Study of muscular fatigue by EMG analysis during isometric exercise.

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ABSTRACT **— Ten female individuals (age = 21 ± 2 years; weigth = 50 ± 2 kg; heigth = 160 ± 3 cm) were analyzed. For the determination of the electromyographic fatigue threshold (EMG_{FT}), four percentages of load (10, 20, 30 and 40%), in relation the maximum voluntary contraction (MVC) were used, until the subjective exhaustion. The biosignals in these percentages had been linearly adjusted in domain of the number of repetition in which the slopes were obtained. These numbers had been correlated with its respective percentages of load, where the y-intercept of this linear regression corresponds to the EMG_{FT}. The isometric training consisted of the performing of 15 maximum repetitions with an interval of 2 minutes being carried through 3 times per weeks during 4 weeks. The results demonstrated that there is a significant increase ($p<0.05$) of the MVC after training (167.10 ± 33.87 N) in relation the MVC before training (132.17 ± 31.74 N). The value of the EMG_{FT} increased for the semitendinosus (ST) muscle from 18.89 to 21.06% and it remained similar for the biceps femoris (caput longum) (BFCL) muscle from 20.4 to 19.90% where these variations had not been significantly different ($p\leq0.05$). Thus, the isometric training was efficient to further increase of the MVC however it did not influence the value of the EMG_{FT} of these muscles**.

Keywords: Biosignal, Electromyography, Fatigue, Isometric Contraction.

I. INTRODUCTION (HEADING 1)

From the many joints exposed to muscle-skeletal injuries, the knee joint is the one that more suffers consuming in the daily life, for both athletes and non-athletes [1], once for the maintenance of the corporal stability, it is necessary for the muscles of this joint to be the strongest as possible [2]. Such strengthening may be obtained through an isometric force training [3], which range from numbers of repetitions up to weekly frequencies [4,5].

A important fact that be associated with a force output is the neuromuscular fatigue. Neuromuscular fatigue can under certain conditions be reflected in a decreased performance and/or the failure point at wich the muscle is no longer able to sustain the requeried force or work output level [6,7,8].

Research by [9] Dimitrova & Dimitrov (2002) related that Muscle fatigue is recognized as a decline in force, or failure to maintain the required or expected force. It may occur at any point from the nervous centers and conducting pathways to the contractile mechanism of muscle fibers.

Study by [10] Moritani & Yoshitake (1998)Such changes have been shown to be related to hydrogen ion and metabolite accumulation and to sodium and potassium ion concentration shifts. These changes would in turn affect the muscle excitation traction coupling including the muscle membrane properties and muscle action potential propagation, leading to EMG manifestations of muscle fatigue distinct from mechanical manifestations.

The electromyographic signal has quite often been used as a mean of assessment of muscle fatigue [11]. The increase in amplitude of the EMG signal as an empirical measure of localized muscle fatigue or as an indicator of muscle fatigue [9]. The RMS values tended increase with decreasing force as a function of the number of repetitions [12] phenomenon that determines the neuromuscular fatigue process. Studies by [13] DeVries et al. (1982), [14] Matsumoto et al. (1991) and [15] Moritani et al. (1993) have proposed pocedure for identifying the force output associated with the neuromuscular fatigue called the electromyographic fatigue threshold (EMG_{FT}).

One time that frequently the isometric exercise come being used in rehabilitation and training, where the fatigue is a limit factor to performance, whereas, the porpuse of the present study was to analyse the effect of isometric training on index of EMG_{FT} of the *semitendinosus* (ST) and *biceps femoris (caput longum)* (BFCL) muscles

II. Material and Methods

Ten female subjects (mean (SD) age, 21(2) years; mass, 58.88(0.97) Kg; height, 165(3.82) cm) volunteered for this investigation. All subjects provided informed consent prior to any testing. The investigation were approved by university's local Ethics Committee.

The biosignals from the *semitendinosus* (ST) and *biceps femoris (caput longum)* (BFCL) muscles were recorded with pairs of bipolar silver–silver chloride surface electrodes (10 mm electrode diameter, fixed inter-electrode distance of 20 mm). Following skin abrasion with an alcohol soaked cotton pad [16], electrodes were placed with the recommendation of Marson and Gonçalves [12].

A data acquisition module EMG800C by EMG System do Brasil LTDA. Recorded the signal at a sampling frequency of 2 kHz, a gain 1000 using a pass band filter of 20-500 Hz. The analogical signal were digitalized using an A/D converter of 16 bits.

Muscles contraction (force) was measured a load cell (EMG System do Brasil LTDA) with a maximum traction capacity of 5000 N. The knee was 90º of isometric flexion contractions were done by pulling on a cable fixed to the ankle which was kept at 90º relative to the longitudinal axis of the leg. To find MVC media was performed 3 MVC with rest of 5-min by 3 days.

The EMG_{FT} was determinated using the protocol of linear fitting [10]. The EMG_{FT} test was performed against fraction (10, 20, 30 e 40%) of MVC randomly distributed with a ratio of two loads a day separated by an interval of 24 hours and with an interval of 30-min between each load. The EMG_{FT} test was performed until exhaustion or until changes in the fraction value (deviation of 2N).

The isometric training was performed 3 times by week during 4 weeks. Each training session consisted of 15 isometric voluntary contraction with a rest of 2-min between each contraction. After 4 weeks was done a retest of MVC as well as the EMG_{FT} test.

III. Results

Table 1 show the data for each subject as well as the mean (SD) value wich relate that there is a significant increase ($p<0.05$) of the MVC after training (MVC_A=167.10 ± 33.87 N) in relation the MVC before training (MVC_B132.17 ± 33.87 N). The figure 1 desmonstrate that there is an increased for value of the EMG_{FT} of the *semitendinosus* (ST) muscle (18.89 to 21.06% of MVC) and it remained similar for the *biceps femoris (caput longum)* (BFCL) muscle (20.40 to 19.90% of MVC) where these variations had not been significantly different ($p\leq0.05$)

IV. Discussion

The results obtained for the MVC, demonstrate that there was a significant difference ($p\leq0.05$) between the values of the MVC_B (132.17 ± 33.87 N) and MVC_A (167.10 ± 31.74 N), with a greater value obtained after the accomplishment of the isometric training, according to [17] Young et al. (1985); [18] Rutherford and Jones (1986); [19] Jones and Rutherford (1987) and [20] Alway et al. (1989) who also identified this increase due to the improvement of the speed of neural conduction [21,22,23] and/or through the increase of the firing synchronism degree of the motor units [24].

Another evidence of the improvement was the significant evolution of MVC after the training of 15RM verifying an increase in the muscle-skeletal capacity for the generation of the maximum force, in agreement with reports of [17,18,19,20].

Analyzing the values of the EMG_{FT} (figure 1) before and after the training of both ST (18.89 ± 3.80% and 21.06 ±4.95%) and BFCL (20.40 ±4.90% and 19.90 ± 4.05%), respectively, it is verified that these increases on the amplitude of the electromyographic signal, in isometric contractions until exhaustion, are associated with an increasing recruitment of the motor units as well as the firing rate of these units [25,13] thus compensating the reduction of the useful force per muscular fiber [26,27,28,11,15] result of the fatigue process. The values of the EMG_{FT}-before in relation to the EMG_{FT}-after presented no significant difference ($p\leq0.05$).

Table 1– Mean (SD) values of MVC before (MVC_B) and MVC after (MVC_A) isometric training.

Subjects	MVC_B	MVC_A
1	100.00	160.00
2	108.00	205.50
3	142.00	188.00
4	200.90	229.00
5	137.00	138.20
6	129.00	142.30
7	102.00	112.90
8	157.80	170.00
9	102.00	169.60
10	143.00	155.50
	132.17 (± 31.74) N *	167.10 (± 33.87) N

* = $p<0.05$.

It was expected that, due to the force training, the EMG_{FT} indexes would increase, once there is a possibility for the evolution of the EMG-time relation and probably the angular coefficients that originate the EMG_{FT}.

This behavior was not observed in the BFCL muscle after the isometric training that may be explained through the improvement of the recruitment standard of the muscular fibres [29], which is observed in an isometric resistance training in a 8-week period, making the electromyographic activity, related with the force, to turn into lower levels, thus occurring a higher force production with a lower neural intensity [3].

The non-alteration of the EMG_{FT} may be explained by the reduction of the conduction speed of the action potential [30] of the muscular fibres, which may be observed after an isometric training as well as a coativation of the antagonistic muscles [31,32,5], that is, a competing activity in the muscles that includes the set of agonist-antagonists, making the joint to become more rigid and difficult to be disturbed during of the contractions after an isometric training [33].

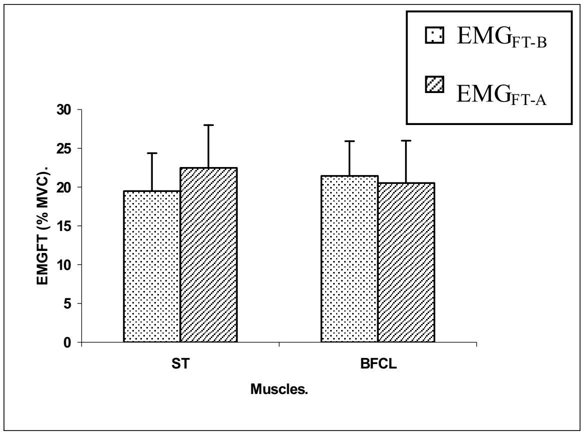

Fig. 1. Mean (SD) values of the EMG_{FT} before (EMG_{FT-B}) and EMG_{FT} after (EMG_{FT-A}) isometric training of the ST and BFCL muscles.

Basmajian and DeLuca [7] have demonstrated that the sinergist muscle, at the moment of the movement performance, may generate a higher degree of traction to supply the existing overload, if compared to the other main muscles, making the electromyographic activity to change in these muscles.

Another important factor is the type of training. In this case the training had as main characteristic the force, once it has been performed at 100% of the CVM what comes to promote an improvement in the maximum force [3,34] rather than in the capacity for the muscle to support as long as possible without demonstrating fatigue signals.

The key for the training incentive seems to be the maximum intensity of the isometric contraction. Indeed, the increase on the CVM of the knee muscle extensors observed by [35] Maffiuletti and Martin (2001) is similar to the studies of [36] Carolan and Cafarelli (1992), [5] Garfinkel and Cafarelli (1992) and [19] Jones and Rutherford (1987) when compared to a resistance training.

Maffiuletti and Martin [35] have demonstrated that the isometric resistance training, during 7 weeks, improves the concentric, eccentric and isometric torque. The static resistance training would be using 15% of the CVM, performing a continuous blood perfusion and therefore, an aerobic metabolism. An improvement of the static resistance becomes possible through an increase of the maximum static force. Through what was mentioned above, as the absolute threshold increases, the threshold where the anaerobic metabolic phenomena predominate also increases [37]. Clarkson et al. [38] and Paasuke et al. [39] demonstrated that the isometric resistance training in submaximal loads increases the capacity for the muscle to keep the contraction.

V. CONCLUSION

Therefore, the study concludes that the proposed force isometric training was efficient to promote an increase on the maximum voluntary contraction after a period of 4 weeks however not enough to modify the values of the electromyographic fatigue threshold (EMG_{FT}) for the *biceps femoris (caput longum)* and *semitendinosus* muscles.

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