Mechanomyography signal relationship between time x frequency domain using FES application: preliminary results

Scheeren, E.M.[1]; Krueger E[1]; Nogueira-Neto, G.N.[2,3]; Button, V.L.S.[2]; Nohama, P.[1,3]

[1] UTFPR1, Curitiba/PR, Brazil

[2] UNICAMP2, Campinas/SP, Brazil

[3] PUCPR3, Curitiba/PR, Brazil

Abstract

The goal of this study is to investigate the relationship of the time x frequency domain for a spinal cord-injured volunteer (SCIV) and a healthy volunteer (HV). The test was performed with one HV and one SCIV with bipolar monophasic square wave, pulse active period of 100μs and frequency of 1kHz, and burst active interval of 3ms with frequency set to 50Hz applied to the femoral nerve. The MMG sensor was placed on the belly of rectus femoris muscle and RMS and MF MMG features of the three axes (X, Y and Z) were plotted using linear regression so as to find the relation between them during the protocol. The normalized RMS values of SCIV were greater than HV data and this is related to FES stimuli amplitude applied to SCIV. The slope of the MMG signal presented a different behavior what suggests difference between the volunteers. The slope was steeper for SCIV than HV, probably due to the fast lower power contraction ability and the motor unit recruitment decrease. The preliminary results show that MMG signal can distinguish muscle fiber type of HV and SCIV.

***Keywords**: FES, mechanomyography, spinal cord injury*

Introduction

Mechanomyography (MMG) is used for measuring muscle oscillations [1]. The MMG signal can be analyzed both in temporal and spectral domain [2]. By functional electrical stimulation (FES) it is possible to generate muscle movement [3], in a spinal cord-injured volunteer (SCIV) as well as in healthy volunteer (HV).

The literature suggests that subjects with SCIV suffer reduction in the trophism and decrease in the production of slow muscle fibers due to the voluntary contraction inactivation [4-5]. These factors contribute to the decrease of force production ability [6]. The aim of this study is to investigate the relationship of the time x frequency domain for a SCIV and a HV.

Material and Methods

Subjects

The study was approved by PUCPR human research ethics committee (No. 2416/08). The test was performed with one HV and one SCIV (complete injury level T8).

Electrical stimulation

FES was applied in the rectus femoris muscle of both volunteers (bipolar monophasic square wave, pulse active period of 100μs [7-8] and frequency of 1kHz, and burst active interval of 3ms [9] with frequency set to 50Hz). Self-adhesive stimulation electrodes (5x9cm) were placed in supra-patellar and the femoral triangle regions.

General procedures

An electrogoniometer was used in the acquisition of the knee angle. MMG sensor was placed with double-face tape on the muscle belly. The MMG sensor was built with a high sensitivity Freescale MMA7260Q triaxial accelerometer (800mV/G at 1,5G; G, gravitational acceleration) and placed on the belly of the rectus femoris. Electronic circuits allowed 10x amplification and 4-40Hz band-pass filtering (3rd order Butterworth), focusing the MMG spectral content (Silva and Chau) [10]. A LabVIEW™ program was coded to acquire MMG signals. All signals and volunteers data were saved into European Data Format (EDF) files. The data acquisition board was a Data Translation™ DT300 series with 1kHz sampling rate. Volunteers were positioned on an adapted bench (70° hip and 90° knee angles; 0º was the maximum extension angle). The stimulus amplitude employed in the protocol allowed raising the knee from 90º to 40º of flexion (HV: 90V e SCIV: 156V). After a rest period of 5min, a single repetition was performed using FES (5s rise and 15s plateau). For MMG analysis, 1s windows were measured and root mean square (RMS) and median frequency (MF) parameters were calculated, respectively, in time and frequency domains. The RMS and MF values of the three axes (X, Y and Z) were plotted in the Cartesian plane. A regression line was obtained to relate the behavior of one variable to another.

Results

Fig. 1A shows the regression lines of the MF and RMS values of the three axes (X, Y and Z) for SCIV and HV and Fig. 1B shows MMG sensor's axes orientation drawl. Table1 shows the equation slopes of regression lines and their correlation coefficients.

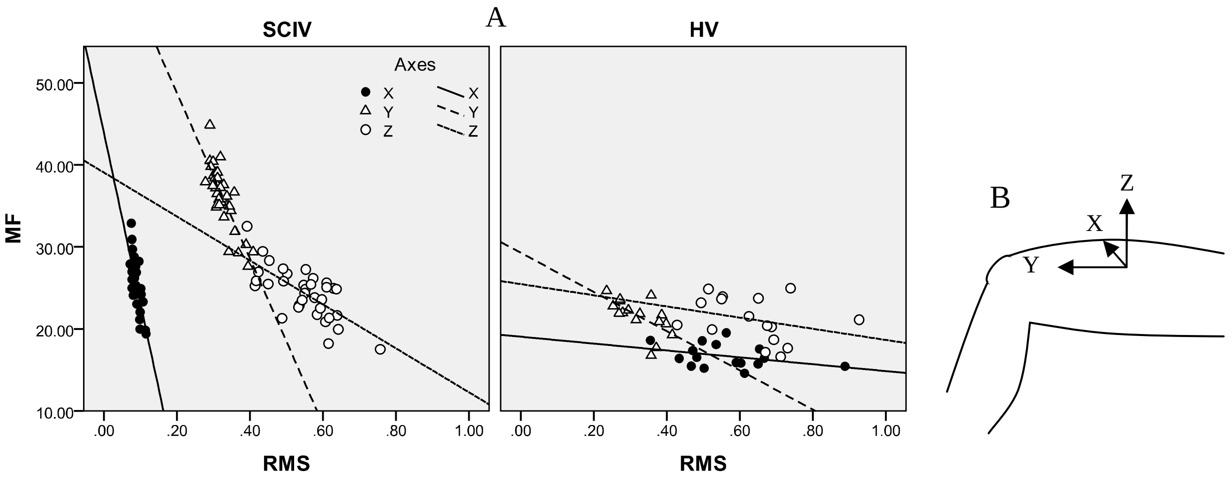

Fig. 1: (A) Regression lines estimated from X, Y, and Z MMG RMS and MF data of SCIV and HV; (B) MMG sensor's axes orientation.

Table 1: Slope and correlation coefficients of X, Y and Z axes and angle linear regression (RMS x MF)

	Slope			Correlation coefficient		
	X	Y	Z	X	Y	Z
SCI	-0.99	-1.23	-1.38	0.73	0.81	0.75
HI	-0.14	-0.32	-0.35	0.47	0.80	0.67

SCIV – Spinal cord-injured volunteer; HV – healthy volunteer

Discussion

The comparison between the two volunteers revealed that the RMS values of SCIV were greater than HV data, which could be related to the amplitude of the FES applied to SCIV due to the atrophy and reduction in types I and II fibers [11].

The coefficients shown in Table 1 indicate a strong correlation (R >0.7) for SCIV (axes X, Y and Z) and moderate (X and Z axes) and strong (axis Y) for HV volunteers. The slope suggests a different behavior of the MMG signal between the two volunteers. The slope was steeper for SCIV than HV, suggesting fast lower power contraction ability, firing rate and motor unit recruitment decrease. Probably, in addition to the SCIV voluntary muscle contraction inactivity, the MMG signal diverse behavior would be related to cross-bridges dynamic differences and to the Ca^{++} transient [12]. The differences in the slope between HV and SCIV (Table 1) can be associated with the decrease in the slow muscle fibers for SCIV [4-5]. It is indicating the MMG capability to distinguish the fiber muscle type.

Conclusions

Evidences suggest changes in muscle fibers recruitment pattern between the volunteers and that MMG signal can distinguish the type of muscle fiber of HV and SCIV. The results from studies with HV cannot be extrapolated to the SCIV population due the fiber type pattern, thus requiring specific studies of FES applied to SCIV.

References

[1] Ohta Y, Shima N, Yabe K. In vivo behaviour of human muscle architecture and mechanomyographic response using the interpolated twitch technique. J Electromyogr Kinesiol, 19(3): e154-e61. 2009.

[2] Al-Zahrani E, Gunasekaran C, Callaghan M, et al. Within-day and between-days reliability of quadriceps isometric muscle fatigue using mechanomyography on healthy subjects. Journal of Electromyography and Kinesiology, 19(4): 695-703. 2009.

[3] Seki K, Ogura T, Sato M, et al. Changes of the evoked mechanomyogram during electrical stimulation. Annual Conference of the International Functional Electrical Stimulation Society; 2003; Brisbane; 2003.

[4] Burnham R, Martin T, Stein R, et al. Skeletal muscle fibre type transformation following spinal cord injury. Spinal Cord, 35(2): 86-91. 1997.
[5] Talmadge R, Castro M, Apple D, et al. Phenotypic adaptations in human muscle fibers 6 and 24 wk after spinal cord injury. Journal of Applied Physiology, 92(1): 147. 2002.
[6] Andersen JL, Gruschy-Knudsen T, Sandri C, et al. Bed rest increases the amount of mismatched fibers in human skeletal muscle. J Appl Physiol, 86(2): 455-60. 1999.
[7] Fujita K, Handa Y, Hoshimiya N, et al. Stimulus adjustment protocol for FES-induced standing in paraplegiausing percutaneous intramuscular electrodes. IEEE Trans Rehabil Eng, 3(4): 360-6. 1995.
[8] Jezernik S, Wassink RGV, Keller T. Sliding mode closed-loop control of FES: controlling the shank movement. IEEE Trans Biomed Eng, 51(2): 263-72. 2004.
[9] Scheeren EM, Nogueira-Neto GN, Krueger-Beck E, et al. Investigation of muscle behavior during different functional electrical stimulation profiles using mechanomyography. 32nd Annual International Conference of the IEEE EMBS; 2010; Buenos Aires Sheraton Hotel, Buenos Aires; 2010. p. 3970-3.
[10] Silva J, Chau T, Naumann S, et al. Systematic characterisation of silicon-embedded accelerometers for mechanomyography. Medical & Biological Engineering & Computing, 41(3): 290-5. 2003.
[11] Lotta S, Scelsi R, Alfonsi E, et al. Morphometric and neurophysiological analysis of skeletal muscle in paraplegic patients with traumatic cord lesion. Spinal Cord, 29(4): 247-52. 1991.
[12] Gobbo M, Cè E, Diemont B, et al. Torque and surface mechanomyogram parallel reduction during fatiguing stimulation in human muscles. Eur J Appl Physiol, 97(1): 9-15. 2006.

Acknowledgements

The authors would like to thank CAPES, FINEP and CNPQ.

Author's Address

Eduardo Mendonça Scheeren
UTFPR
escheeren@gmail.com