Preliminary evaluation of mechanomyographic signal of rectus femoris muscle between spinal cord injured and healthy subjects

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Abstract

Mechanomyography (MMG) is a practical alternative to monitor muscle contraction during FES application aiming to restore functional movements. This paper describes a preliminary study to evaluate the difference between the rectus femoris muscle MMG response of a healthy volunteer (HV) and a spinal cord injured volunteer (SC), during FES application, and to determine a correlation between the temporal and spectral MMG features. The test was performed with bipolar monophasic square wave, pulse active period of 100 μs and frequency of 1 kHz, and burst active interval of 3 ms with frequency set to 50 Hz applied to the femoral nerve to stimulate quadriceps muscle. The MMG sensor was placed on the rectus femoris muscle belly. Temporal (RMS) and spectral (MF) MMG features were used. Non-parametric statistics were used to evaluate the differences between the volunteers and the correlations between the MMG features. The results showed that RMS and MF are inversely related over the time during FES application, with ρ= -0.426 to SC and ρ= -0.579 to HV. The preliminary findings indicate that HV and SC MMG features are similar in response, what is important to be employed in closed loop systems with FES.

***Keywords**: Functional Electrical Stimulation, Mechanomyography, Rehabilitation.*

Introduction

Mechanomyography (MMG) technique allows the measurement of oscillations in muscular tissue using up to three axis to provide vibrational information [1, 2]. Functional electrical stimulation (FES) can generate functional movements when applied to people with spinal cord injury [3, 4] as well as to healthy people. During FES application, the electrical pulses can create interference over electromyography (EMG) signals due to circuit limitations [5]. MMG is not directly affected by FES, because the former registers mechanical oscillations of muscles under contraction in spite of the electrical pulses generated by FES.

This paper describes a preliminary approach to evaluate the difference between the *rectus femoris* muscle MMG response of a healthy subject (HV) and an SCI one (SC) during FES application, and to determine the correlation between temporal and spectral MMG features.

Material and Methods

This study was approved by PUC human research ethics committee under register 2416/08. Two volunteers participated in the study: a HV and a T8 SC. The FES stimulus waveform was a bipolar monophasic square wave with parameters adjusted to (1) pulse active period of 100 μs and frequency of 1 kHz, and (2) burst active period of 3 ms, and a frequency of 50 Hz. After trichotomy and skin cleaning, self-adhesive electrodes (5x9 cm) were positioned over the knee region (anode) and over femoral triangle (cathode) in order to stimulate the quadriceps muscle. The MMG sensor was positioned over the belly of *rectus femoris* muscle and a custom electrogoniometer placed laterally to the knee to acquire the knee angle.

The developed MMG sensors used Freescale MMA7260Q MEMS triaxial accelerometers with high sensitivity 800 mV/G at 1.5 G (G, gravitational acceleration). Electronic circuits allowed 10x amplification and 4-40 Hz Butterworth filtering (third order). A LabVIEW™ program was coded to acquire MMG signals. All signals and volunteer data were saved into European Data Format (EDF) files. The data acquisition board was a Data Translation™ DT300 series with 1 kHz sample rate. The *rectus femoris* muscle is bipenate [6] and so, during contraction, fibers displacement occurs in at least two directions. Therefore, modulus signal was obtained from the three individual MMG sensor axes.

The volunteer was seated on an adapted chair with the hip and knee angles set to 70º [7] and 90º, respectively. The maximum knee extension was

defined as 0º. The stimulus amplitude (peak value) employed in the protocol allowed to raise the knee from 90º of flexion to 40º (HV: 90 V and SC: 156 V). After determining this amplitude, a 5 min rest interval was respected before beginning the acquisition. FES started with Rise and Plateau values of 5 s and 15 s, respectively. The total time was 20 s, however only 16 s was considered for signal analysis that started when knee angle was lower than 65º. The analysis window length (AWL) was 1 s [8], and for each AWL two MMG features were computed: temporal root mean square (RMS) [9] and spectral median frequency (MF) [10, 11].

Wilcoxon signed ranks test was used for statistical analysis in order to check the differences between the two volunteers and Spearman correlation coefficients were investigated to check the relation between features of each volunteer. Data were normalized by maximum value during the 16 s of artificial contraction to each MMG feature.

Results

Fig. 1 shows the behaviour of MMG modulus (RMS and MF) of HV and SC during the protocol. Wilcoxon signed ranks test showed that to RMS, values were greater to SC; however, to MF, the greater values occurred with HV, where p= 0.008 to RMS and p= 0.023 to MF. Table 1 shows the mean values and that signals showed moderate negative correlation to SC (ρ= -0.426) and HV (ρ= -0.579). Only the HV presented statistical significance in Spearman coefficient ($p < 0.05$).

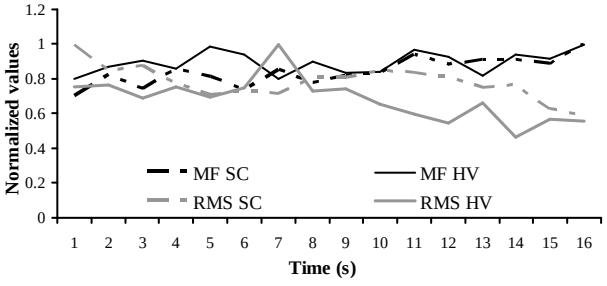

Fig. 1: Normalized values (RMS and MF) of HV and SC.

Table 1: Mean and standard deviation of normalized values (RMS and MF) for HV and SC, and correlation coefficient.

Vol	RMS	MF	ρ
SC	0.78±0.09	0.84±0.07	-0.426
HV	0.68±0.12	0.89±0.06	-0.579*

Vol: Volunteer; SC: spinal cord injured volunteer; HV: healthy volunteer; *: statistical significant ($p < 0.05$); ρ: Spearman's coefficient.

Discussion

Due to voluntary contraction inactivation, SC denoted a reduction in muscular trophism and in the production of slow fibers, changing the proportion between slow and fast type muscle fibers, leading to a decrease in power production [12]. Only the capacity of force generation can be controlled individually with tension, whereas the change in the proportion of fibers can not be controlled. Thus, the RMS and MF data presented in Fig. 1 and Table 1 can have pointed out that event, due to the reduction in the amplitude of RMS data over time be related to the decrement of force [13] or by the decrease in motor unit recruitment [14].

MMG spectral feature MF may provide information regarding motor unit firing rate [15]. The increase of MF over the time showed in Fig. 1, to both HV and SC, can be due to the motoneuron increasing its firing rate to sustain the muscular torque. Since the duration of FES application was only 20 s, and the lactate was not measured (technical limitation), affirming that these effects followed muscle fatigue lacks evidence support.

Conclusions

Considering the results, the motor unit recruitment strategies of contracting muscles of a healthy and a spinal cord injured volunteers involved in this study were different. The histological changes in the muscle tissue of subjects with spinal cord injury are factors of great importance in this difference, in addition to muscle atrophy due to inactivity. The responses of mechanomyographic features were inversely related. The artificial contraction by FES was short, only 20 s, without triggering muscular fatigue.

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