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Motor Unit Contractions Evoked by Stimulation with Variable Interpulse Intervals

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During natural contractions motor units (MUs) are activated by variable frequency discharge patterns of motoneurones. The aim of this review was (1) to discuss differences between tetanic contractions developed at constant and random frequencies of pulses; (2) to show results of mathematical decomposition of these tetani into series of twitch-shaped responses to individual pulses; (3) to indicate that it is possible to predict the tetanic force of a MU with high accuracy by using regression equations derived on a basis of the relationships between the parameters of the decomposed twitches and the force level at which the next response begins.

K e y w o r d s: motor unit, tetanic force, decomposition, rat

1. Introduction

Numerous studies have revealed that the rate of motoneuronal firing – a major factor regulating the force of motor units (MUs), is not constant during voluntary contractions and the interpulse intervals (IPIs) are variable [1–7]. During usual daily voluntary activity the MUs generate non-uniform unfused tetani, which are characterized by variable force and fusion degree [8–13]. However, only constant frequency contractions have been analyzed in the majority of experimental studies, and development of the MU unfused tetani following a train of pulses at the variable IPIs has so far received little attention. In few reports only small changes in regular stimulation rates have been applied, by linear changes in frequency of stimulation or by adding or deleting individual pulses [14–18]. It has been evidenced that even minimal changes in the stimulation pattern can significantly modify the force generated by the MU. Moreover, it has been revealed that fast the MUs are highly susceptible to modifications of the firing rate in comparison to the slow MUs [17, 19–21].

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In this review we presented results of the three consecutive steps in the analysis of the unfused tetanic contractions of MUs evoked by patterns of stimulation with the variable IPIs, which were based on a series of experiments in the functionally isolated MUs of the rat medial gastrocnemius (MG) muscle [22], and on a recently developed algorithm and computer program for mathematical decomposition of the MU tetanic contractions into a train of individual twitch-shape responses to the successive pulses [23, 24]. Initially we discussed differences between the tetanic contractions evoked by stimulation patterns at constant frequencies and the tetani evoked by respective patterns of random stimuli at the same mean frequencies and the same number of pulses. Subsequently we presented results of the decomposition of tetani evoked by stimulation at the variable IPIs, and we analyzed variability of the time and force properties of the decomposed twitches, either for the fast and slow MUs. Finally, we discussed effects of the previously developed mathematical approach to the prediction of force generated by the MUs stimulated by variable frequency patterns. Our aim was also to demonstrate significance of these findings in understanding physiology of a MU force development during natural contractions.

2. Material and Methods

2.1. Functional Isolation of Motor Units

Electrophysiological experiments were performed on adult female Wistar rats under pentobarbital anesthesia (initial dose of 60 mg/kg, i.p., supplemented as required). The depth of anaesthesia was verified by controlling the withdrawal reflex. All experimental procedures followed the European Union guidelines of animal care as well as the principles of the Polish Law on The Protection of Animals and were approved by the Local Bioethics Committee. After the experiments, the animals were killed with an overdose of pentobarbital (180 mg/kg).

The surgical procedures have been previously described in detail [22, 25]. Briefly, the medial gastrocnemius muscle and the respective branch of the sciatic nerve were isolated and other muscles of the hind limb were denervated. Laminectomy over the L2-S1 segments was performed, and dorsal as well as ventral roots of the spinal nerves were cut proximally to the spinal cord. The animals were immobilized in a steel frame and the operated hind limb and the spinal cord were covered with paraffin oil. The muscle was connected to an inductive force transducer by the Achilles tendon to measure the contractile force under isometric conditions and stretched up to the passive force of 100 mN [26]. The functional isolation of MUs was achieved by splitting the L5 or L4 ventral roots into thin filaments, which were electrically stimulated with suprathreshold rectangular pulses (amplitude up to 0.5 V, duration 0.1 ms). A bipolar silver electrode in the muscle served to record evoked action potentials. The "all-or-none" appearance of the twitch contractions and the MU action potentials in response to the stimuli of increasing amplitude indicated the activity of a single MU.