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The image of motor units architecture in the mechanomyographic signal during the single motor unit contraction: *in vivo* and simulation study

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Abstract

The mechanomyographic (MMG) signal analysis has been performed during single motor unit (MU) contractions of the rat medial gastrocnemius muscle. The MMG has been recorded as a muscle surface displacement by using a laser distance sensor. The profiles of the MMG signal let to categorize these signals for particular MUs into three classes. Class MMG-P (positive) comprises MUs with the MMG signal similar to the force signal profile, where the distance between the muscle surface and the laser sensor increases with the force increase. The class MMG-N (negative) has also the MMG profile similar to the force profile, however the MMG is inverted in comparison to the force signal and the distance measured by using laser sensor decreases with the force increase. The third class MMG-M (mixed) characterize the MMG which initially increases with the force increases and when the force exceeds some level it starts to decrease towards the negative values. The semi-pennate muscle model has been proposed, enabling estimation of the MMG generated by a single MU depending on its localization. The analysis have shown that in the semi-pennate muscle the localization of the MU and the relative position of the laser distance sensor determine the MMG profile and amplitude. Thus, proposed classification of the MMG recordings is not related to the physiological types of MUs, but only to the MU localization and mentioned sensor position. When the distance sensor is located over the middle of the muscle belly, a part of the muscle fibers have endings near the location of the sensor beam. For the MU MMG of class MMG-N the deflection of the muscle surface proximal to the sensor mainly influences the MMG recording, whereas for the MU MMG class MMG-P, it is mainly the distal muscle surface deformation. For the MU MMG of MMG-M type the effects of deformation within the proximal and distal muscle surfaces overlap. The model has been verified with experimental recordings, and its responses are consistent and adequate in comparison to the experimental data.

Keywords: Motor unit architecture; Evoked contraction; Mechanomyogram; Muscle model; Computer simulation

1. Introduction

Several studies have shown that MMG signal properties depend on the muscle contraction force (Orizio et al., 1999), the muscle length (Weir et al., 2000) and the muscle fatigue level (Bichler and Celichowski, 2001). The observations mentioned above, suggest that the MMG reflects changes of the motor units (MUs) activity. Moreover, majority of authors believe that the MMG is generated as a result of the transversal deformation of the muscle surface. Such an effect has been observed during the whole muscle contraction experiments by using laser distance sensors (Orizio et al., 2003), accelerometers (Madeleine et al., 2006) and microphones (Jaskólska et al., 2007). The MMG signals are available as well recorded during a single motor unit (MU) contraction (Bichler and Celichowski, 2001). This let to consider the hypothesis that the MMG, which

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is caused by the transversal deformation of the muscle surface, is generated also due to the muscle pennation. Hence, the MU contraction force generates deflection in the transversal direction, whereas the main part of the contraction force is directed in the longitudinal axis as it was shown in Fig. 1A. This remark has been partially supported already by the results obtained with the membrane model of the muscle presented in our previous paper (Kaczmarek et al., 2005).

The morphological and electrophysiological experiments have revealed that a single MU occupies restricted territory on the cross-section of the muscle (Bodine-Fowler et al., 1990; Kernell et al., 1995; Kanda and Hashizume, 1992). The MU territory size depends on numerous factors including the MU type, and the location of this territory is variable for different MUs. The laser sensor applied for MMG studies creates a possibility to observe changes of the distance between a single point on the muscle surface and the sensor. Hence, it can be claimed that the muscle transversal deformation measured in a single point would depend on the relative MU location with a respect to the sensor position. The MMG signal generated during a single MU contraction should display a positive phase in a case, when the laser distance sensor records muscle surface displacement generated by the movement of the MU proximal connection (PC) point and a negative phase, when the sensor records the displacement evoked by the movement of the MU distal connection (DC) point (Fig. 1A). The PC point is the MU connection to the surface proximal to the laser sensor, the DC point is the MU connection to the distal part of the muscle surface.

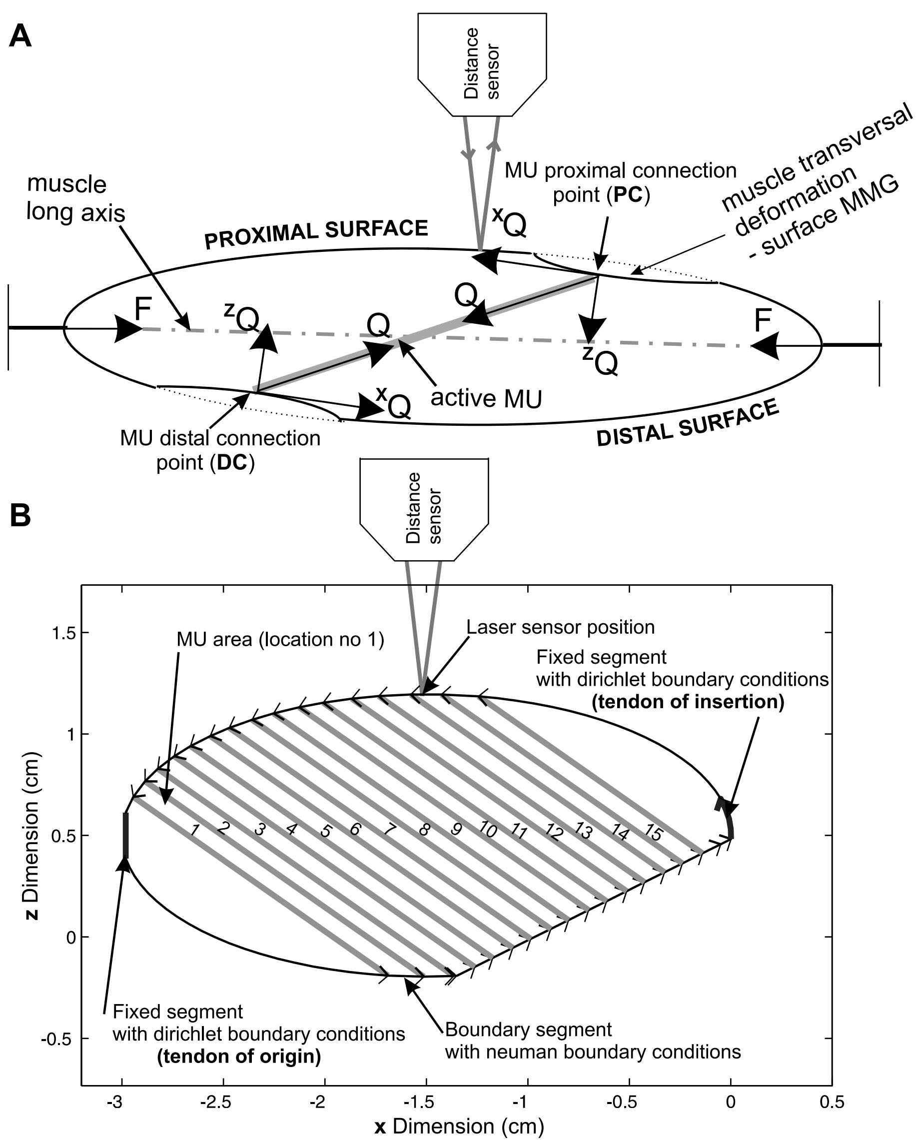

Fig. 1. The MMG generation idea (A) and the longitudinal cross-section model of the MG muscle (B) with 15 MUs areas. The fixed segments denote the location of the tendon of origin and the tendon of insertion. The MU territory covers the area between two neighboring gray lines. The PC point is the MU connection to the surface proximal to the laser sensor and the DC is the MU connection to the distal part of the muscle surface.