Root Mean Square Value of the Electromyographic Signal in the Isometric Torque of the Quadriceps, Hamstrings and Brachial Biceps Muscles in Female Subjects

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ABSTRACT

Background: The surface electromyography (EMG) is a technique to capture and measure electrical activity and muscle action potential. It is applied to specify the production of force and to analyze muscle fatigue. The Root Mean Square (RMS) value has been used to quantify the electric signal because it reflects the physiological activity in the motor unit during contraction.

Purpose: To evaluate a possible linear relationship between the RMS value of the EMG signal and the contraction force of the rectus femoris, vastus medialis, lateralis, biceps femoris, semitendinosus, and brachial biceps muscles.

Methods: The analysis was performed on 24 females, university students with a mean age of 20 (± 6) years that practice physical activity regularly. The RMS value of the EMG signal of the mentioned muscles was measured during isometric contraction every 10 seconds with loads of 2, 4, 6, and 8 kilograms, and were normalized by the percentage in relation to the maximum isometric voluntary contraction (MIVC). The position of the volunteers during the analysis was standardized and the angle of the adjacent joint was monitored by an electrogoniometer.

Results: The results of this experimental condition demonstrated that the RMS value of the EMG signal is an increasing linear function of the imposed load. This positive correlation was found for the rectus femo-

ris (p < 0.01), vastus lateralis (p < 0.01), vastus medialis (p < 0.01), biceps femoris (p < 0.01), semitendinosus (p < 0.01), and brachial biceps muscles (p < 0.001).

Conclusion: A linear relationship with the required torque was found between the contraction force and the RMS value of the EMG signal in females for the analyzed muscles.

INTRODUCTION

The surface electromyography (EMG) is a method used to analyze muscular condition during rest or functional activities. It is a technique to capture and measure the electrical activity and changes of muscle electric potential and makes possible an investigation of muscle synergies, as well as muscle predominance in specific patterns of movement.

The registered EMG signal in the belly muscle is the collective action potential of all muscular fibers of the motor unit that work together because they are innervated by the same motor neuron.[1,2]

Several factors can influence the capture of the EMG signal. These factors can be divided into physiological--type of muscle fiber, nerve fiber conduction, body temperature; anatomical (as a diameter of the muscle fiber), position (depth) of the muscle in relation to the electrode and thickness of the skin; and technical, related to instrumentation during EMG analysis, involving aspects related to the capture and processing of data.[3,4]

Nevertheless, a common variable is essential when a comparison is necessary, especially when it is impossible to totally eliminate these variables. The most common reference for the normalization of the EMG signal is the percentage of the maximum isometric voluntary contraction (MIVC), more often used to analyze the static muscular contraction activity.[2,5,6]

Once the muscle electric signal has been captured, it is analyzed or processed by using the "root mean square" value (RMS) which has been widely utilized. In this form of processing, the EMG signal is submitted to mathematical treatments that are designed to quantify the intensity and the duration of several events of the EMG signal.[3,7]

The RMS value is, therefore, a parameter frequently chosen because it reflects the level of the physiological activities in the motor unit during contraction.[7]

For small muscles, the relationship between force and the EMG signal tend to be linear, whereas in bigger muscles that need a better motor recruitment, the same relationship tends to not be linear, because the amplitude variations of the muscle electric signal do not correspond to the force variations.[2]

The general purpose of this study was to associate the RMS value of the EMG signal with the contraction force of big muscular groups in young women. The specific purpose was to observe for EMG analysis if the rectus femoris, vastus lateralis and medialis, biceps femoris, semitendinosus and brachial biceps muscles have different patterns when submitted to weights of 2, 4, 6, and 8 kgs.

The null hypothesis (H0) is based on the presence of progressive and linear patterns when the EMG signal and contraction force of big muscle groups are related in different overload conditions. As tested, the hypothesis (H1) is expected to find a non-linear increase between the RMS value and the contraction force.

METHODS

Subjects

It was a transversal analytic study performed between July 2007 and August 2008 in the Motion Analysis Laboratory of the Centro Universitário São Camilo, São Paulo.

Twenty four volunteers with a mean age of 20 ± 6 years participated in the research study according to the following inclusion criteria: female gender, university students with the right side dominant that performed physical activity regularly at least 3 times per week.

The following exclusion criteria were used: women that presented body mass in-

dex (BMI) less than 18.5 kg/m² and greater than 25 kg/m², neurological changes such as limb sensitivity deficit, traumatic diseases of the muscular-skeletal system like fibromyalgia, ligament injuries in the shoulder, elbow, or knee in the last 6 months, and other diseases that prevented the completion of the exercises.

Procedures

All volunteers were informed of the procedures to be performed and signed an Informed Consent Form according to the norms of the National Health Council, Resolution 169/69. This study was approved by the Ethics Committee on Research, protocol 125/07.

The EMG surface analysis procedures were performed in the quadriceps muscles (rectus femoris, vastus lateralis and medialis), hamstrings (semitendinosus and biceps femoris), and brachial biceps. Two capture electrodes were placed on the belly muscles, always in the right limb, and in the direction of the muscle fibers.

For analysis of the rectus femoris, vastus lateralis, and medialis muscles, the volunteers were seated in a back-supported extensor chair while performing a full extension

of the knee associated with the dorsiflexion of the ankle. The electrodes were placed at a 50% imaginary line between the anterior-posterior iliac spine, and the superior edge of the patella of the rectus femoris muscle. For the vastus lateralis, the electrodes were placed at an 80% imaginary line between the anterior-posterior iliac spine and the lateral side of patella. For the vastus medialis, the electrodes were placed at an 80% imaginary line between the anterior-posterior iliac spine, and the joint line located in front of the anterior edge of the medial ligament (Figure 1).

The analysis of the semitendinosus muscle was performed with volunteers in prone position at a 45º leg flexion and hip medial rotation. The electrodes were placed at a 50% imaginary line between the ischiatic tuberosity and the medial condyle of the tibia. In the analysis of the biceps femoris muscle, the volunteers remained in supine position with a 45º knee flexion and hip lateral rotation. The electrodes were placed along the imaginary line between the ischiatic tuberosity and the lateral condyle of the fibula, which is located at 50% of this line (Figure 2). The joint angle measurement was made by electrogoniometry.

In the analysis of the brachial biceps muscle, the volunteers were in orthostatism and supported by the wall in an upright trunk position at a 45° forearm flexion (measured by electrogoniometry). The surface electrodes were placed along the imaginary line between the medial

Figure 1: Positioning of the electrodes for quadriceps muscle analysis

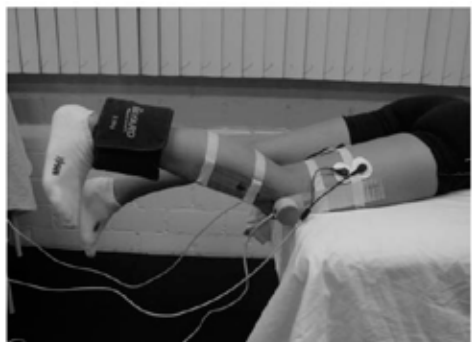*Figure 2: Positioning of the electrodes for hamstrings muscle analysis*

Figure 3: Positioning for analysis of the brachial biceps muscle

acromium and the cubital fossa, at 1/3 of the cubital fossa (Figure 3).

The position of the electrodes adopted for the analysis of the muscles was based on Seniam: European Recommendations for Surface Electromyography.[8]

All the analyzed muscles performed isometric contractions with weights of 2, 4, 6, and 8 kg. The reference electrode was fixed on the anterior part of the tibia on the left limb. An electrogoniometer was used for standard joint angle, and the MIVC was also performed for all the studied muscles. The order of the contraction evaluations with specific loads was randomized.

Evaluation

A surface electromyography device from EMG System was used for the study. This equipment contains eight differential types of independent channels. It has a high pass filter of 20 Hz, and a low pass filter of 500 Hz to minimize interference with low frequency noise that originates from unwanted movement of cables and electrodes. The high frequency noise that originates from several sources has a gain selection stage of 100-fold in the entrance as well as an isolator source from the electric network that is connected to a ground wire.

The surface electrodes were a differential active-type, with a gain of 20-fold and with a length of 10 mm and a width of 2 mm. The distance between the capture electrodes was 20 mm. In all evaluations, the reference electrode was kept on the anterior area of the opposite tibia.

The subjects´ skin surface was cleaned with alcohol and hair was removed before the electrodes were positioned in order to decrease the possibility of capturing interference. These precautions reduce surface tension and improve the conductivity of the signal. The capture time of muscular activity was performed during a period of 10 seconds.

After the myoelectrical activity capture, the RMS value of the EMG signal was used as a means of processing or quantification.

The mean of the RMS value generated in the muscles during the isometric contraction was reconstructed in a dispersion graph, and had an associated required torque with weights of 2, 4, 6, and 8 kg. The MIVC was utilized to try to find a possible linear relationship. The limb position for the MIVC evaluation followed the same standardization as the other analyzes.

Analysis of the data

The "method of the minimum squared" was used to evaluate the linearity between the RMS value, in µV, and the imposed load, in kilograms, for adjustment of a straight line and the "coefficient of determination," r^2, based on Pearson's coefficient of correlation. Beyond r^2 a x^2 test was also performed to calculate the adjustment quality of the straight lines with significance of 95%. The results and the values of the x^2 and their respective probabilities, as well as the coefficient determinations are shown in figures 4 to 9.

Previous data that was described in the literature regarding the mean and sample standard deviation and a significance of 5% was utilized to calculate the minimum size, n, of the sample. The following formula was used:

$$n = \left(\frac{1.96 \, \sigma}{e} \right)^2.$$

σ is the sample standard deviation, and *e* is the difference between the average of the sample and the average of the population. In this study, it was accepted as being equal to 10%.

RESULTS

The following is the demonstration of the six muscles evaluated in the condition of MIVC and the maintenance of 2, 4, 6, and 8 kg weights (Table 1):

signal analysis employed. In this study, RMS value was used because it is a parameter that better reflects the levels of muscle activity at rest and during contraction, and for this reason, one of the most widely used in scientific studies.[12,14]

According to De Luca[10] and Wang et al[12] who analyzed the quantitative relation between EMG signal and force, the contraction must always be isometric.

Table 1: *Mean ± standard deviation of the RMS values (µV) of the six analyzed muscles in MIVC and during maintenance of 2, 4, 6, and 8 kg weights.*

	MIVC (µV)	2 kg (µV)	4 kg (µV)	6 kg (µV)	8 kg (µV)
Rectus femoris	222.6 ± 142.9	71.3 ± 35.7	81.4 ± 43.6	98.6 ± 50.8	108.7 ± 57.2
Vastus lateralis	265.1 ± 106.0	114.1 ± 43.1	151.3 ± 121.0	136.7 ± 50.2	143.7 ± 53.6
Vastus medialis	182.2 ± 79.4	74.4 ± 32.6	90.0 ± 55.1	98.2 ± 47.5	115.8 ± 59.0
Bceps femoris	321.4 ± 195.5	68.0 ± 37.5	86.7 ± 45.4	104.6 ± 48.6	126.8 ± 58.7
Semitendinosus	399.0 ± 196.3	81.9 ± 33.9	108.8 ± 44.8	144.7 ± 63.2	173.5 ± 69.3
Brachial biceps	419.2 ± 182.6	84.2 ± 25.2	150.9 ± 59.2	229.7 ± 103.1	321.9 ± 122.7

Once performed, the RMS value of the EMG signal was used to capture the mentioned conditions, as well as a data normalization of the percentage in relation to the MIVC.

The results showed that in these experimental conditions the RMS value of the EMG signal and the imposed load have linear behavior (Figures 4 to 9).

DISCUSSION

The study showed a linear relationship between the RMS values of the EMG signal and the contraction force of the quadriceps, hamstrings and brachial biceps muscles. These findings have been supported by some researchers who explained that the EMG signal amplitude should increase linearly in concert with the imposed load in the muscle.[9-11]

However, other authors demonstrated that big muscles, mainly the biarticular muscles, do not have this relationship, because the linearity between muscular tension and EMG signal would occur only within smaller muscles such as the face and the hands.[1,7,12,13]

An important aspect is the type of EMG

Therefore, the instability of the electrodes in relation to skin can influence the signal capture. This was the main reason for selecting the isometric contraction option along with different weights; this procedure normalized the MIVC signal.

The MIVC have been used as a method for normalization in EMG studies.[6,15] On the other hand, Yang & Winter[16] believe that it is not the most trustworthy method because maximum contraction implies that all the motor units are triggering maximum capacity. These same authors concluded that the MIVC can be influenced by emotional factors or the environment. Likewise, a standardized evaluation was performed in terms of correctly positioning the volunteer, providing a quiet environment, and previously training only one examiner.

Another factor that corroborates the option of utilizing the MIVC application is that several studies had used MIVC as a method of normalization of the EMG signal.[10,16-19]

Krishnan et al[20] studied the differences in the EMG activity of the quadriceps and hamstrings muscles between males

Figure 4: *Percentage of the MIVC of the rectus femoris muscle in the condition of 2, 4, 6, and 8 kg weight support*
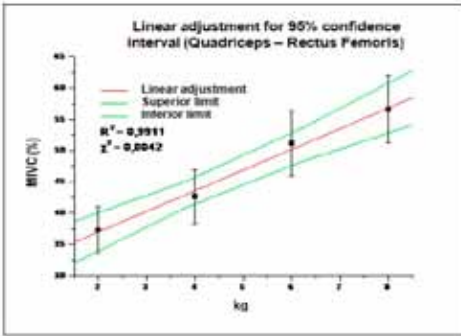

Figure 5: *Percentage of the MIVC of the vastus lateralis muscle in the condition of 2, 4, 6, and 8 kg weight support*
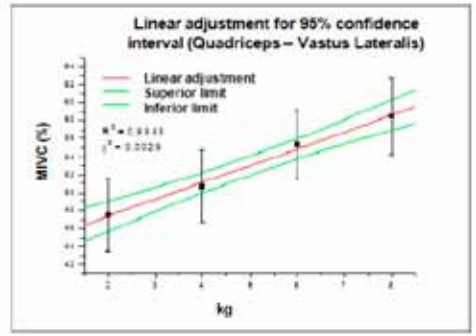

Figure 6: *Percentage of the MIVC of the vastus medialis muscle in the condition of 2, 4, 6, and 8 kg weight support*
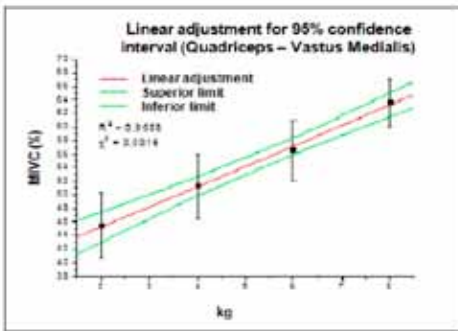

Figure 7: *Percentage of the MIVC of the biceps femoris muscle in the condition of 2, 4, 6, and 8 kg weight support*
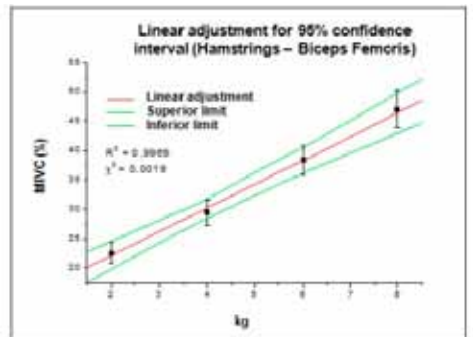

Figure 8: *Percentage of the MIVC of the semitendinosus muscle in the condition of 2, 4, 6 and 8 kg weight support*
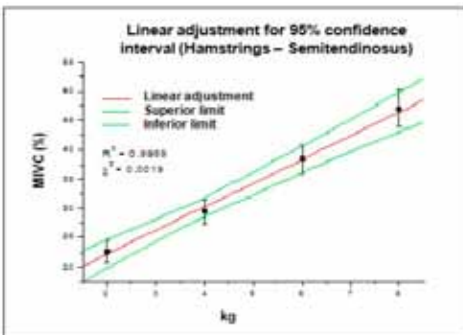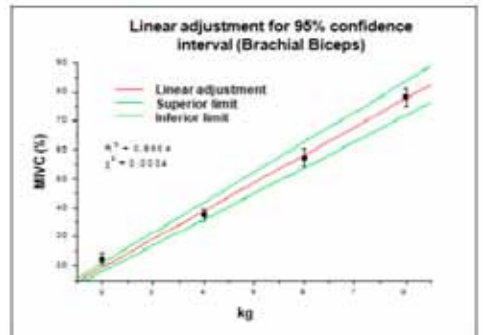

Figure 9: *Percentage of the MIVC of the brachial biceps muscle in the condition of 2, 4, 6, and 8 kg weight support*

and females, concluding that there exist differences in the composition and morphology of the muscular fiber. The amplitude of the potential action generated for muscular fibers is proportional to its diameter. In consequence, fast fibers generate larger potentials than slow fibers. This explains why muscular activity is greater in males. Males have a greater amount of fast fibers in relation to females.[21] To prevent this gender influence, only females were evaluated.

A study performed by Serrão et al[19] examined muscle fatigue after eccentric exercise of quadriceps in females. The maximum isometric torque was quantified by RMS value and by frequency analysis of the EMG signal before and after a series of eccentric exercises of high intensity. The results showed that this type of exercise leads to an intense decrease in the isometric torque. In the present study, a linear relationship was observed between the force of muscular contraction and the RMS value, and demonstrated that this parameter of quantification can be used in future static and functional analyses.

In the attempt to evaluate this contraction and EMG signal relationship, Buxbaum et al[22] analyzed the electrical activity of the bite muscles in women. Each analysis consisted of data obtained during rest and orofacials functional activities. The outcome of the EMG evaluation by force spectrum resulted in a trustworthy and sensible tool.

Wang et al[12] showed the relationship between force and the corresponding electrical activity by surface EMG of the bite muscles in subjects with unilateral temporo-mandibular dysfunction. The volunteers performed maximum contraction and different levels of isometric contractions. This activity showed an important weakness in the MIVC on the symptomatic side of the masseter. The relationship between these contractions was nonlinear. However, the relationship was linear between the EMG activity and force of the bite muscles on the contra lateral side.

With the purpose to avoid some bias, the present study evaluated healthful female subjects in a homogeneous group, as much in relation to age, body mass index and type of physical activity performed.

A lack of research studies regarding the same methological purpose for big muscular groups was noted in a previous review of the literature. These results may be used as a calibration curve of the employed equipment and as a basis for future clinical researches. There is, however, a necessity to evaluate the same muscular groups at other angles and conditions, mainly the functional ones.

CONCLUSION

A linear relationship between contraction force and RMS value of the EMG signal of the quadriceps, hamstrings and brachial biceps was found in women with the required torque of 2, 4, 6, and 8 kg weights.

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