REV BRAS ORTOP. 2015;50(2):180–185

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Original Article

Neuromuscular efficiency of the vastus lateralis and biceps femoris muscles in individuals with anterior cruciate ligament injuries☆

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ARTICLE INFO

Article history:
Received 20 May 2013
Accepted 11 March 2014
Available online 7 April 2015

Keywords:
Anterior cruciate ligament
Muscle fatigue
Biomechanics

ABSTRACT

Objective: To analyze strength and integrated electromyography (IEMG) data in order to determine the neuromuscular efficiency (NME) of the vastus lateralis (VL) and biceps femoris (BF) muscles in patients with anterior cruciate ligament (ACL) injuries, during the preoperative and postoperative periods; and to compare the injured limb at these two times, using the non-operated limb as a control.
Methods: EMG data and BF and VL strength data were collected during three maximum isometric contractions in knee flexion and extension movements. The assessment protocol was applied before the operation and two months after the operation, and the NME of the BF and VL muscles was obtained.
Results: There was no difference in the NME of the VL muscle from before to after the operation. On the other hand, the NME of the BF in the non-operated limb was found to have increased, two months after the surgery.
Conclusions: The NME provides a good estimate of muscle function because it is directly related to muscle strength and capacity for activation. However, the results indicated that two months after the ACL reconstruction procedure, at the time when loading in the open kinetic chain within rehabilitation protocols is usually started, the neuromuscular efficiency of the VL and BF had still not been reestablished.

☆ Work developed jointly by the Hospital Universitário do Oeste do Paraná (HUOP), Laboratório de Pesquisa do Movimento Humano (LAPEMH) and Universidade Estadual do Oeste do Paraná (UNIOESTE), Cascavel Campus, Cascavel, PR, Brazil.
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http://dx.doi.org/10.1016/j.rboe.2015.03.010

Eficiência neuromuscular dos músculos vasto lateral e bíceps femoral em indivíduos com lesão de ligamento cruzado anterior

RESUMO

Objetivo: Analisar a força e a integral da eletromiografia (IEMG) para obter a eficiência neuromuscular (ENM) dos músculos vasto lateral (VL) e bíceps femoral (BF) em pacientes com lesão de ligamento cruzado anterior (LCA) nas fases pré-operatória e pós-operatória, comparar o membro lesionado nos dois momentos e usar o membro não cirúrgico como controle.

Métodos: Foi feita a coleta de dados da EMG e da força de BF e VL durante três contrações isométricas máximas nos movimentos de flexão e extensão do joelho. O protocolo de avaliação foi aplicado nos momentos pré e pós-operatório (dois meses após a cirurgia) e obteve-se a ENM dos músculos VL e BF.

Resultados: Não foi encontrada diferença na ENM do músculo VL entre os momentos pré e pós-cirúrgico. Por outro lado, houve aumento da ENM do BF no membro não cirúrgico dois meses após a cirurgia.

Conclusões: A ENM fornece boa estimativa da função muscular por estar diretamente relacionada à força e à capacidade de ativação dos músculos. Entretanto, os resultados apontam que dois meses após o procedimento de reconstrução do LCA, quando normalmente são iniciadas cargas em cadeia cinética aberta nos protocolos de reabilitação, a eficiência neuromuscular do VL e BF ainda não está restabelecida.

Palavras chave:
Ligamento cruzado anterior
Fadiga muscular
Biomecânica

Introduction

The anterior cruciate ligament (ACL) is one of the most important structures for stabilizing the knee joint and is one of the most frequently injured ligaments during sports activities.[1] ACL injury causes great incapacity for the limb and also some long-term problems such as osteoarthritis.[2] Even after surgical reconstruction and rehabilitation, significant deficits may remain, for example in relation to the knee extensor and flexor muscle strength.[3]

Muscle weakness subsequent to ACL injury generates imbalances between agonist and antagonist muscles during knee flexion and extension movements. These imbalances often cause difficulty in rehabilitation for individuals undergoing ACL reconstruction procedures. The persistent asymmetry in the torque ratio between knee extensors and flexors that is observed in this situation has shown that it is of great importance to attempt to identify and reverse the causes of persistent muscle weakness subsequent to ACL injury and reconstruction.[4]

Several factors need to be taken into consideration in relation to recovery of knee flexion and extension strength subsequent to ACL injury. The most important of these factors relate to muscle architecture and the integrity of the origin and insertion of the muscles, along with the efficacy of the neural activity that arrives at the motor plate.[5,6]

Neural factors relate particularly to the efficacy of activation of the motor units during muscle contraction. It is known that the greater the number of motor units recruited through a stimulus is, the greater the resultant muscle generated will also be.[7] Biomechanically, neuromuscular efficiency is calculated through the relationship between the amount of neural stimulus and the capacity to generate force that a muscle has.[8]

Thus, the relationship between the muscle force moment and the integrated electromyographic signal (IEMG), which is considered to be the best variable for describing the intensity of the neuromuscular effect during sustained muscle activity, has been used to estimate neuromuscular efficiency (NME).[9–11] This can be interpreted as an individual's capacity to generate a force moment in relation to his level of muscle activation.[8] Nonetheless, studies involving muscle architecture and electromyographic analysis have demonstrated that results from the vastus lateralis (VL) and biceps femoris (BF) muscles are easier to measure and, especially, more reproducible in relation to their agonists,[12,13] which makes these muscles appropriate representatives of the behavior of the knee extensor and flexor muscle groups, respectively.

The return to normal or to sports activities after ACL reconstruction usually takes place after the sixth postoperative month.[14] However, patients start to bear weight in open kinetic chain exercises and to subject the ACL to greater tension generally after the sixth postoperative week in accelerated protocols and after the twelfth postoperative week in conservative protocols.[14,15] Despite this, not much data exists regarding the state of neuromuscular efficiency at this stage of the rehabilitation.

Therefore, this study sought to analyze muscle force and IEMG in order to determine the neuromuscular efficiency of the vastus lateralis (VL) and biceps femoris (BF) muscles in patients with ACL injuries at two times: (1) just before the operation; and (2) during the postoperative phase, two months after a procedure to surgically reconstruct the ACL.

Materials and methods

The sample was composed of 12 male individuals of mean age 29.27 ± 6.90 year who presented unilateral ACL injuries and who, after the preoperative evaluation, underwent a surgical procedure to reconstruct the ACL, followed by physiotherapy. The surgical procedures were performed by the same orthopedists, using the tendons from the semitendinosus and gracilis muscles as grafts, fixed in the femur by means of the Rigidfix® system and in the tibia using absorbable interference screws, for all the individuals. This study was approved beforehand by the local ethics committee, in accordance with report no. 155/2012-CEP (CAAE 06519712.4.0000.0107).

After the operation, the patients were followed up by specialist physiotherapists, with periodic 60-min sessions twice a week, from the time of hospital discharge until the two-month reassessment.

Assessment protocol

The assessment protocol was carried out just before the operation and two months after the surgical procedure. The data-gathering in relation to muscle strength and electromyography (EMG) was done bilaterally.

The strength evaluations were performed at the Laboratory of Human Movement Research (LAPEMH) of the Physical Rehabilitation Center (CRF) of the State University of the West of Paraná (UNIOESTE). A structure appropriate for this purpose was used. The subject was seated on a high extensor table with the hip flexed at 90°, without contact between the popliteal fossa and the table and/or contact between the lower limbs and the floor. After the patient had been properly positioned, a load cell of 200 kgf coupled to the laboratory wall was fitted to the patient's ankle by means of a non-extendable ankle band, in such a way that the force vector was always exerted at 0° in relation to the axis of the load cell. In this position, in which there was restriction of knee movement, the patient was instructed to perform a series of maximum voluntary isometric contractions (MVICs).

While performing the MVICs, with knee flexion and extension, the joint was positioned flexed at 60° (0° = total extension of the knee). The position of the knee was determined with the aid of a fleximeter and all the tests were recorded using a conventional video camera (Panasonic, NV-GS180), positioned perpendicularly at a distance of 1.5 m, in alignment with the intercondylar fossa of the knee, in order to obtain images of the lower limbs in the sagittal plane during the MVICs.

To determine the knee joint angle on the recorded images, three markers of diameter 5 mm were fixed to the lower limbs before the contractions were performed: on the greater trochanter of the femur, knee joint interline and lateral malleolus of the ankle. The video data were gathered at 30 Hz using the VirtualDub software (v.0.9.11). In order to precisely assess the real joint position, the Kinovea software (v.0.8.15) was used.

Three repetitions of the MVICs were performed in each open kinetic chain exercise. The contraction was maintained for 5 s, with resting periods of 120 s, in each direction of movement (extension and flexion). In all the evaluations, the researchers gave verbal encouragement commands in order to stimulate the patients during the isometric contraction.

The analog data relating to EMG and strength were obtained using a 12-channel biological data-gathering system (BioEMG 1100, Lynx, Brazil), by means of the AqDados software (Lynx AqDados v. 7.2), which also had a channel containing data from a light synchronization system that was also gathered by the video camera, in order to identify the time at which the peak force was attained. In preparation for gathering EMG data, the patient's skin was shaved and then cleaned using 70% alcohol. The EMG data were gathered using disposable surface electrodes positioned on the bellies of the vastus lateralis (VL) and biceps femoris (BF) muscles, in a bipolar layout.

Data analysis

To obtain the EMG data, the interval was limited to 0.25 s before and after the peak force. Following this, the signals were rectified and filtered (third-order Butterworth bandpass filter from 10 to 500 Hz) in order to obtained the integrated EMG (IEMG) signal values for the VL and BF muscles in the time domain over the 0.5 s interval, only for the MVIC in which the greatest peak of isometric force occurred in knee extension and flexion. The signals gathered were processed in the MatLab® environment (Mathworks, USA).

The data obtained in relation to muscle strength were normalized so as to obtain a mathematical projection of greater reliability for the force exerted individually by the VL and BF muscles. For this, the criterion of the equivalent percentage contribution of these muscles in relation to the total physiological cross-sectional area of the respective muscle groups was used. Thus, the proportions of 36% for the VL and 40% for the BF were used as the basis for the entire knee extensor and flexor muscle group (100%), respectively. These percentages followed the pattern described in an *in vivo* study in which the individuals in the sample presented mean age, height and weight similar to those of the patients selected for the present sample.[16] Subsequently, the muscle force was divided to obtain 50% of the MVIC and the NME of the VL and BF muscles was calculated using the ratio of strength/IEMG, at 50% of the MVIC. This concept started from the assumption that at submaximal contractions of up to 50%, the relationship of force *versus* EMG was constant.[17]

Statistical analysis

For the statistical analysis, the Shapiro–Wilk test was used to identify the normality of the variables. The independent Student's t test was used to identify differences in force, IEMG and NME between the injured and uninjured limbs and the paired Student's t test was used to compare variables between before and after the operation (two months postoperatively). The significance limit was established as $p = 0.05$.

Results

In evaluating the images recorded during the MVICs, no significant differences were found between the operated and non-operated knees either before or after the operation, in

Table 1 – Means and standard deviations of the knee joint angle, recorded during the MVICs at the preoperative and postoperative stages. No significant differences were found.

Limb	Preoperative		Postoperative	
	Extension	Flexion	Extension	Flexion
Operated	52.44 ± 5.6	65.9 ± 8.8	53.1 ± 7.9	64.9 ± 6.7
Non-operated	52.49 ± 5.0	65.2 ± 7.3	51.6 ± 6.8	62.8 ± 8.4

Source: The present authors.

relation to the positioning during the MVICs in extension and flexion (Table 1).

Taking knee flexion movements as the reference, in comparing from before to after the operation, it was seen that the limb that underwent surgical repair presented significant decreases in IEMG and in BF muscle strength (Table 2a,b). On the other hand, in the non-operated limb, while the IEMG decreased, the magnitude of the BF strength was maintained (Table 2c).

For the VL muscle, comparing the two times, although the operated limb presented diminished muscle strength after the ACL reconstruction (Table 2d), the magnitude of the IEMG did not change. In relation to the non-operated limb, no differences were found in comparing the situations before and after the surgery.

Both before and after the operation, the strength of the BF and VL muscles was diminished in the operated limb, in comparison with the other limb (Table 2e–h).

It was found that the NME of the BF in the non-operated limb increased from before to after the operation (Fig. 1). Moreover, it could be seen that the NME of the BF in the non-operated limb had increased in relation to the operated limb, at the evaluation two months after the operation. However, no difference in relation to the NME of the VL was found.

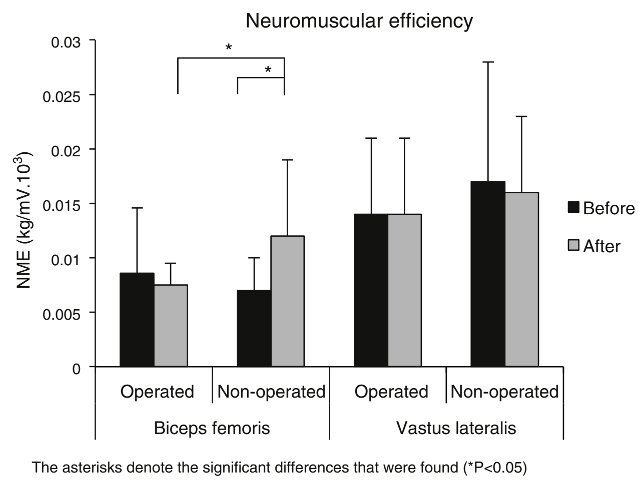

Fig. 1 – Means and standard deviations of the neuromuscular efficiency (NME) of the BF and VL muscles at the two times evaluated. The asterisks denote the significant differences that were found (*$p < 0.05$).

Discussion

Neuromuscular efficiency is related to muscle fiber activation and production of force by a given muscle. Thus, individuals who are capable of producing greater muscle force with lower magnitude of muscle fiber activation are considered to be more efficient.[18] In the present study, it was sought to measure muscle strength and IEMG, in order to determine the neuromuscular efficiency of the VL and BF muscles in patients with ACL injuries, both before and after the operation.

After the surgical procedure, these patients may have a tendency to protect the operated limb, through limiting their movement of it and the weight borne by it. This may lead to atrophy and weakness of the anterior and posterior musculature of the thigh. Gerber et al.,[19] observed atrophy and that the quadriceps and biceps femoris muscle strength had diminished by 20% and 30%, respectively, three months after ACL reconstruction, even though the patients were undergoing a rehabilitation process. Their data corroborate the findings of the present study, in relation to the strength and IEMG of the BF muscle of the operated limb, given that diminished strength and neural recruitment were observed after the surgical procedure. This was possibly because at the postoperative

Table 2 – Means and standard deviations of the integrated electromyography (IEMG) values in mV/sec and estimated force in kgf, exerted by the BF and VL during knee flexion and extension, respectively.

	Limb	Operated		Non-operated	
	Variable	IEMG	Force[a]	IEMG	Force
BF	Preoperative	1077.56 ± 1004.64[a]	5.66 ± 1.77[b,e]	977.84 ± 531.23[c]	6.23 ± 1.56[e]
	Postoperative	588.78 ± 246.79[a]	4.00 ± 1.06[b,f]	708.40 ± 354.84[c]	6.87 ± 1.57[h,f]
VL	Preoperative	912.61 ± 714.11	10.41 ± 4.27[d,g]	1028.77 ± 734.34	11.50 ± 2.15[g]
	Postoperative	749.63 ± 430.92	8.70 ± 3.29[d,h]	840.59 ± 415.51	11.23 ± 2.35[h]

Source: The present authors.

The letters represent the significant differences encountered, respectively with their pairs ($p < 0.05$).

evaluation performed two months after the surgical reconstruction of the ligament, the joint was still healing and presented weakness and muscle inhibition.

For the non-operated limb, comparing the pre and postoperative data, it was seen that the electrical activity (IEMG) of the BF muscle also decreased, although without change to the muscle strength. Even though the methodology used did not allow direct measurement, it can be supposed that this result was due to the learned effect caused by the tests performed and also due to the great use of the limb contralateral to the injury after the surgical procedure, given that patients are generally afraid of applying force, thus offloading weight from the operated limb and avoiding moving it after the procedure.[20] Moreover, the decrease in IEMG without change to the strength of the BF was responsible for the increase in its NME. This effect was probably related to the muscle demand on the contralateral limb generated through excessive use.

However, this was not shown to be valid for the VL muscle, given that no differences in the variables studied were found. This finding, in a certain manner, denotes that the VL muscle on the non-operated side was not greatly influenced by the surgical procedure or by the physiotherapeutic rehabilitation process.

It is important to emphasize that the graft used (from the semitendinosus and gracilis) is the one most commonly used in Brazil. However, the functional results presented do not seem to differ from those from the middle portion of the patellar tendon.[21]

The muscle force produced is dependent on the joint angle, according to the force–length relationship. Specifically in relation to the knee, it has been well established that the optimum angle for force production is close to 60°.[22] From the images recorded while the MVICs were being performed, it was certain that there were no significant differences between the joint angles, either in relation to movement or in relation to the assessment time (before or after the operation).

Neuromuscular alterations subsequent to an injury are representative of a complex clinical state, which may be manifested through the presence of muscle inhibition in the uninjured musculature around the compromised joint.[23] This neural response has two major physiological purposes: (1) to diminish the load around the injured joint, so as to promote protection against new injuries;[24] and (2) to provide compensatory motor strategies, so as to maintain the functions of the limb in the presence of muscle inhibition.[25]

These arguments might explain the data found in the present study, with regard to the comparison made between the pre and postoperative stages of the VL muscle in the operated limb, in which there was a decrease in muscle strength without any significant change to the IEMG. This result was possibly due to the presence of muscle inhibition, with the aim of sparing the joint and avoiding early recurrence of the injury.[26]

Likewise, it is well known that ACL injuries are associated with poor neuromuscular control, which leads to diminution of the proprioceptive information as a function of changes to the efficiency of the mechanical receptors responsible for neuromuscular control,[27] disturbances of the somatosensory system[28] and decreased muscle activation and force.[29] According to Hewett et al.,[30] coordinated coactivation of the hamstrings and quadriceps has an important role in decreasing the risk of primary injury. This agonist–antagonist balance may protect the knee against recurrent injury to the reconstructed ACL. These physiopathological indications would explain the findings of the present study with regard to comparisons between the limb with ACL injury and the sound limb.

Since the postoperative evaluation of the present study was made only two months after the surgical procedure, the limb was still undergoing recovery. This could be seen from the lower muscle strength found in comparing the limbs analyzed. It was decided to make evaluations two months after the surgical procedure in order to obtain indications of the state of neuromuscular efficiency of these muscle groups at the average time when open kinetic chain exercise procedures are started in most rehabilitation protocols.[14,15] Nonetheless, one limitation of the present study is precisely the lack of evaluation of the subjects after six months, caused by the large loss of subjects that occurred beyond the second postoperative month. Hence, it is recommended that future studies should evaluate NME conditions after this time.

Lastly, the results reported here emphasize the complexity of the process of functional recovery of knee joints that undergo ACL reconstruction and rehabilitation, and the need to be attentive toward recovery of the neuromuscular efficiency of the muscles involved in the joint, before activities at more vigorous levels that might lead to recurrence of the ligament lesion are resumed.

Conclusion

An increase in the NME of the BF muscle in the non-operated limb was observed two months after the operation. In comparing the limbs, the BF on the non-operated side was more efficient at the postoperative stage. No differences in the NME of the VL muscle were seen.

The force, electromyographic activity and neuromuscular activity data showed asymmetries between the limbs two months after the ACL reconstruction surgery. Thus, at that time, the operated knee was not fit for normal or sports activities. Furthermore, it is worth emphasizing that special attention is needed around the second month after the surgery, during the rehabilitation process, with regard to starting the stage of open kinetic chain weight-bearing, given that the limb still presents diminished neuromuscular efficiency.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

To UNIOESTE and to the Araucária Foundation for the scientific initiation bursary.

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