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Reliability of Power Spectral Analysis of Surface Electromyogram Recorded during Sustained Vastus Medialis Isometric Contraction in Assessment of Muscle Fatigability

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Abstract

The aim of this study was to determine the within-day and between-days reliability of surface electromyographic (EMG) power spectral analysis in assessing fatigability of the vastus medialis (VM) muscle during knee and hip flexion under constant load application. The subjects were 13 healthy adult men free of knee abnormalities. Surface EMG was recorded from vastus medialis obliquus (VMO) and vastus medialis longus (VML) during sustained isometric contractions at 60% of maximal voluntary contraction until exhaustion on the leg press machine (static leg press test). Linear regression analysis was applied to median frequency (MF) time series to calculate initial MF and MF slope. For VMO and VML, the initial MF showed moderate to high reliability, while the MF slope showed high reliability (Intraclass correlation coefficient (ICC) = initial MF: 0.63 - 0.92, MF slope: 0.70 - 0.86). The results demonstrated that spectral analysis of surface EMG recording during isometric VM muscle contraction has high within-day and between-days reliability in the assessment of fatigability of the VMO and VML.

Keywords

Vastus Medialis Oblique, Vastus Medialis Long, Muscle Fatigue, Electromyography, Isometric Contraction

1. Introduction

The strength of the quadriceps muscle correlates with locomotor function in patients with osteoarthritis of the knee [1] [2]. Among the quadriceps muscles, the VM muscle is the major contributor to the stabilization and protection of the knee joint [3], and has been used as representative muscle of the quadriceps in investigations on muscle atrophy [4]. There are two components of VM; VMO and VML [5]. The VML, the proximal part of VM, inserts into the base of the patella, while the VMO, the distal part of the VM, originates mainly from the adductor magnus tendon and inserts at the medial margin of the patella. The quadriceps muscle becomes weak after injury to and reconstruction of the anterior cruciate ligament [6] [7] [8] [9], and weakness after the latter is associated with fatigue resistance [10].

The use of EMG power spectral analysis has demonstrated that muscle fatigue is associated with a shift in the MF toward lower values [11] [12] [13]. EMG power spectral analysis is also sometimes combined with histochemical analysis to determine muscle fiber type [14]. For example, Kupa *et al.* [14] reported that muscles with high percentages of fast glycolytic and fast oxidative glycolytic fibers exhibited greater MF initial value as well as greater reduction in MF over the course of contraction than those with higher concentrations of type I muscle fibers. Thus, EMG spectral parameters correlate with muscle fiber composition, and changes in MF have also been used as the marker of local muscle fatigability.

The unsupported trunk holding test (also known as "Sørensen back endurance test"), combined with EMG power spectral analysis, is a reliable method to measure the fatigue rate of back muscles [15]; the MF slope recorded during the test correlates significantly with the relative area of type I muscle fibers [16]. Recent studies described the relationships between age and sex with EMG power spectral analysis of back muscles during the trunk holding test [17] [18].

Previous studies used the dynamometer system (watching the dynamometer values) to measure the fatigability of the quadriceps muscle and reported either low [19] [20] [21] or moderate [22] [23] reliability of the MF slope. These results are probably related to the inappropriate application of constant load to the quadriceps during the dynamometer task load. It is desirable to apply a constant load to the quadriceps in the leg position holding task, similar to the trunk holding test, for accurate assessment of muscle fatigability. To our knowledge, there is no highly reliable method to measure the fatigability of VM. We assumed that an important factor in assessing the reliability of surface EMG power frequency analysis is to sustain posture, like in the trunk holding test. The aim of this study was to examine the within-day and between-days reliability of surface EMG power spectral analysis of the quadriceps during sustained quadriceps muscle isometric contraction, in the assessment of VM muscle fatigability.

2. Methods

2.1. Subjects

Thirteen healthy adult men participated in the present study. None of the subjects had history of knee symptoms and all were healthy at the time of the study. Subjects were asked to refrain from vigorous physical activity on the day before and the day of testing to avoid the effects of cumulative muscle fatigue. The study was approved by the Human Ethics Committee of Wakayama Medical University, and a written informed consent was obtained from each subject before participation.

2.2. Task Application

Knee extensor muscle strength was measured with the leg press machine (gym80, SYGNUM, Gelsenkirchen, Germany). After resting for 15 minutes in the sitting position, the subject was seated with right hip and knee flexion at 90˚ on the leg press machine (**Figure 1**). The largest load that the subject could maintain with the knee at 90˚ flexion for 5 sec was defined as maximal voluntary contraction (MVC). The leg press machine was fixed to apply 60% of MVC with the right hip and knee at 90˚ flexion. After resting for 15 minutes in the sitting position, the subject was instructed to press and sustain an isometric contraction leg press as long as possible (static leg press test; **Figure 1**). The test was terminated when the subject could no longer maintain the knee at 90˚ flexion (defined as >90˚ flexion for 5 sec) despite strong verbal encouragement. The endurance time was recorded using a stopwatch and was taken as an indicator of knee extensors isometric endurance.

2.3. EMG Signal Recording and Analysis

The EMG activity was monitored during the static leg press test. Before attaching the electrodes, the area chosen for electrode placement was prepared by shaving (when appropriate) and cleaned with an alcohol swab. For this purpose,

Figure 1. Photo showing body position during MVC and the static leg press test. The subject was asked to maintain 90˚ flexion of the hip and knee and perform leg press on the wall plate, achieving persistent pushing power.

two 10-mm silver-silver chloride surface electrodes were placed 2 cm apart over VMO and VML. The active electrodes were placed over the VML based on SENIAM recommendations [24]; electrode placement on the VMO was at a distance of approximately 50 mm from the superior medial side of the patella along a line inclined to 50˚ with respect to the anterior superior iliac spine [25]. The inter-electrode axis of the electrodes was aligned with the assumed direction of muscle fibers. The signal was bandpass filtered (20 - 500 Hz), amplified using MQ 16 (Marq-Medical of Denmark, Farum, Denmark), digitized using an A/D converter/Vital Recorder2 (Kissei Comtec, Nagano, Japan) and stored on a computer at 2000 Hz sampling rate. The MF indices were derived from the raw EMG signal as described above and plotted against time during the test using the Kinema Tracer Fast Fourier Transform spectrum analysis program (Kissei Comtec). Linear regression analysis was applied to the MF time series (MF as a function of time) to calculate the initial MF and MF slope. In a preliminary study, we confirmed that MF derived from the two muscles decreased linearly with the test time (**Figure 2**).

Thus, assessment of fatigability of knee extensor muscles during the leg load press test was evaluated using the above technique.

2.4. Assessment of Reliability

The study was an inter-rater reliability study. The within-day assessment consisted of two repetitions of the test package separated by an interval of 90 min. The between-days assessment included performing the leg press load test after 7 days from the first test. Tests within the same day were completed with one electrode set, while the electrodes were replaced in the between-days tests.

2.5. Statistical Analysis

Data were expressed as mean ± standard deviation (SD). ICC (1, 2) was used to express relative reliability of the measures [26]. ICC expresses the ratio of between-subject variance to within-subject variance and is a unitless value [26].

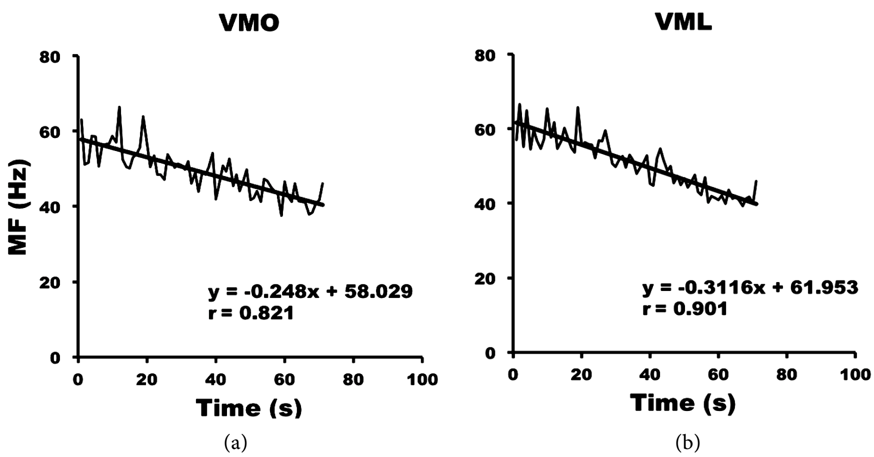

Figure 2. Changes in MF in the VMO (a) and VML (b). In a preliminary study, the MF derived from these muscles was shown to decrease linearly with test time. P < 0.05.

Munro's descriptors of reliability coefficients were used to describe the degree of reliability: 0.00 to 0.25—little, if any correlation; 0.26 to 0.49—low correlation; 0.50 to 0.69—moderate correlation; 0.70 to 0.89—high correlation and 0.90 to 1.00—very high correlation [27].

Standard error of the measurement (SEM) was used to express absolute reliability of the measure [28]. SEM was calculated from the square root of the error variance (*i.e.*, mean of standard deviations from within-day and between-days) and has the same unit as the tested variable. Smaller SEM values reflect more reliable measures [28]. The SEM was also expressed as percent of the mean value for the measure to allow comparison of absolute reliability between measurements (SEM/mean × 100%).

Before analyzing the correlation between MVC or initial MF and MF slopes, the normality of the data was checked using the Shapiro-Wilk test. A p value <0.05 denoted the presence of statistically significant difference. Statistical analysis was performed using the Statistical Package for Social Sciences software, version 23.0, for Windows (SPSS Inc., Chicago, IL).

3. Results

Characteristic of age was 25.6 ± 2.7 years, height was174.7 ± 5.7 cm, body weight was 68.7 ± 7.2 kg, and body mass index was 22.5 ± 2.4 kg/m^2 (**Table 1**).

All subjects completed three test sessions. The MVC was 91.1 ± 14.5 at the first time, 90.2 ± 14.2 at the second session, and 89.9 ± 14.1 at the third session. The endurance time, initial MF and MF slope recorded in these three sessions are listed in **Table 2**. **Table 3** shows within-day and between-days reliabilities of all measurements. Both within-day and between-days reliabilities of the

Table 1. Anthropometric characteristics of the subjects.

	Age (year)	Height (cm)	Body weight (kg)	Body mass index (kg/cm^2)
Male (n = 13), mean ± SD	25.6 ± 2.7	174.7 ± 5.7	68.7 ± 7.2	22.5 ± 2.4

Table 2. Mean data of the MVC, endurance time, initial MF and MF slope recorded at the three sessions.

	First session	Second session	Third session
MVC (kg)	91.1 ± 14.5	90.2 ± 14.2	89.9 ± 14.1
Endurance Time (sec)	54.8 ± 10.0	56.1 ± 9.4	60.6 ± 13.7
Initial MF (Hz)			
VMO	61.3 ± 10.0	61.7 ± 9.1	67.1 ± 12.9
VML	68.7 ± 11.0	66.1 ± 10.4	69.6 ± 9.8
MF slope (Hz/sec)			
VMO	−0.374 ± 0.119	−0.351 ± 0.119	−0.398 ± 0.159
VML	−0.415 ± 0.210	−0.316 ± 0.184	−0.383 ± 0.163

Data are mean ± SD.

Table 3. Within-day and between-days reliabilities of MVC, endurance time, initial MF and MF slope.

	Within-day		Between-days	
	ICC (95% CI)	SEM (%)	ICC (95% CI)	SEM (%)
MVC (kg)	0.96 (0.92 - 0.96)	0.89 (96.0%)	0.96 (0.88 - 0.99)	1.10 (89.3%)
Endurance time (sec)	0.70 (0.27 - 0.90)	2.10 (170%)	0.70 (0.22 - 0.90)	2.29 (39.7%)
Initial MF (Hz)				
VMO	0.88 (0.66 - 0.96)	1.32 (315.7%)	0.63 (0.15 - 0.87)	2.51 (43.3%)
VML	0.92 (0.69 - 0.98)	1.01 (38.7%)	0.92 (0.77 - 0.96)	1.17 (128.1%)
MF slope (Hz/sec)				
VMO	0.86 (0.67 - 0.96)	0.015 (66.7%)	0.70 (0.28 - 0.90)	0.03 (124.0%)
VML	0.78 (0.20 - 0.94)	0.029 (29.5%)	0.82 (0.53 - 0.94)	0.03 (96.3%)

Data are mean ± SD.

MVC were 0.96, categorized into "very high correlation", with limited 95% CI values, suggesting high accuracy of our measurements. However, both reliabilities of endurance time were not that high, 0.70, and the 95% CIs were broader than those of MVC, though still categorized as "high correlation". On the other hand, the reliabilities of the initial MF and MF slope indicated mostly high or very high correlations. For VML, both within-day and between-days reliabilities of the initial MF and MF slope were categorized as "high or very high". For the VMO, within-day reliabilities were also categorized as "high", though the between-days reliabilities were less than high; 0.63 (moderate) for the initial MF and 0.70 (high) for the MF slope, and the 95% CIs were broader than those of the VML.

4. Discussion

The main finding of this study was the reliability of the within-day and between-days of MF and MF slope surface parameters of EMG power spectral analysis derived from the VMO and VML and recorded during the leg load press test. The results suggest that EMG power spectral analysis of the VM muscle during the leg load press test is highly reliable method for assessment of VM muscle fatigability.

The present study demonstrated significant reliability of the initial MF and MF slope of the VMO and VML in the assessment of VM muscle fatigability; the main reason was probably related to the use of larger submaximal loads for the quadriceps compared with those applied in previous studies [19] [20] [21] [22] [23]. The present study did not use a visual biofeedback system; the subjects performed a simple task designed to keep the leg at identical position and the subjects managed to achieve quadriceps muscle isometric contraction. EMG power spectral analysis during sustained quadriceps muscle isometric contraction should be one of the most important techniques, and thus the present study demonstrated the high reliability of the MF slope of the VMO and VML.

With regard to the relevance of the parameters of the EMG power spectral analysis, previous studies suggested that the MF slope during fatigue reflects the changes in action potential propagation of individual muscle fibers, which is the result of the associated accumulation of metabolic by-products (lactate and extracellular K+) [29] [30]. EMG power spectral analysis is sometimes combined with histochemical analysis to determine the muscle fiber type. In particular, muscles with larger percentages of fast glycolytic and fast oxidative glycolytic fibers exhibit more rapid reduction of MF over the course of contraction than those with higher concentrations of type I muscle fibers. Kupa *et al.* [14] indicated that these properties allow the use of surface EMG techniques to obtain noninvasive electrophysiological "muscle biopsy" and to estimate muscle fiber composition. Changes in MF have also been used as a marker of local muscle fatigability; the MF slopes of the VMO and VML continually decreased during isometric contraction.

One limitations of this study is a small sample size. Future studies should examine whether the pattern of results observed here are found with a larger sample, based on a priori sample size calculations. Another limitation of this study is examined only healthy adult men. In future, also the reliability of VM muscle fatigability is needed for women.

5. Conclusion

Surface EMG recording and power spectral analysis during sustained quadriceps muscle isometric contraction showed high within-day and between-days reliability in the assessment of fatigability of the VMO and VML.

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