Group Mean (95% CI)				Control Group Mean (95% CI)			
Extension	TTAV (%)	LR (%)	DT (%)	ROM (deg)	TTTA (%)	LR (%)	DT (%)	ROM (deg)
60°/s	7.15 (3.45;10.86)	89.47 (83.86;95.08)	3.36 (.64;6.08)	81.44* (77.22;85.66)	6.21 (2.51;9.92)	90.45 (84.84;96.06)	3.40 (.68;6.12)	87.71* (83.49;91.93)
120°/s	12.29 (8.59;16.00)	79.09 (73.47;84.70)	8.61 (5.89;11.32)	82.32 (78.10;86.55)	10.58 (6.88;14.29)	81.83 (76.21;87.44)	7.58 (4.86;10.30)	87.30 (83.07;91.52)
300°/s	31.37 (27.67;35.08)	44.65 (39.04;50.26)	23.97 (21.25;26.69)	81.65 (77.43;85.87)	33.19 (29.48;36.89)	41.49 (39.04;35.88)	25.31 (22.59;28.03)	85.00 (80.77;89.22)
Flexion	TTAV (%)	LR (%)	DT (%)	ROM (deg)	TTAV (%)	LR (%)	DT (%)	ROM (deg)
60°/s	4.54 (1.13;7.95)	89.44 (83.96;94.92)	6.00 (3.40;8.60)	82.11 (78.32;85.90)	3.73 (.33;7.14)	90.65 (85.17;96.13)	5.60 (3.00;8.20)	84.77 (80.98;88.56)
120°/s	10.31 (6.90;13.72)	80.37 (74.89;85.84)	9.02 (6.42;11.62)	83.57 (79.78;87.36)	9.44 (6.04;12.85)	81.82 (76.34;87.29)	8.73 (6.13;11.32)	87.05 (83.26;90.84)
300°/s	26.38 (22.97;29.79)	49.09 (43.61;54.57)	24.52 (21.92;27.12)	82.80 (79.00;86.59)	30.58 (27.17;33.99)	47.71 (42.23;53.18)	21.70 (19.10;24.30)	85.88 (82.09;89.67)

Bold and *= The mean difference is significant at the $p < 0.05$ between groups, °/s: degrees per second, TTAV: time to attain velocity, LR: load range, DT: deceleration time, %: percentage of each phase in relation to total range of motion, ROM: range of motion, deg: degrees.

Table 3. Peak torque and angle of peak torque at different velocities.

Involved	ACL Group Mean (95% CI)		Control Group Mean (95% CI)	
Extension	PT/BM (N.m/kg)	AngPT (deg)	PT/BM (N.m/kg)	AngPT (deg)
60°/s	2.80* (2.49;3.12)	65.50 (61.14;69.87)	3.43* (3.12;3.75)	67.23 (62.87;71.60)
120°/s	2.31* (1.99;2.62)	55.74 (51.38;60.11)	2.94 * (2.62;3.26)	59.35 (54.98;63.72)
300°/s	1.22 (.91;1.54)	57.40 (53.03;61.76)	1.27 (0.95;1.58)	59.21 (54.84;63.58)
Flexion	PT/BM (N.m/kg)	AngPT (deg)	PT/BM (N.m/kg)	AngPT (deg)
60°/s	1.66* (1.46;1.86)	35.07 (29.49;40.66)	1.96* (1.75;2.16)	29.20 (23.62;34.79)
120°/s	1.49 (1.29;1.69)	38.12 (32.53;43.71)	1.66 (1.46;1.86)	39.50 (33.91;45.08)
300°/s	1.20 (1.00;1.40)	36.93 (31.34;42.51)	1.18 (0.98;1.38)	41.21 (35.63;46.80)

Bold and *= The mean difference is significant at the $p < 0.05$ between groups, °/s: degrees per second, PT/BM: peak torque/body mass, AngPT: angle of peak of torque, N.m/kg: Newton meter/kilogram, deg: degrees.

representing lower torque). For flexion, the difference in the format of figure was lower between groups and the changes in torque were lower during the ROM (Figures 1 and 2).

DISCUSSION

This study evaluated isokinetic variables of post ACLR subjects compared to matched controls; the results indicate that extension PT/BM was lower in the ACLR group at 60 and 120 °/s. This deficit is in accordance with those reported by Hart et al.²⁴ who also found persistent quadriceps weakness in post ACLR subjects.

The results of the present study demonstrate that a deficit greater than 15% existed in the ACLR group for extensor PT/BM compared to controls, primarily at 60 °/s and the acceptable deficiency in isokinetic muscle strength should be ~15%.²⁵ A systematic review found strength deficits occur in the both the extensors of the knee (more pronounced after patellar tendon bone reconstructions) and the flexors of knee (more pronounced after hamstring autografts).²⁶ The authors recommended isokinetic examination of the knee as one criteria to decide if an athlete should be allowed to return to unrestricted sporting activities.²⁶

Figure 1. Surface map of the extension torque-angle-velocity relationship.

Figure 2. Surface map of the flexion torque-angle-velocity relationship.

Thomas et al.²⁷ evaluated patients before and six-months post ACLR compared to controls and showed a deficit in PT/BM of 33% for extension and 10% for flexion. In a review of ACLR graft choice (hamstring vs. bone patellar tendon) after two years, an average muscle deficit of 10% in the flexors and extensors was observed in both grafts. However, for the flexor muscles, residual deficits were significantly higher in the hamstring group.²⁸ It is important to consider that weakness post-surgery may be associated with detraining, incomplete rehabilitation, a combination

of crossover inhibition of motor activation, or inadequate reconditioning post ACLR.¹⁰ Similarly, the results of Anderson et al.²⁹ showed that the ACLR group had some PT deficits, even after six months post-surgery. According to Hiemstra et al.,³⁰ deficits in extensor torque have been shown to be as much as 25% one-year post ACLR.

Regarding ROM at 60 °/s, the differences occurred only for extension. Both groups were allowed to move between full extension (zero degrees) and 90

degrees of flexion, however, the control group extension ROM was greater by approximately six degrees (they more closely approached full extension). This could be related to quadriceps weakness, crepitus at terminal knee extension, or persistent mild joint stiffness that contributes to a loss of full extension after ACLR.^{31,32}

The ACLR group had difficulty accelerating at all three velocities, indicated by greater TTAV values when compared to control group. These differences may be related to the injury, since control of movement during acceleration could be affected, and the ability to attain the specific isokinetic velocity at a given range of motion may also be impaired.³³ Moreover, the TAV_{3D}, which provides a qualitative evaluation, demonstrated that the control group was able to maintain higher torques at higher velocities. In flexor and extensor muscles, the range of motion and the distribution of the torque during the range can change in post ACLR patients.³⁰ Hence, a lower extensor torque was demonstrated when compared to controls.

The TAV_{3D} for both groups at all velocities in extension demonstrated that the torque was not sustained during the ROM. Analysis of TAV_{3D} may contribute to the interpretation of isokinetic results and may be used to characterize muscle performance during the recovery period four to six months post ACLR. For flexion, the ACLR group did show a difference with the control group where the control group was able to sustain torque while in the ACLR group PT was not sustained. The study of Mazuquim et al.¹⁸ showed that professional soccer players sustained torque across a greater ROM in relation to those who were under 17, therefore showing higher muscle efficiency in more experienced athletes. In this study, it was observed that the ACLR group sustained less torque during the ROM which could be a limitation factor for performance of functional activities, mainly for high demand sports.

The limitations of this study include the low number of subjects and the lack of evaluation of eccentric muscle actions. However, isokinetic phase measurement could be a valuable way to evaluate patients post ACLR.^{34,35} Future studies that perform post ACLR testing should include isokinetic

muscle performance for both concentric and eccentric actions. Isokinetic results should continue to be compared to performance-based outcome measures for better understanding of the post-reconstruction patient.³⁴⁻³⁶

CONCLUSION

The findings of the present study demonstrate statistically significant PT/BM deficits for the knee extensors at 60 and 120°/s and for the knee flexors at 60°/s in the injured knee of the ACL group compared to uninjured controls. Extension ROM was also less for the ACL group at 60°/s. TAV_{3D} may offer additional information when analyzing isokinetic outcomes post ACLR.

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