MECHANISMS OF AGONIST AND ANTAGONIST ACTIVATION IN THE KNEE OF INDIVIDUALS WITH RECONSTRUCTED ANTERIOR CRUCIATE LIGAMENT: A KINETIC AND ELETROMYOGRAPHIC STUDY

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SUMMARY

Purpose: To assess and compare torque and electromyographic activity of the vastus lateralis and biceps femoris muscles upon knee extension and flexion in open kinetic chain. Methods: Fifteen male subjects were distributed in two groups: Test Group (TG) (32.2 ± 7.1 years) composed by five subjects who had previously been submitted to anterior cruciate ligament arthroscopic reconstruction (patellar tendon); and Control Group (CG) (30.1 ± 10.7 years) composed by ten uninjured subjects. Data acquisition was performed using Cybex 6000 at 100°.s-1; 10 seconds of electromyography data were obtained using active differential electrodes (Delsys-Bagnoli 8) at a sample rate of 1000 Hz. Root Mean Square (RMS) values and temporal pattern of muscles activation based on movement phase were considered (linear envelope). Results: Injured legs showed greater flexion peak torque and smaller extension peak torque; greater agonist activation and smaller antagonist activation for the biceps femoris muscle, and smaller agonist activation for the vastus lateralis muscle. Linear envelope showed that test group showed smaller vastus lateralis muscle activation comparing to control group. Conclusion: Despite the rehabilitation period, injured legs still showed extensor torque deficit, which may explain the remaining complaints presented by anterior cruciate ligament reconstructed subjects.

***Keywords:** Anterior Cruciate Ligament; Physical therapy; Electromyography; Biomechanics; Knee.*

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INTRODUCTION

The anterior cruciate ligament (ACL) stabilizes tibial anterior displacement and the varus and valgus movements of this joint[(1)]. *In vivo* studies show that direct load tensions on this ligament would produce inhibition of the femoral quadriceps favoring knee flexors. These findings may have a clinical significance, because knee functions should potentially be impaired by ruptures of those ligament mechanoreceptors[(2-5)]. Osternig et al.[(6)] investigated the coactivation of quadriceps and ischiotibial muscles on the isokinetic dynamometer in speed racer and long-runner women, and found that knee flexors are more active during knee extension than during quadriceps flexion. This could be associated to a stronger quadriceps force, which would require a higher antagonist coactivation of flexors for coordinating and decelerating the limb. Additionally, the larger muscular mass of the quadriceps could also favor flexion deceleration by a viscoelastic effect, meaning that this flexion would be primarily controlled by a passive mechanism[(6)]. Nielsen and Kagamihara[(7,8)] suggested the existence of a specific motor program for muscle coactivation in which the reciprocal model´s interneurons would be actively inhibited by central commands. That is, there would be a drop of the reciprocal inhibition, which would increase the level of excitement of motorneurons of the antagonist muscles, resulting in coactivation. The same theory is also advocated by other authors[(9-12)]. Carolan and Cafarelli[(10)] found that endurance drills on knee extensors resulted in less coactivation between extensors and flexors. Thereby, they believe that after a week of training, the reduction of the strength opposing to movement, would contribute to a significant increase of the voluntary maximum extension contraction. Literature shows evidences that the muscle coactivation occurring in the knee would act protecting and stabilizing the joint during powerful contractions, and also could distribute the pressure through the joint and minimize joint fatigue and damages[(4-6,9,12-17)].

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Osternig et al.[4] found that the flexor muscles of ACL injured knees generated less antagonist activity when compared to the contralateral limb, and didn't find significant differences for muscle torque both in the group with ACL injury and in the control group. A recent study confirmed this theory[18]. Makihara et al.[19] found lower flexor isometric and isokinetic torque values from 60° of knee flexion in individuals submitted to ACL reconstruction using the tendon of semitendinous and gracilis muscles. This study aimed to assess and compare the torque and electromyographic activity of vastus lateralis and biceps femoralis muscles between injured and uninjured members of individuals with reconstructed ACL to a group of healthy individuals at extending and flexing the knee in an open chain, thus contributing to rehabilitation protocols, potentially focusing more specific muscular work out, stimulating the mechanism of muscle coactivation.

MATERIALS AND METHODS

Subjects

Our sample was constituted of 15 male volunteer subjects in the age group of 20 to 40 years old, five with reconstructed ACL assigned to the Test Group (TG) and ten subjects showing no osteomyoarticular injuries or dysfunctions assigned to Control Group (CG). In order to compose the TG, we selected subjects submitted to ACL reconstruction through arthroscopy using patellar tendon at least eight months previously to data gathering, and they should have been clinically and physiotherapeutically discharged. All subjects signed a Free and Informed Consent Term as approved by the local Committee of Ethics (Research Protocol # 559/01).

Material

For torque assessments, the isokinetic dynamometer *Cybex 6000 (New York, USA*) was used, and, for electromyographic (EMG) studies, active differential bipolar electrodes (*Delsys-Bagnoli 8, Boston, USA*) made of Ag/AgCl, with size of 10 X 1 mm, inter-electrodes distance of 10 mm and pre-amplification of 10 on the electrode and 100 on the conditioner, totaling a gain of 1000, were employed. The sampling frequency was 1000 Hz and the acquisition time was 10 seconds. A 12-Bit A/D converser was used. For identifying the motor point of the vastus lateralis and biceps femoralis muscles, a Universal Pulse Generator (*Omni Pulse 900, Piracicaba, Brazil*) generating 1-ms pulse trains in a tetanizing frequency (20 – 80 Hz) was used.

Evaluation protocol

From each patient´s medical file we retrieved diagnostic, injury and surgery dates, injured knee, dominant knee and surgery type data. At interview, the most common complaint, time and place of rehabilitation were identified, proceeding to physical examination for inspection, palpation and evaluation of knee alignment. The motor points of vastus lateralis and biceps femoralis muscles were bilaterally identified by electric stimulation for subsequent placement of surface electrodes. These were fixed with double-face and transpore-type tape to preclude these electrodes to move during the exercise. The protocol employed for the *Cybex* was the execution of knee extensions and flexions at 100°.s-1, with a total range of motion of approximately 120° (0° corresponding to total extension). The subjects were positioned at sedestation with hips flexed at approximately 90°, and the rotational axis of the dynamometer was aligned to knee axis. Before acquiring the data, we established a familiarization step, in which the subjects would execute three knee flexion and extension movements followed by a rest period of 180 seconds previously to the assessment in order to avoid muscle fatigue. The subjects executed five repetitions at the selected speed, with the CG starting the test with the dominant limb, while the TG initiated it with the uninjured limb.

Data analysis

On the EMG, Root Mean Square (RMS) values obtained by means of sign rectification and by the selection of phases corresponding to knee flexion and extension for each muscle, and the temporal pattern of activation of the muscles as a function of the movement phase represented by the linear envelope were considered as a way to qualitatively represent the temporal coordination of muscle activity during movement. For obtaining linear envelopes, mathematic stages in a mathematic programming environment (Matlab) were developed using the following procedure: after removing the offset of the gross sign, the electromyographic signal was rectified by full wave, filtering was provided with a 4th order low-pass butterworth-type filter with cut frequency of 5 Hz; then, the signal was normalized in intensity by its average and as a function of knee flexion and extension time (0 – 100% of the cycle). The following variables were extracted: 1) first activation peak of the vastus lateralis muscle; 2) end of the vastus lateralis muscle activation; 3) first activation peak of the biceps femoralis muscle; 4) end of the biceps femoralis muscle activation; 5) start of biceps femoralis muscle activation. (Figure 1).

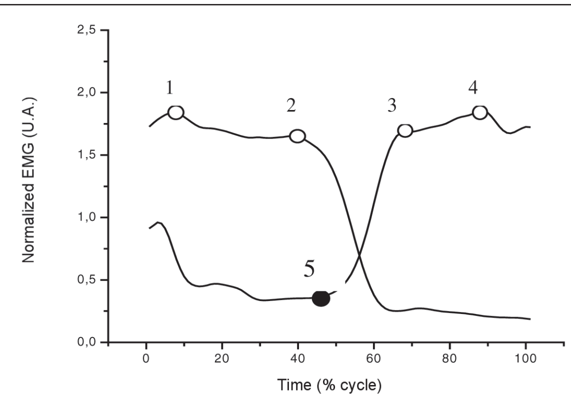

Figure 1 – *Illustration of the assessed electromyographic variables: 1) first activation peak of the vastus lateralis muscle; 2) end of the vastus lateralis muscle activation; 3) first activation peak of the biceps femoralis muscle; 4) end of the biceps femoralis muscle activation; 5) start of the biceps femoralis muscle activation.*

Statistical analysis

The Shapiro Wilk´s W-test tested the normality of distribution of all continuous variables in the present study. The variables were described for each experimental group in terms of averages and standard deviation. Comparative inter-group analyses were made comparing dominant limbs on the CG to the injured and uninjured limbs of the TG, and the non-dominant limb of the CG to the uninjured limb of the TG. In the intra-group analysis, we compared the dominant to the non-dominant limb of the CG, and the injured to the uninjured limb of the TG. The two-way ANOVA was used, with one factor being the experimental group and the other, the contralateral limb (repeated measurements), followed by Tukey´s HSD test, being considered as significant the differences with a significance level of 5%.

RESULTS

The studied groups were found to present statistically similar results for age (CG=30.1±10.7 y.o., and TG=32.2±7.1 y.o.) and body mass index (BMI) (CG=23.6±2.1 kg, and TG=25.2±1.8 kg {(Student´s t-test)}. The clinical characteristics of the TG are described on Table 1. All subjects were operated by the same surgical team, using the interference screw for fixating the graft. Also, they were rehabilitated at the same institution following a pre-established and well-recognized protocol.

Subjects TG	Injury Duration (months)	Surgery time (months)	Rehabilitation time (months)
1	14	13	4
2	17	16	7
3	39	12	8
4	20	17	15
5	16	13	5
Average/ SD	21.2 ± 10.1	14.2 ± 2.1	7.8 ± 4.3

Table 1 – *Clinical characteristics of the Test Group (TG): duration of injury, surgery and rehabilitation (months).*

Torque evaluation

In the inter-group analysis (Table 2), the flexor torque peak was higher for the injured side of the individuals in the TG when compared to CG subjects´ dominant sides (p=0.049). Similarly, the flexor torque peak for TG subjects´ uninjured side was higher when compared to CG subjects´ non-dominant limb (p=0.017). In the intra-group analysis, for TG, the injured limb showed lower extensor torque peaks (p= 0.032), while for CG, no differences were found between limbs (Table 3).

Electromyographic evaluation

The inter-groups comparison of the RMS values can be found on Table 4. The TG showed a lower RMS of the biceps femoralis on the uninjured limb during its agonist phase compared to CG subjects´ non-dominant limb (p= 0.016). When assessing the interaction effect between groups and sides, we found a statistically significant difference for biceps femoralis muscle activation both in the agonist (p=0.001) and antagonist phases (p=0.001). For vastus lateralis muscle, differences were found only for the agonist phase (p=0.001), thus being similar for the antagonist activation of this muscle (p=0.656). Therefore, in the intra-group analysis (Table 5), the CG showed a stronger agonist activation for biceps femoralis muscle on the dominant limb (p=0.024), while the TG showed statistically significant differences for both muscles, and a higher agonist activation (p=0.001) and a lower antagonist activation (p=0.001) of the biceps femoralis muscle on the injured limb and lower agonist activation of the vastus lateralis muscle on the injured limb (p=0.001).

TORQUE PEAK (N.m)	Control Group	Test Group	P
Extensor- Dominant/ Injured	183.50 ± 35.87	178.00 ± 31.18	0.775
Flexor- Dominant/ Injured	96.30 ± 20.69	118.80 ± 16.40*	0.049
Extensor -Non-Dominant/ Uninjured	189.60 ± 35.71	209.40 ± 31.73	0.314
Flexor- Non-Dominant/ Uninjured	92.00 ± 18.40	118.40 ± 16.34*	0.017

(* statistically significant difference).

Table 2 – *Inter-group averages, standard deviation, and significance levels for knee extensor and flexor torque peaks (N.m).*

Analysis of the Linear Envelope

Figures 2 and 3 illustrate the mean envelopes of the TG and CG for the muscles of both studied sides. We can see that the vastus lateralis muscle activation is reduced along its agonist

TORQUE PEAK (N.m)	Control Group			Test Group		
	Dominant	Non-dominant	p	Injured	Uninjured	P
Extensor	183.50 ± 35.87	189.60 ± 35.71	0.818	178.00 ± 31.18*	209.40 ± 31.73	0.032
Flexor	96.30 ± 20.69	92.00 ± 18.40	0.702	118.80 ± 16.40	118.40 ± 16.34	0.999

(* statistically significant difference).

Table 3 – *Intra-group averages, standard deviation, and significance levels for knee extensor and flexor torque peaks (N.m).*

Muscle	Side	Phase	RMS (mV)		p
			Control G	Test G	
Biceps Femoralis	Dominant/ Injured	Agonist	1.22 ± 0.39	1.21 ± 0.34	0.999
		Antagonist	0.44 ± 0.23	0.34 ± 0.17	0.743
	Non-Dominant/ Uninjured	Agonist	1.08 ± 0.49	0.56 ± 0.33 *	0.016
		Antagonist	0.44 ± 0.21	0.68 ± 0.49	0.074
Vastus Lateralis	Dominant/ Injured	Agonist	1.27 ± 0.18	1.16 ± 0.38	0.747
		Antagonist	0.32 ± 0.27	0.35 ± 0.12	0.996
	Non-Dominant/ Uninjured	Agonist	1.25 ± 0.39	1.47 ± 0.13	0.179
		Antagonist	0.28 ± 0.32	0.34 ± 0.31	0.933

(* statistically significant difference).

Table 4 – *Inter-group averages, standard deviation, and significance level of RMS (mV) values for biceps femoralis and vastus lateralis muscles, during agonist and antagonist phases, for the Control Group (Control G) and Test Group (Test G).*

Muscles	Phase	Control Group			Test Group		
		DL	ND L	p	IL	UI L	p
Biceps Femoralis	Agonist	1.22 ± 0.39*	1.08 ± 0.49	0.024	1.21 ± 0.34*	0.56 ± 0.33	0.001
	antagonist	0.44 ± 0.23	0.44 ± 0.21	0.999	0.34 ± 0.17*	0.68 ± 0.49	0.001
Vastus Lateralis	Agonist	1.27 ± 0.18	1.25 ± 0.39	0.977	1.16 ± 0.38*	1.47 ± 0.13	0.001
	antagonist	0.32 ± 0.27	0.28 ± 0.32	0.841	0.35 ± 0.12	0.34 ± 0.31	0.999

(*statistically significant difference) (DL – Dominant Limb; ND L – Non-Dominant Limb; IL – Injured Limb; UI L – Uninjured Limb).

Table 5 – *Intra-group averages, standard deviation, and significance level of RMS (mV) values for biceps femoralis and vastus lateralis muscles, during agonist and antagonist phases, for CG and TG.*

action (0-50% on movement cycle) for the TG, especially on injured limb (Figure 2). In the same environment, CG shows a stable activation (Figure 3).

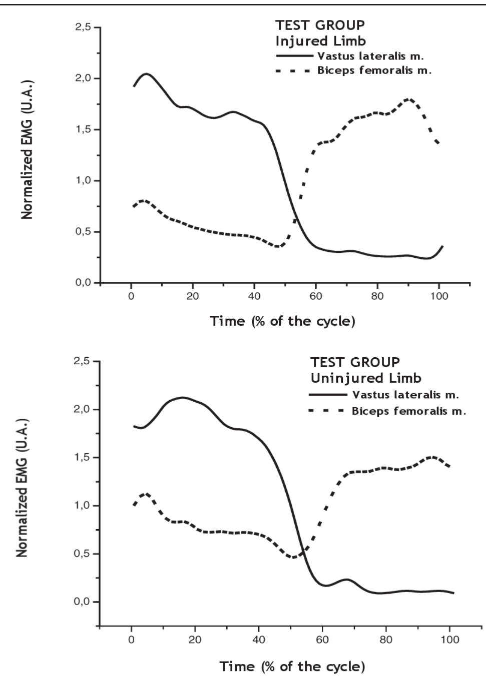

Figure 2 – *Illustration of the average linear envelopes of the Test Group for injured and uninjured limbs, respectively.*

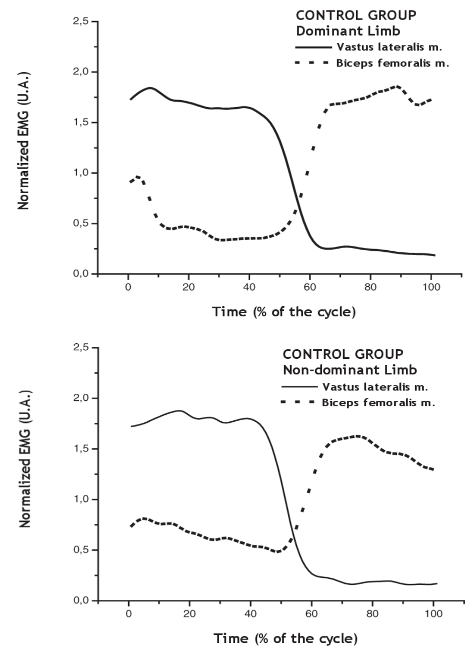

Figure 3 – *Illustration of the average linear envelopes of the Control Group for dominant and non-dominant limbs, respectively.*

Table 6 shows the intra-group linear envelope of biceps femoralis and vastus lateralis muscles during agonist and antagonist phases. No statistically significant differences were found between CG subjects´ limbs. In the CG, the injured limb was found to present the first activation peak of the vastus lateralis earlier than the uninjured limb (p=0.001). In the inter-group comparison, for linear envelope variables, the groups were shown to be statistically similar concerning muscle recruitment time pattern, except for the first vastus lateralis peak, which occurred earlier on the injured limb when compared to the dominant limb (p=0.001).

DISCUSSION

The theory behind this study was that individuals rehabilitated from ACL reconstruction did not show extensor torque differences, but indeed, differences concerning muscle activation pattern and intensity, especially associated to biceps femoralis muscle during its antagonist phase, as reported by literature[4,6-10]. However, the injured limb showed lower extensor torque peaks when compared to uninjured limbs, inconsistently with other studies[4,18], but showing a recovery deficit in those individuals. Furthermore, in the inter-group analysis, we could also see a higher flexor torque peak on the injured limb compared to the dominant limb. Literature[4,18] do not mention differences concerning flexor torque as well, and this fact is supposedly associated to rehabilitation programs focusing knee flexors

Muscles	Linear Envelope Variables (%)	Control Group			Test Group		
		DL	ND L	p	IL	UI L	P
Biceps femoralis	activation start	49,50 ± 6,85	51,90 ± 4,89	0,740	51,60 ± 4,72	53,80 ± 3,90	0,909
	1st activation peak	68,40 ± 7,93	69,10 ± 6,85	0,996	66,40 ± 7,13	65,20 ± 2,68	0,999
Vastus Lateralis	1st activation peak	6,50 ± 6,47	6,10 ± 6,95	0,998	5,80 ± 3,42*	12,00 ± 7,45	0,001
	activation end	44,30 ± 4,64	40,90 ± 2,60	0,350	42,20 ± 4,15	44,40 ± 5,37	0,999

(* statistically significant difference) (DL = Dominant Limb; ND L = Non-Dominant Limb; IL = Injured Limb; UI L = Uninjured Limb).

Table 6 – *Linear envelope variables (% movement cycle) and intra-group significance levels for biceps femoralis and vastus lateralis on CG and TG.*

strength gain, avoiding tibial anterior displacement forces, that could be tensioning the graft[20]. Regarding muscle activation strength, we found a statistically significant difference between groups and sides for biceps femoralis muscle during agonist and antagonist phase. The injured limb showed higher agonist activation in this muscle, i.e., it recruits more motor units in this specific task, and it could be correlated to muscular training performed during rehabilitation. Additionally, only one flexor muscle was assessed by electromyography, with the joint torque being constituted by the action of several flexor muscles of the knee. Another important result, which is consistent with literature, is the lower antagonist activation of the biceps femoralis muscle in individuals with reconstructed ACL[4-6,9-17]. Even considering the limitations previously described, it is interesting to note that, despite of the higher flexion torque and of the higher agonist activation in this group of muscles – suggesting a well trained musculature in a joint stabilization moment – we can infer that this muscle structure was not properly activated. However, this can be associated to the lower extensor torque on the injured limb, as well as to the lower agonist activation of this muscle, meaning that this extensor moment was not enough to activate the antagonist muscles, and this extension deceleration may have been provided by the viscoelastic effect of flexor muscles of the knee[6] . The lower antagonist activation of the biceps femoralis muscle in individuals with reconstructed ACL, as identified by the lower RMS values, is consistent with literature, such as on the reports by Osternig et al.[4] and Solomonow et al.[5] who noticed an important coactivation reduction in individuals with reconstructed ACL, and they justify this fact by the absence of mechanoreceptors in the graft, which would be responsible for activating knee flexors, regulating the extensor torque. Thus, we can infer, as did those authors, that such activation reduction may be a muscle control deficit in those individuals. Amiridis et al.[21] justified the lower coactivation of the knee flexors in high-performance athletes when compared to sedentary individuals as a function of the training demands for muscle hypertrophy. Therefore, they infer that such reduced antagonist activation of the biceps femoralis muscle can also evidence a better prepared musculature, as oppositely to a deficit. Baratta et al.[13] disagree with the fact that ischiotibial strength drills are responsible for the lower coactivation of this muscle. Conversely, they believe that a routine training program for this muscle in athletes would lead this population to present coactivation levels similar to healthy individuals.

This coactivation increase is believed to be a potential early response due to the increased muscular recruitment for strength gain, but not necessarily one could say that this coactivation increase will remain. The qualitative analysis of linear envelopes suggest a reduced activation of the vastus lateralis muscle on TG during knee extension movement, which, to a certain extent, was expected as a way to avoid shearing forces to the graft. It is interesting to notice that this pattern is reflected on the uninjured limb; The present study also found that the CG and the TG were shown to be similar to each other in terms of muscle recruitment time pattern as observed by linear envelopes variables, except for the first peak of the vastus lateralis muscle, which occurred earlier on the injured limb compared to CG individuals´ dominant limb and TG subjects´ uninjured limb. This earlier activation is likely to occur on the injured limb as a way to offset a progressive activation reduction that occurs throughout the extension movement (0-50% of the movement cycle). Some limitations were seen over the development of this study, including: a small sample in the TG group; the fact that the individuals were operated by different surgeons and rehabilitated by different physical therapists; however, it is worthy to highlight that the purpose of the study was to assess individuals who had already been discharged from clinical and physiotherapeutic programs showing the same status as the majority of the patients who, after an injury, receive surgical treatment, some physical therapy sessions, and are discharged. At this moment, the purpose was not to check if the surgical technique, the rehabilitation protocol, as well as the recovery of the donor area may have influenced the assessed variables. These variables may be considered in future studies.

CONCLUSION

Although rehabilitated, the surgically repaired limb remained with extensor torque deficits, showing a lower and decreasing activation of the vastus lateralis muscle and a lower muscle coactivation. These deficits may explain some of the clinical complaints that patients frequently remain presenting, such as quadriceps muscle atrophy, instability and pain. Possibly, an earlier strength work on the quadriceps muscle might be more significantly beneficial for ACL repair recovery by the improvement of the muscle coactivation mechanism.

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