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Correlating motor unit morphology with bioelectrical activity – A simulation study ☆

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HIGHLIGHTS

- Extending the amount of information available from EMG examinations.
- Improving the understanding how motor unit structure correlates with motor unit potential recordings.
- Indicating the origin of atypical motor unit potentials.

ABSTRACT

Objectives: The aim was to determine motor unit morphology underpinning the various MUP waveforms using MUP analysis.
Method: The simulation method is based on the decomposition of MUP into single fiber potentials. Number of fibers, fiber diameters and fiber to electrode distances were determined. The impact of each muscle fiber on the MUP waveform was determined and quantified by its percentage contribution.
Results: The origin of the four examined MUPs of distinct waveforms have been explained by showing the histograms of fiber diameters and their distance to the electrode. In the case of a low amplitude MUP it was found that it originated from fibers of smaller than normal diameters with no dominant fiber. In another case of a MUP of short duration its shape was due to a single fiber close to the electrode which contributed to about 80% of the MUP. In case of polyphasic MUP, muscle fiber diameters variability was responsible for MUP characteristic. MUP from normal muscle originated from few fibers of similar diameters. Correlation between MUP's characteristic and morphological features has been indicated. Our findings are consistent with the neurophysiological knowledge about the origins of MUP. The approximation method enables MUP analysis that provides quantitative description of motor unit morphology.
Conclusion: MUP analysis using an approximation method enables to get an insight into motor unit morphology and therefore increases understanding of the way the motor unit structure correlates with MUP waveform.
Significance: Extending the amount of information available from EMG examinations.

1. Introduction

Simulation studies on motor unit potentials (MUPs), apart from clinical experience, are important in understanding how the morphological features such as number of fibers, their diameters and distribution within the motor unit area influence the MUP waveform (Dumitru et al., 1997; Nandedkar et al., 1988b; Nandedkar and Sanders, 1989; Stålberg and Karlsson, 2000, 2001; Zalewska et al., 2004). Simulation enables the relationship between motor unit morphology and MUP shape variability to be determined.

Motor unit potentials have been modeled since electromyography was first established (Nandedkar, 2002) by providing a link between muscle morphology and bioelectrical activity (Fig. 1). Modeling procedure (illustrated in Fig. 1a) invariably require assumptions regarding the structure of a motor unit i.e. the area

☆ To the memory of Prof. Irena Hausmanowa-Petrusewicz, my Teacher and my Friend.

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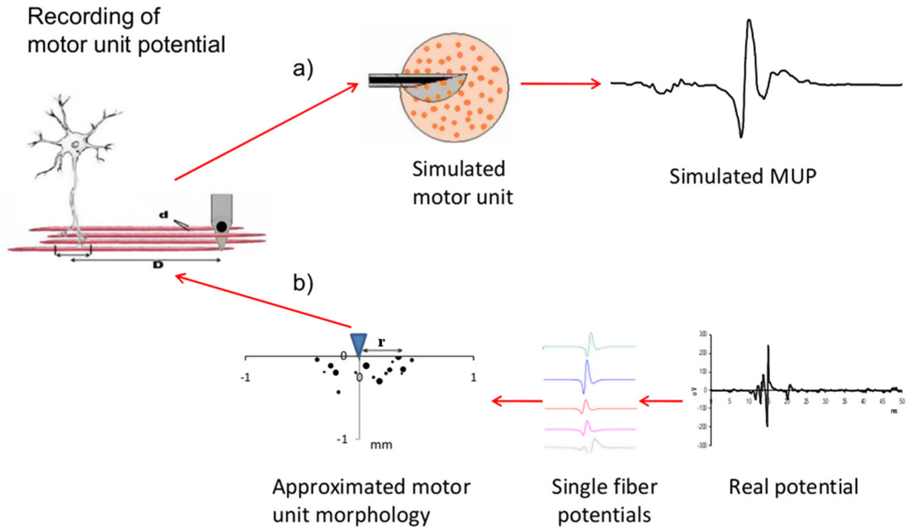

Fig. 1. Simulation of motor unit potential (Fig. 1a) and approximation of motor unit morphology (Fig. 1b) as a link between structure and motor unit bioelectrical activity. (a) Simulation-modeled motor unit structure and simulated MUP, (b) Approximation of the motor unit morphology as a procedure inverse to that used in MUP simulation. Decomposition of MUP into SFPs allows for an evaluation of numbers of fibers, fiber diameters (d), distance (r) relative to the electrode (marked as a triangle) and recording distance (D). The results are shown on a graph indicating number of fibers, their diameters and distance to the electrode. Note, that the model indicates distance (r) but not direction of the fiber relative to the electrode.

it covers, number of fibers, their diameters, and their locations within the motor unit area. The bioelectrical potential i.e. MUP recorded by an electrode inserted among muscle fibers can then be predicted as shown in Fig. 1a (Nandedkar et al., 1988a, 1988b; Stålberg and Karlsson, 2000, 2001).

On the basis of experience resulting from modeling studies, we have taken a step forward by introducing an inverse approach, namely the method for the approximation of structural features through the analysis of MUP (Zalewska and Hausmanowa-Petrusewicz, 2008). The principle of this inverse method is illustrated in Fig. 1b with consecutive steps from the right to the left. Starting from the MUP (shown on the right in Fig. 1b), including decomposition of the MUP into single fiber potentials (SFPs), this procedure leads to determination of the distribution and sizes of muscle fibers as the sources of these SFPs (as shown in Fig. 1b). Muscle fibers contributing to the MUP are indicated.

The approximation procedure has been applied to explain the origin of some atypical MUPs. The difficulties in MUP interpretation are still encountered in clinical practice regarding some atypical potentials, that are mostly irregular (polyphasic or/and polyturn potentials), for example long polyphasic MUPs or potentials with satellite components. Irregularity of the MUP's shape is a nonspecific feature either for potentials in myogenic or in neurogenic disorders. Irregularity of the shape of MUP' waveform by itself reflects reorganization of motor unit morphology and has been found to be of value in the evaluation of the intensity of the undergoing pathological processes (Zalewska et al., 2004).

The interpretation using the approximation method of the atypical large MUP recorded in Emery-Dreifuss Muscle Dystrophy has been presented in Rowinska Marcinska et al. (2005). The origin of satellite components in MUPs in neuromuscular disorders Spinal Muscle Atrophy and Amyotrophic Lateral Sclerosis has been described in Zalewska et al. (2012a) and satellites in MUPs recorded in muscle dystrophy were considered in Zalewska et al. (2013).

This study is a continuation of our previous study aimed to determine motor unit morphology underpinning the various MUP waveforms using the approximation method. In the current study we analyzed MUPs recorded in various neuromuscular disorders, including atypical MUPs.

2. Material and methods

The approximation method (Zalewska and Hausmanowa-Petrusewicz, 2008) applied in this study takes advantage of the relationships between motor unit morphology and parameters of its MUP determined in simulations (Nandedkar et al., 1988a, 1988b; Nandedkar and Sanders, 1989; Dumitru et al., 1997; Zalewska et al., 2012b). The amplitude and duration of a single muscle fiber potential (SFP) recorded with a needle electrode depends mainly on muscle fiber diameter, electrode distance from the end-plate zone and distance between the electrode and muscle fiber. The relationships are as follows (labels d, r and D shown in Fig. 1): the potential becomes shorter and higher with increasing fiber diameter (d) and on the contrary it becomes smaller and longer with increased electrode to fiber distance (r). The duration of MUP generated by fibers differing in diameter (hence having different propagation velocities) increases with increasing electrode to end-plate distance (D) and due to this dispersion the MUP amplitude decreases. These relationships were used in determining the contribution of each muscle fiber to the MUP waveform.

The velocity of propagation of the potential along a muscle fiber is proportional to the fiber diameter (Nandedkar and Stålberg, 1983). This means that, an electrode records first the potential from the largest fiber. The potentials from smaller fibers reach the electrode later and form the later components of the MUP. Time dispersion resulting from the differences in fiber diameters and hence in propagation velocity of several single fiber potentials is responsible for complex shape of motor unit potential (Zalewska et al., 2004).

The principle of the approximation procedure is depicted in Fig. 2. In the first step, a random distribution of muscle fibers is generated (shown in the column "Muscle fibers" in Fig. 2), and a MUP is simulated (the curve at the top in Fig. 2). The model is compared with a real potential (the curve at the bottom in Fig. 2) and differences between both these potentials at each point are calculated. The procedure for minimization of these differences adjusts the fiber distribution, and a new model of the MUP is calculated. The procedure is repeated until convergence is achieved (the consecutive curves depicted from top to bottom in Fig. 2 illustrate the progress of the iterations). When a minimum is reached the result-