Analysis of the medium frequency of the electromyographic signal of individuals with lesion of the anterior cruciate ligament in isometric exercises of open and closed kinetic chain

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ABSTRACT

Subjects with injury of the anterior cruciate ligament (ACL) have shown relevant functional alterations in the knee muscles. Therefore, it is extremely important to characterize these alterations, as well as to emphasize an efficient rehabilitation protocol for these subjects and consequently return them to physical activities. The purpose of this study was to investigate the medium frequency (Fmed) of the electromyographic signal in ACL subjects with lesions during isometric exercises in open (OKC) and closed kinetic chain (CKC). Forty subjects (with and without lesion) performed knee extension during maximal voluntary isometric contraction on Leg Extension and Leg Press at 30º, 60º and 90º of knee flexion. The results showed smaller Fmed values for ACL deficient subjects when compared with counter lateral and control groups in OKC exercises ($p < 0,05$). However, there was not significant difference in CKC exercises between groups ($p > 0,05$), not showing thus, this kind of injury. Therefore, the Fmed can be considered an efficient tool in the LCA injury characterization. Moreover, CKC exercises seem to be the best alternative for rehabilitation of the ACL deficient subjects.

INTRODUCTION

Lesion of the anterior cruciate ligament (ACL) is one of the most serious and recurrent lesions during physical activities[1]. Instability in the knee joint occurs with ACL injury due to excessive internal rotation and tibial anterior translation, especially at the last extension degrees, leading to limitations in the daily routine and sports activities of these individuals[2-3]. The role of the periarticular muscles becomes essential in order to compensate the stability loss, once the knee's joint stability is dependent on the combination among ligament tension, congruency between the articular surfaces and contraction of the periarticular muscles[3-4].

Several studies have emphasized the important role played by the muscles in the knee joint stability, especially in individuals with ACL lesion, showing thus its role in the joint stability[3,5-7].

The main functional alterations in individuals with ACL lesion are the strength loss and the reduction of the muscle voluntary activity standard, being these alterations more evident in the thigh quadriceps muscle (QC)[8-10]. When the ACL is injured, the lesion affects not only the joint stability but also the neuromuscular performance, with consequent weakness of the TQ muscle due to the loss of the mechanoreceptors placed there. This lack of receptors suppresses the recruiting of the motor units during voluntary contraction and such blocking of the sensory inference results in the inactivation of the periarticular muscles[8-9,11].

Williams *et al.*[9], observed through surface electromyography (SEMG), decrease in the voluntary muscle activation of the TQ muscle in individuals with ACL lesion compared with individuals without lesion during static and dynamic exercises. Later, the same authors verified weakness and significant atrophy of the quadriceps muscle in individuals with ACL unilateral lesion comparing the injured and contralateral limbs and failure in the voluntary activation in both groups[10].

The aims of the rehabilitation protocols are the recovery of the muscular strength, reestablishment of the joint mobility, normalization of the neuromuscular control and return to sports activities with degrees similar to the ones prior to lesion. These aims are based on continuous knowledge of the functional deficits of the lower limbs in patients with ACL lesion, once the pre-surgery muscular strengthening facilitates the early return to sports practice after joint reconstruction surgical procedure[12-13], through the combination of exercises in open (OKC) and closed (CKC) kinetic chains with the purpose to regain muscular strength[14-15].

Michelson *et al.*[14], observed faster recovery in patients post ACL reconstruction, combining OKC and CKC, when compared with isolated exercises in CKC. Ross *et al.*[15], showed that the OKC and CKC combination may be used in the ACL post-reconstruction rehabilitation without excessive tension on the joint and stress on the patellofemoral joint.

Such exercises have been evaluated through the RMS analysis of the SEMG signal in order to verify the voluntary activation pattern of the knee muscles, both in normal individuals and others with ACL lesion[16-19].

Nonetheless, the SEMG presents other tolls that have been little explored in the literature that analyses individuals with ACL lesion as medium frequency (Fmed). The Fmed of the electromyographic signal is a variable that divides the power spectrum in two equal regions[20], and can be used for physiological muscular fatigue[21] and type II fiber atrophy detection[22] with consequent variation in the velocity of conduction in the muscular fiber[23].

Moreover, the Fmed depends on the muscular characteristic, that is, the type of predominant fiber in each muscle. Concerning the VL muscle, a directly proportional relation among the torque increase, contraction intensity and the Fmed seems to occur, finding high indices of the Fmed with increase of the contraction intensity for a few seconds of exertion in normal individuals[24].

Conversely, different authors verified the reduction of the Fmed in the thigh muscles using or not fatigue protocols[21-22,25-27].

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***Figure 1** – Positioning in open kinetic chain (OKC)*

***Figure 2** – Positioning in closed kinetic chain (CKC)*

McHugh *et al.*[21] researching the Fmed in individuals with pre and post surgical ACL lesion, found a remarkable reduction of the Fmed during isometric contraction in the injured limb compared with the contralateral limb during a fatigue protocol. Even without a fatigue protocol, McNair *et al.*[22] also found significant reduction of the Fmed in individuals with ACL lesion during isometric contraction.

Therefore, the studies revealed that the Fmed is influenced by the ACL lesion and that the rehabilitation protocols are designated to the combination of different types of exercises. Nevertheless, studies analyzing the Fmed have been focusing more the exercises performance in OKC. Besides that, the behavior of the Fmed in CKC is not established in individuals with ACL lesion.

A better understanding of the Fmed behavior can guide us in order to establish the most efficient rehabilitation type.

Thus, the aim of this study was to analyze the Fmed behavior of the electromyographic signal of individuals with ACL lesion in isometric exercises of OKC and CKC.

MATERIALS AND METHODS

Sample

40 male volunteers participated in this study (31,1 ± 7,45 years, 174 ± 6,65 cm of height); twenty individuals with unilateral ACL lesion and twenty individuals without ACL lesion. The group with ACL lesion was subdivided in two groups of 20 volunteers each; injured ACL and contralateral to the ACL injured (ACL-C). The group without lesion, control group, was divided as well in two subgroups: dominant control (AD) and non-dominant control (AND).

The volunteers were informed on the aims of the work and signed the clarified formal and free consent form, approved by the Ethics and Human Research Committee of the Clinical Hospital of the Medicine School of Ribeirão Preto of the São Paulo University (HCFMRP-USP). The triage of the volunteers with ACL lesion was performed at the knee infirmary HCFMRP-USP. The lesion was also confirmed through clinical examinations and positive answer of the anterior drawer, pivot shift and Lachman specific tests.

ACL unilateral lesion, healthy contralateral limb and lesion time longer than six months were adopted as inclusion criteria. Volunteers who presented bilateral ACL lesion, lower limbs fracture, combined joint lesions, pain, joint blocking or previous surgeries were excluded from the study.

Instruments

The OKC Leg extension apparel (Queens®, São Paulo, Brasil) and the CKC Leg Press apparel (Nakagym®*,* São Paulo, Brasil), were used for the isometric effort of the leg extension.

The myoelectric capture was performed through active electrodes of differential simple surface (EMG SYSTEM DO BRASIL®, São José dos Campos, Brasil) consisted of two pure silver parallel rectangular bars of 10 x 2 mm, 10 mm spaced and steady on an acrylic capsule of 20 x 41 x 5 mm. These electrodes presented entrance prevention higher than 10 GΩ, minimum CMRR of 130 dB and gain of 20 times.

The SEMG signal analysis was through an 8 channel- signal conditioner module and analogical/digital conversing plaque of 12 bites of resolution of dynamic sample frequency of 1KHz (*Myosystem Br-1*, PROSECON®, Uberlândia, BRA). This signal conditioner presents Butterworth analogical filter of second order of low – pass of 500 Hz and high-pass of 20 Hz.

A stainless steel circular reference electrode was placed on the tibial anterior tuberosity of the limb to be tested with gel and adhesive tape in order to help in the reduction of the acquisition noise.

Experimental protocol

As a warm-up, the volunteers performed three alternated series of 30 seconds of active muscular stretching for the quadriceps and hamstring muscles, followed by three series of 20 repetitions of submaximal contractions in the OKC apparel with two minute-intervals between the series.

Later, the sites for the SEMG electrodes positioning was established. The SEMG electrodes positioning was performed according to Bevilaqua-Grossi *et al.*[28], for the long vast lateral (LVL), thigh straight (TS), oblique vast medial (OVM) muscles and according to the SENIAM rules[29] for the thigh biceps (TB) and semitendinosus muscles (ST).

The volunteers were accordingly placed on the leg extension seat with posterior chest support, 100° of hip flexion, 90° of knee flexion, upper limbs parallel to the chest and the limb that was not being tested remaining relaxed or in position comfortable for the volunteer. The volunteers were stuck to the apparel in order to avoid compensatory movements during the leg extension exertion (figure 1). The volunteers were accordingly placed on the leg press seat with upper limbs parallel to the chest for CKC exertion. The limb to be tested was leveled on an imaginary line between the antero superior iliac backbone-lateral femoral condyle-fibular malleoli in order to avoid hip rotation, abduction and adduction compensatory movements. The foot of the limb to be tested was placed on the resistance platform with tarsi-tibial angle at 90°. The limb that was not being tested remained relaxed or in position comfortable for the volunteer (figure 2).

The volunteer was instructed to perform the leg extension movement during seven seconds of CIVM for the 30°, 60° and 90° an-

TABLE 1
Fmed normalized indices of all groups and muscles in open kinetic chain (OKC) and closed kinetic chain (CKC) exercises

	OKC			CKC		
	ACL	ACL-C	A	ACL	ACL-C	A
LVL	99,38 ± 13,30*	106,17 ± 11,77	101,66 ± 13,15	99,23 ± 12,24	103,16 ± 20,80	98,02 ± 14,41
TS	95,74 ± 12,02*	103,33 ± 14,15**	98,21 ± 13,49	103,06 ± 17,75	110,72 ± 33,44	107,46 ± 20,81
OVM	105,64 ± 22,01	103,38 ± 21,45	105,11 ± 19,34	96,84 ± 14,76	92,18 ± 16,68	95,51 ± 17,43
TB	87,43 ± 25,43**	89,59 ± 27,65	106,5 ± 20,16	84,86 ± 19,88	78,29 ± 19,88	90,13 ± 15,31
ST	80,29 ± 27,64	87,70 ± 29,49	87,22 ± 24,87	97,02 ± 27,31	99,32 ± 39,75	94,14 ± 30,12

LVL – long vast lateral, TS – thigh straight, OVM – oblique vast medial, TB – thigh biceps, ST – semi tendinosus.
* p ≤ 0,05 in the comparison between the ACL and ACL-C groups. ACL – injured ACL group, ACL-C – contralateral to ACL lesion group.
** p ≤ 0,05 in the comparison between the ACL and A. ACL groups – injured ACL group, A – control group.

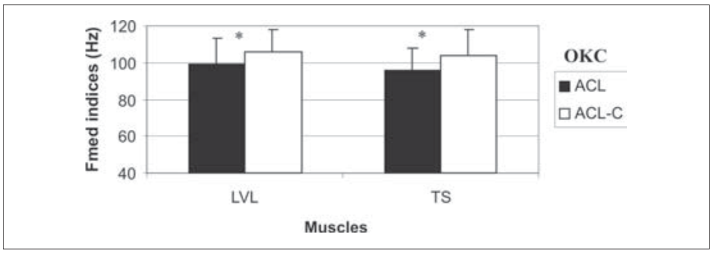

Figure 3 *– Fmed normalized indices of the long vast lateral (LVL) (p = 0,03) and thigh straight (TS) (p = 0,02) muscles in the ACL and ACL-C groups (n = 20) in open kinetic chain (OKC). ACL –injured ACL group, ACL-C –contralateral to ACL lesion group.*
* p ≤ 0,05

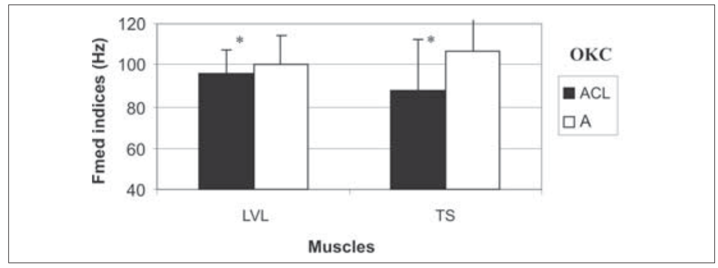

Figure 4 *– Fmed normalized indices of the thigh straight (TS) (p = 0,05) and thigh biceps muscles (TB) (p = 0,001) in the ACL and A groups (n = 40) in open kinetic chain (OKC). ACL –injured ACL group, A – control group.*
* p ≤ 0,05

gles. Three repetitions of the extension CIVM for each analyzed angle were performed and interval of two minutes was given for each volunteer between the contractions in order to avoid the muscular fatigue effects. The angles, apparels and limb to be tested order were random.

SEMG Fmed data analysis

The SEMG raw signals were digitally processed, being the 5 final seconds of each CIVM analyzed and filtered with pass-ribbon filter of 20-500 Hz. The Fmed data normalization in each angulation was performed through the CIVM of knee extension at 50° of flexion for the centers of the quadriceps muscles, in OKC and CKC as well. Conversely, for the centers of the hamstring muscle, the normalization was performed through the knee flexion CIVM at 30° of flexion in OKC.

Statistical analysis

The method of Variance Analysis (ANOVA) with repeated measures and the technique of contrasts formation were used for the comparison between groups in the different types of exercises, OKC and CKC, whenever necessary. It was adopted as significance index $p \leq 0,05$.

RESULTS

Significant statistical difference was not observed when comparing dominant control group and non-dominant control group. Therefore, they will be considered as a single control group (A) ($p > 0,05$).

During exercises in OKC, the results revealed Fmed indices lower for the ACL group in relation to the other groups. In the exercises in CKC, no statistical difference was observed for the Fmed indices in relation to the evaluated muscles between the different studied groups ($p > 0,05$) (table 1).

The Fmed indices were significantly lower for the TS ($p = 0,02$) and LVL ($p = 0,03$) muscles in the comparison between the ACL and ACL-C groups, (figure 3); while in the comparison between the ACL and A groups, significant statistical difference was observed for the TS ($p = 0,05$) and TB ($p < 0,001$) muscles, (figure 4).

DISCUSSION

The results of this study revealed that the Fmed in the injured group presented indices significantly lower when compared with the contralateral group and control group for the VLV and TS muscles during the exercises in OKC.

These results may be derived from the changes in the activation of the thigh muscles of individuals with ACL lesion in order to avoid the excessive tibial anterior translation that occurs, especially in the end of the extension in OKC favored by the quadriceps muscle action. In this situation a reciprocal inhibition of this muscle occurs in order to avoid the increase of the tibia shearing in relation to the femur[8-9]. Moreover, this quadriceps inhibition may be caused by the loss of mechanoreceptors placed in the ACL[8-9,11] or type II fibers atrophy[23]. According to these results one may suggests that the Fmed may be a parameter for the characterization of the ACL lesion, confirming the results by McNair *et al.*[23] who found significant decrease of the Fmed in the limbs with ACL lesion when analyzing the Fmed behavior in the VL muscle in individual with ACL lesion, comparing injured limb with contralateral healthy limb.

Other studies that proposed to analyze the Fmed behavior also verified significant reduction of the Fmed when performing fatigue-induction protocols[22,26-28]. Such decrease was given to the change in the muscle fibers type due to the protocol. The aim of this study was to evaluate the Fmed behavior in individuals with chronic ADL lesion with no use of a fatigue-induction protocol, and even then, it was observed similar behavior between individuals with and without ACL lesion who performed this fatigue protocol. Such results reinforce the hypothesis that individuals with chronic ADL lesion present type II fibers atrophy in the quadriceps muscle.

Works that analyzed the Fmed behavior of the quadriceps and hamstring muscles simultaneously during exercises in OKC and CKC were not found in the literature. The results revealed that, probably as compensatory mechanism, in order to hold the excessive internal rotation and tibia anterior translation, the ACL lesion may trigger a higher activation of the hamstring muscles, especially the TB in OKC, leading to an overload of this muscle due to its constant activation to keep the joint stability. This overload in the chronic lesion could lead to changes in fibers type, triggering hence, type II fiber atrophy and resulting in a decrease of the Fmed. Such explanation can explain the lower indices of the Fmed found in the TB muscle in OKC. Nonetheless, more studies are necessary in order to better understand the Fmed indices behavior of the hamstring muscles in individuals with ACL lesion.

Significant differences were not found in the Fmed indices between the groups during the exercises in CKC. These results suggest that the exercise in CKC does not seem to induce a different response in the individual with ACL lesion, that is, the Fmed behavior of the thigh muscles was not altered in the exercises in CKC, differently from the exercises in OKC, which due to their more selective nature, result in a higher stress for the knee joint[2,30]. The exercises in CKC are mentioned as safer due to the lower stress caused in the ACL, lower shearing force[2,30-31], higher joint stability and for activating not only the specific muscles of the knee joint but other muscles of the lower limb as well[30,32]. Moreover, exercises in CKC seem to be similar to the functional activities, which are essential to the sports practice and/or recreational activities return[31]. The results of this work suggest that the use of exercises in CKC seems to favor the joint stability in the rehabilitation of individuals with ACL lesion, especially in the initial lesions[31-32], minimizing the lesion effects on the muscular fatigue, once Fmed alteration of the thigh muscles does not occur.

Among the study's limitations, a relevant variable to be used along with the Fmed would be the muscular strength analysis. Such resource, besides acting as feedback for the volunteers during the CIVM, would offer a better control of the movement from the force exerted by each volunteer, once the velocity of the muscular fiber conduction is influenced by the contraction force. Moreover, although not being the aim of our study and being the Fmed an efficient tool in the muscular fatigue quantification, a fatigue-induction protocol could have shown evidence on the difference between the groups and exercises.

CONCLUSION

Within the experimental conditions we may conclude that the Fmed presents lower indices for individuals with ACL lesion in OKC for the LVL, TS and TB muscles, suggesting that it is a parameter of the EMG signal able to characterize this kind of lesion.

The Fmed is influenced by the kind of exercises, whether OKC or CKC. The exercises in CKC seem to minimize the ACL lesion effects and can be more efficient in the rehabilitation of these individuals when compared with exercises in OKC.

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