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ORIGINAL ARTICLE

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Differences in bioelectrical activity of quadriceps muscle during various types of contraction

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Key words: *electromyography, quadriceps muscle, muscle fatigue, muscle contraction.*

Abstract

Background: *The aim of the study was to estimate differences in bioelectrical activity between rectus femoris (RF) and vastus medialis (VM) muscles of each lower limb.*

Material/Methods: *29 female and 18 male adult subjects participated in the study. Each subject performed the following quadriceps contractions with each lower limb: concentric, isometric, eccentric and 30-sec. long maximal voluntary isometric contraction. 3 parameters were obtained in surface electromyography (SEMG): mean RMS amplitude (RMS), mean percentage value of maximal voluntary contraction (%MVC) and mean frequency (MF).*

Results: *RF occurred to have a lower percentage activity (-28.43%) and absolute amplitude (-36.57%) value than VM during all three basic forms of contraction against gravity. Except the RMS values for concentric contraction, all the mentioned parameters were significantly different. In contrast, RF had a higher MF rate than VM. Differences were at the mean level of 22.57% for all activities.*

Conclusions: *There are no differences in SEMG of quadriceps muscle between both lower limbs. VM and RF differ from each other in RMS, %MVC and MF during all types of studied contractions.*

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Introduction

The quadriceps femoris is a well known and often studied muscle. When it comes to evaluating its function, the most common method is dynamometric measurements [1] of a knee torque. A drawback of this method is that it estimates overall muscle activity upon this particular joint. It cannot be distinguished which part of the quadriceps is more active than another or if there occurred a pathological disbalance leading to osteoarthrotic changes [2].

One of the methods that cope with this issue is surface electromyography (SEMG). Currently there is more and more research on the quadriceps muscle using this method, especially in pathological conditions [3, 4, 5, 6] or to improve performance [7]. However, the nature of bioelectrical signals is still insufficiently understood even under normal conditions. Therefore the authors of this paper attempt to highlight the main differences in quadriceps femoris heads activity.

The aim of this study was to determie the differences in bioelectrical activity of vastus medialis and rectus femoris under various types of contraction among healthy subjects and also between the dominant and contralateral lower limb.

Material and methods

Participants

47 healthy young adults (23.4 ±1.5 years) participated in the study, 29 women and 18 men. 28 of them had domination of the left lower limb (based on kicking preference) and the for the remaining 19 it was the right limb. All participants were students who declared lack of any regular sport activity. The characteristics of the group are shown in Table 1. All of them gave their informed consent.

Table 1. Characteristics of the studied group

	Min	Max	Mean	Standard deviation
Age	20	28	23.42	1.46
Height	151	191	174.04	8.21
Weight	42	102	67.68	13.73
BMI	17.21	31.28	22.21	3.41

Measures

Two muscles were taken into consideration: vastus medialis (VM) and rectus femoris (RF). They were chosen because of their morphological and functional diversity [8, 9].

All SEMG measurements were performed on a resistance training chair. Each volunteer was sitting in a position in which their torso was leaned back and created an angle of ~90° with the thighs. The pelvis was stabilized with a strap belt. Shanks of the lower limbs loosely hanged down.

The participants' skin was prepared according to SENIAM organization [10] including hair shaving, abrasion and clearance with alcohol and electrode placement.

Two electrodes were applied on the RF muscle in half-distance between anterior spina iliaca superior and a superior edge of the patella, next 2 for VM were placed at 4/5 on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament. The reference electrode was applied to skin above the patella. The size of active area of each round–shaped Ag/AgCl electrode had 1 cm in diameter. The electrodes were produced by Sorimex (Poland).

Acquired electromyography signal was amplified, rectified and smoothed with Root Mean Square (RMS) by 50 ms window and normalized by MVC (300 ms window). All these operations were done by Noraxons MyoTrace 400 – 4-channel device and MyoResearch XP Master Edition software (USA). Parameters of the used EMG device are 20-500 Hz high and low pass filters, resolution of 16 bit and the 1000 sampling rate on each channel.

Procedure

Both quadriceps muscles were examined in a random order. The SEMG signals of the studied muscles were acquired during the following tasks:

- rest activity (5 sec.)
- concentric contraction against gravity (3 sec.)
- isometric contraction against gravity (3 sec.)
- eccentric contraction against gravity (3 sec.)
- maximal voluntary isometric contraction (30 sec.).

To better estimate muscle fatigue, the maximal voluntary isometric contraction (MVC) was divided into three 10-sec. consecutive time intervals: MVC1, MVC2, MCV3. The MVC was conducted for 60° of flexion because of its potential to develop maximal activity by both muscles [11, 12, 13].

From such prepared SEMG signal, the following parameters were taken into analysis: the mean percentage value of MVC (%MVC), the mean RMS value and the mean discharge frequency of motor units (MF).

Statistical analysis

Each variable was tested with Kolmogorov-Smirnov and Fisher-Snedecor tests to check a similarity to normal distribution and the homogeneity of variances respectively.

To find statistical significant differences in bioelectrical activity of the quadriceps muscle, the two-way ANOVA test was run. The following factors were considered: the lower limb (dominant, contralateral) and the muscle (vastus medialis, rectus femoris). All statistics were calculated with Statistica 10 softwere ver. 10.0.1011.7 by StatSoft Inc (USA).

Results

All SEMG measurements showed some significant differences between the studied muscles but none between the limbs.

Normalized Amplitude

The amplitude measurements normalized by MVC showed that during concentric, isometric and eccentric contractions RF was less active than VM, i.e. -1.1 pp (F = 5.8333, p = 0.017), -7.98 pp (F = 27.596, p = 0.0000) and -3.03 pp (F = 15.297, p = 0.0001), respectively.

In contrast to previous results, this parameter for MVC1 was significantly higher (3.7 pp, F = 5.1357, p = 0.0244) for RF. All normalized results are shown in Tab. 2.

Table 2. Mean values (SD) of mean percentage value of MVC of each muscle and limb during each activity

Muscle	Activity [%MVC]						
	Rest	Concentric contraction	Isometric contraction	Eccentric contraction	MVC1	MVC2	MVC3
Dom. VM	1.26 (1.12)^{a*}	6.09 (3.52)^{a}	20.69 (12.17)^{a}	9.68 (5.06)^{a}	68.02 (11.5)^{a}	71.68 (9.74)^{a}	73.97 (10.15)^{a}
Con. VM	1.48 (1.11)^{a}	5.83 (3.52)^{a}	22.42 (13.16)^{a}	10.7 (7.22)^{a}	68.39 (11.25)^{a}	72.87 (9.59)^{a}	72.98 (9.68)^{a}
Dom. RF	1.48 (1.03)^{a}	4.95 (3.0)^{b}	13.76 (7.65)^{b}	7.32 (4.61)^{b}	71.16 (11.77)^{b}	72.39 (8.44)^{a}	74.45 (8.99)^{a}
Con. RF	1.48 (0.87)^{a}	4.76 (2.35)^{b}	13.39 (6.88)^{b}	7 (3.78)^{b}	72.65 (10.89)^{b}	74.32 (8.12)^{a}	72.4 (7.32)^{a}

*Dom. – dominant, con. – contralateral, VM – vastus medialis, RF – rectus femoris. * Means in individual columns identified with the same letter did not differ significantly at p > 0.05.*

Absolute amplitude value

The RMS amplitude results resembled those normalized by MVC (Tab. 3). However, only isometric and eccentric contractions showed significant differences. The mean amplitude for RM was significantly lower than for VM in isometric (-40.7%, F = 31.311, p = 0.0000) and in eccentric (-32.43%, F = 17.865, p = 0.0004).

What is interesting, there was a tendency for 30. sec. MVC trail. For both dominant muscles (VM and RF), we observed a continuous increase in the RMS parameter during all the trail, whereas for contralateral muscles it reached its top value during the second 10. sec. interval (MVC2) and decreased in MVC3.

Table 3. Mean values (SD) of mean RMS value of each muscle and limb during each activity

Muscle	Activity [μV]						
	Rest	Concentric contraction	Isometric contraction	Eccentric contraction	MVC1	MVC2	MVC3
Dom. VM	2.11 (1.02)^{a*}	12.02 (7.23)^{a}	43.0 (28.79)^{a}	19.68 (3.21)^{a}	156.46 (97.31)^{a}	162.31 (92.1)^{a}	164.8 (89.12)^{a}
Con. VM	2.1 (0.7)^{a}	9.72 (5.21)^{a}	40.25 (23.02)^{a}	17.75 (9.83)^{a}	141.94 (92.43)^{a}	152.2 (97.22)^{a}	148.33 (89.56)^{a}
Dom. RF	2.39 (1.02)^{b}	8.49 (5.23)^{a}	24.6 (13.55)^{b}	12.74 (7.9)^{b}	155.07 (106.66)^{a}	160.38 (116.93)^{a}	162.5 (107.95)^{a}
Con. RF	2.36 (0.65)^{b}	9.47 (8.72)^{a}	24.77 (12.99)^{b}	12.55 (7.55)^{b}	163.06 (147.62)^{a}	164.73 (142.22)^{a}	158.82 (134.17)^{a}

Dom. – dominant, con. – contraleral, VM – vastus medialis, RF – rectus femoris. Means in individual columns identified with the same letter did not differ significantly at p > 0.05.*

Mean frequency discharges

In this particular parameter, we did not consider resting activity, because of its noise asynchronous discharges. In all other activities, there were significant differences between muscles but none between lower limbs. RF muscle proved to have a higher discharge rate than VM. For concentric, isometric and eccentric contractions of RF it was about 23% higher than for VM (F = 66.984, p = 0.0000; F = 105.84, p = 0.0000; F = 54.778, p = 0.0000 respectively). For MVC trial results were similar but the difference decreased gradually during the task from 27.8% (F = 120.36, p = 0.0000) in MVC1, through 20.6% (F = 65.108, p = 0.0000) in MVC2, down to 16.8% (F = 66.984, p = 0.0000). Moreover, the frequency of the RF muscle during the 30 sec. MVC trial decreased more than that of VM muscle. All the mentioned results are shown in Fig. 1.

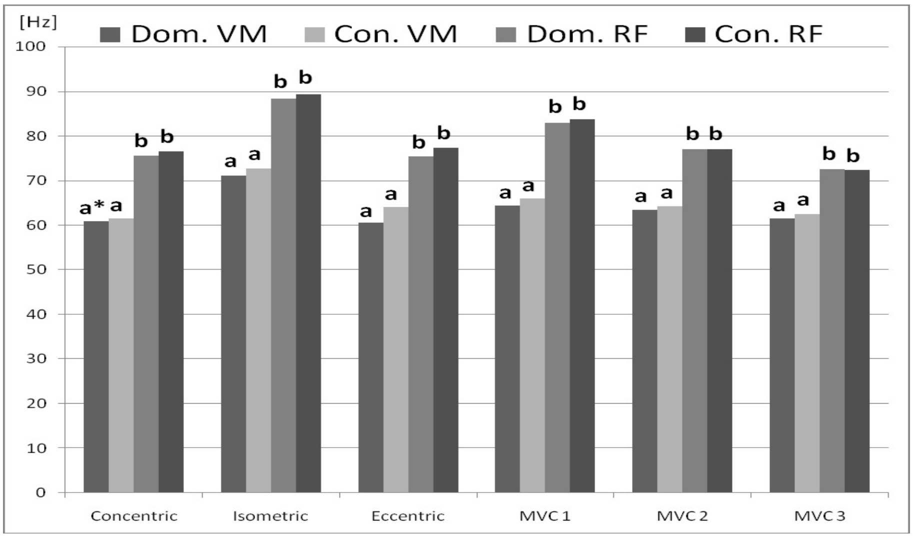

Fig. 1. Mean frequencies during each form of activity of vastus medialis and rectus femoris muscles of each limb
*Legend: Dom. – dominant, con. – contralateral, VM – vastus medialis, RF – rectus femoris. *Means in individual columns identified with the same letter did not differ significantly at p > 0.05*

Discussion

Main findings

Our study showed that there were no significant differences between the dominant and the contralateral lower limb in bioelectrical activity during isolated motor tasks. It agrees with recent study of Carpes et al. [14]. As is well known, RF and VM differ morphologically and functionally. In academic textbooks [15, 16], it says that the VM muscle consists of more fast twitch fibers than the slow ones, which gives the muscle mainly a phase function. Conversely, the RF muscle seems to have more slow twitch fibers and slow motor units than the fast ones.

According to our study and some other authors, the above statement cannot be regarded as true [17, 18, 19]. The frequency parameter in SEMG depends mainly on conduction velocity of motor units [20]. It means that fast twitch fibers have a higher discharge rate than slow ones. In our study, we achieved higher MF values for RF than for the VM muscle during each activity. This also explains why the reduction of MF was greater in RF than in VM.

Fatigue

For this study, a special 30-sec. MVC task was processed. These specific conditions of prolonged isometric contraction were chosen to determine the SEMG fatigue image of these two muscles. Such a kind of contraction could be performed only by healthy subjects without knee joint injuries or cardiovascular disorders. Górski et al. [21] described a similar condition of the quadriceps muscle during 30 secs., but in that cause, it was a contraction elicited by 50 Hz electric stimulation. Under this conditions, energy needed to complete the trial mainly came from phosphocreatine and glucose. Because of the isometric character of contraction, most of glucose undergoes anaerobic glycolysis. In such muscle work, muscle pump does not occur and some of the blood vessels are closed; therefore, it is impossible to supply substrates needed to produce energy from the external environment of muscle cell. In this case, the energy is produced by internal resources: the mentioned phosphocreatine and muscle glycogen. In consequence, the contraction is mainly made by fast twitch motor units.

During prolonged or repeated contractions, an increase in the amplitude and a decrease in the frequency can be observed in SEMG survey [19, 22, 23]. This phenomenon is caused by a reduction in the conduction velocity of motor units. Muscles, when they are greatly active, produce lactic acid, which increases acidity of the intracellular environment. This has a direct influence on the conduction velocity. However, the relation between conduction velocity and a decrease in MF is not commensurate. Therefore, it is likely that there are more conditions which determine this phenomenon [22].

One of them might be greater contribution in activity of slow motor units after fatigue of the fast ones. Other one is probably temporal synchronization of active motor units.

The mentioned before increase in the amplitude combined with the increase in MF was explained by De Luca in 1979 [22]. According to this scientist, the reason for this lies in a shift of the power spectrum in lower frequencies, which makes tissues between an electrode and the muscle to act as a low-pass filter. In consequence, electrodes receive much more value of signal.

Activation level

We achieved the highest activity of the quadriceps muscle during isometric contractions against gravity. Next one was eccentric and then concentric contractions. It was expressed by all three studied parameters (%MVC, RMS, MF). Results of isometric contraction are very similar to these achieved by Bowyer et al. [24]. He investigated that during straight leg rise of the dominant leg (with 3 sec. of quadriceps isometric contraction) the average activation level of vastus medialis oblique was at 20.3% for females and 24.7% for males. In our study it reached the mean level of 20.6% for both genders.

Beltman et al. [11] in their study investigated the activation pattern of the quadriceps muscle during each form of maximal contraction using Interpolation Twitch Technique (ITT). The author achieved significantly higher knee torque for lengthening and isometric than for shortening contractions, but none between the two first ones. The activation level looked different for maximal isometric and dynamic contractions (60°/sec.). Eccentric contraction reached the lowest activation ratio in comparison to others. It must be pointed that the author used a dynamometric method to evaluate the maximal activation, not SEMG. In such a case it is hard to compare it to our results.

As we can see, not many studies describe the bioelectrical activity of the quadriceps muscle among healthy subjects. It should be pointed that it is crucial to understand the mechanisms of non-pathological state, before we can measure and evaluate clinical cases.

Limitations

The main limitation of this particular study is lack of associated isokinetic measurements. We recommend further research including both methods to estimate a correlation between SEMG and torque.

Conclusions

The rectus femoris muscle has a higher mean frequency among healthy people during all forms of contractions against gravity and MVC than vastus medialis. There are no significant differences in bioelectrical activity of the quadriceps muscle between limbs in healthy adult subjects. None of the types of the quadriceps muscle contractions against gravity required more than 25% of MVC. Vastus medialis has higher amplitude parameters than rectus femoris during anti-gravity contractions.

Ethical approval

Study was conducted according to the declaration of Helsinki and with assent of the Bioethical Committee of Ludwik Rydygier Collegium Medicum in Bydgoszcz of Nicolaus Copernicus University of Toruń nr KB 417/2011.

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