# Characteristics of Motor Unit Potentials in Human Skeletal Muscle During the Denervation-Reinnervation Process

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Traditionally measured parameters of motor unit potentials and parameters of the fast (spike) component of motor units were compared in the common extensor of fingers of 24 patients with chronic progressive diseases of motoneurons or their axons and 12 healthy subjects. The earliest signs of motor unit disorders are shown to be increased in the amplitude, duration, and number of turns in the spike (main) component of potentials. A correlation was found to exist between increases in muscle fiber density and in the number of turns. Analysis of the main component parameters indicates that both concentration of muscle fibers in the central zone of motor units and desynchronization of their activity occur in initial phases of the denervation-reinnervation process.

**Key Words:** *motor unit potentials; electromyography; compensatory innervation*

The available methods of clinical electromyography enable investigators to study the morphofunctional organization of motor units (MUs) over time in various human diseases and to evaluate the course of denervation-reinnervation processes in muscles during the establishment of compensatory innervation.

It was believed for a long time that the main parameter determining the state of a MU in the muscle is duration of the MU potential (MUP). In recent years, attempts have been made to enlarge the capabilities of clinical electromyography through a more detailed processing of the electromyographic signal recorded when the tension of the muscle under study is minimal [1,6,8,9].

The purpose of the present investigation was to examine alterations in the spike (main) component of the MUPs during the development of a denervation-reinnervation process in patients with diseases of motoneurons or their axons, given that these diseases can serve as convenient models for observing changes occurring in the muscle of interest over a relatively short period of time.

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## MATERIALS AND METHODS

Electromyographic examinations were performed with a Counterpoint electromyograph (Dantec Medical) using standard concentric needle electrodes with a leading-off surface of 0.07 $mm^2$ and an electrode with a 25 μ diameter of the leading-off surface for recording muscle fiber potentials.

In each muscle under study, parameters of at least 20 potentials of different MUs recorded by the conventional technique [4] were analyzed. Included in the analysis were MUPs after their 5-fold averaging (weighted MUPs) at a standard amplification (100 or 500 μV) and a ray run of 1-2 msec/cm. We evaluated the duration of the MUP and of its main component (MC), MUP and MC amplitudes, and the number of turns in the MUP and MC for potentials with amplitudes of at least 50 μV (Fig. 1).

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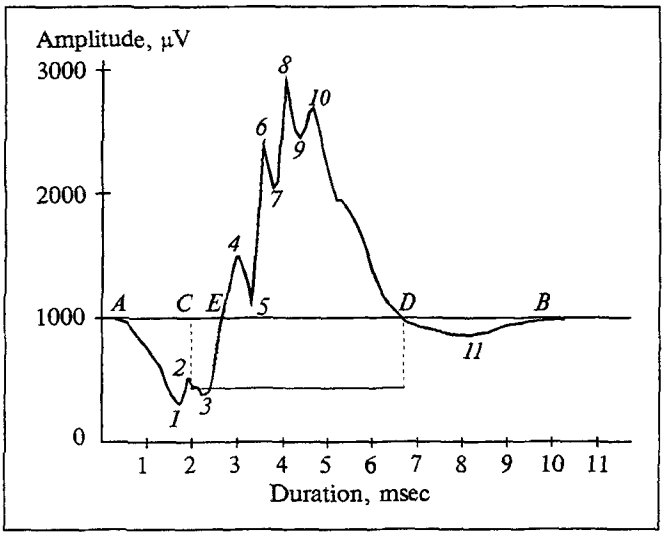


**Fig. 1.** Principles underlying measurement of MUP parameters: *AB*) total duration of the MUP; *CD*) duration of the MC; *AE*) duration of slow MUP components; *1-11*) MUP turns. The MUP amplitude was measured from peak to peak (intersection point on the straight lines) for turn *1* and turn *8*.

Since the duration of MUPs depends on age, the duration of each MUP was expressed in percent of its value in a given muscle for persons of the corresponding age (normalized duration). In most muscles, muscle fiber density in MUs was also estimated from the number of spikes in the potentials from fibers occurring within the recording area of the electrode [13].

The common extensor of fingers was examined in 12 healthy subjects and 24 patients with chronic progressive motoneuron diseases (lateral amyotrophic sclerosis or spinal amyotrophy) or with axonal or demyelinating polyneuropathy. A total of 724 MUPs and 385 muscle fiber complexes were studied.

**TABLE 1.** Duration of the Main Component (MC) of Motor Unit Potentials (MUPs) in Healthy Subjects and Patients with Diseases of Motoneurons or Their Axons and Altered Duration of the Potentials (*M*±s)

| Normalized duration of MUPs, % | Duration of the MC, msec | |
|---|---|---|
| | control | denervation-reinnervation process |
| 25-60 | - | 1.8±0.8 (39) |
| 61-80 | - | 2.1±0.6 (57)* |
| 81-100 | 1.8±0.4 (24) | 2.7±0.9 (107)** |
| 101-120 | 2.0±0.6 (212) | 3.1±1.2 (92)*** |
| 121-140 | 1.9±0.4 (4) | 3.1±1.3 (68)*** |
| 141-160 | - | 3.5±1.3 (68)*** |
| 161-180 | - | 3.2±1.4 (28)*** |
| 181-200 | - | 4.3±1.8 (17)*** |
| 201-220 | - | 4.2±2.9 (4)*** |
| 221-240 | - | 2.8±1.8 (4)*** |
| Total | (240) | (484) |

**Note.** Figures in parentheses are the number of MUPs. *$p<0.05$, **$p<0.01$, ***$p<0.001$. The shaded area includes normal values.

## RESULTS

As the duration of MUPs is the parameter most commonly measured in clinical electromyography to characterize alterations in MUs, the durations of MCs in the healthy subjects (controls) were compared with those in the patients (Table 1).

Of the 240 MUPs measured in the healthy subjects, 94.2% of the MCs were not more than 3 msec in duration while the duration of 99.2% did not exceed 4 msec. Of the 96 MUPs of shortened duration recorded in the muscles of patients with diseases of motoneurons or their axons, the duration of the MC was within normal limits in 68 MUPs (70.8%) and above normal in the remaining 29.2%. The proportion of MUPs with an extended MC was 34.4% among MUPs whose duration was within normal values (81-140%) and 52% among those of increased duration. It should be noted that only duration of the first MC was considered.

In all patients, regardless of how long the MC lasted, a significant increase in its amplitude was recorded ($r=0.39$, $p<0.05$), and the increase in the amplitude did not depend on the duration of the MC (Table 2).

An important role for understanding what contributions individual muscle fibers make to the MC amplitude is played by analysis of the number of turns detected when the MC of MUPs is studied. It can be seen from Table 2 that as the duration of the MC increases in the muscles of patients, so does the number of turns ($r=0.45$, $p<0.005$), and that the number of turns at a given duration of the MCs exceeds that in the MCs of the MUPs of the same duration in the muscles of healthy subjects regardless of the extent to which the MC duration is increased.

In a separate study, the muscle fiber density was examined in 385 MUs of 19 muscles in patients with motoneuron or axonal disease. Muscle fiber density was compared with the number of turns taking into account the durations of MUPs recorded in a given muscle (Fig. 2). A significant correlation was found ($r=0.56$, $p<0.01$) between the muscle fiber density and the number of turns; both the mean density and the mean number of turns in all MUPs were significantly higher than in the control group.

Our findings indicate that analysis of parameters characterizing the MC of MUPs is desirable in studies designed to detect changes in the morphofunctional

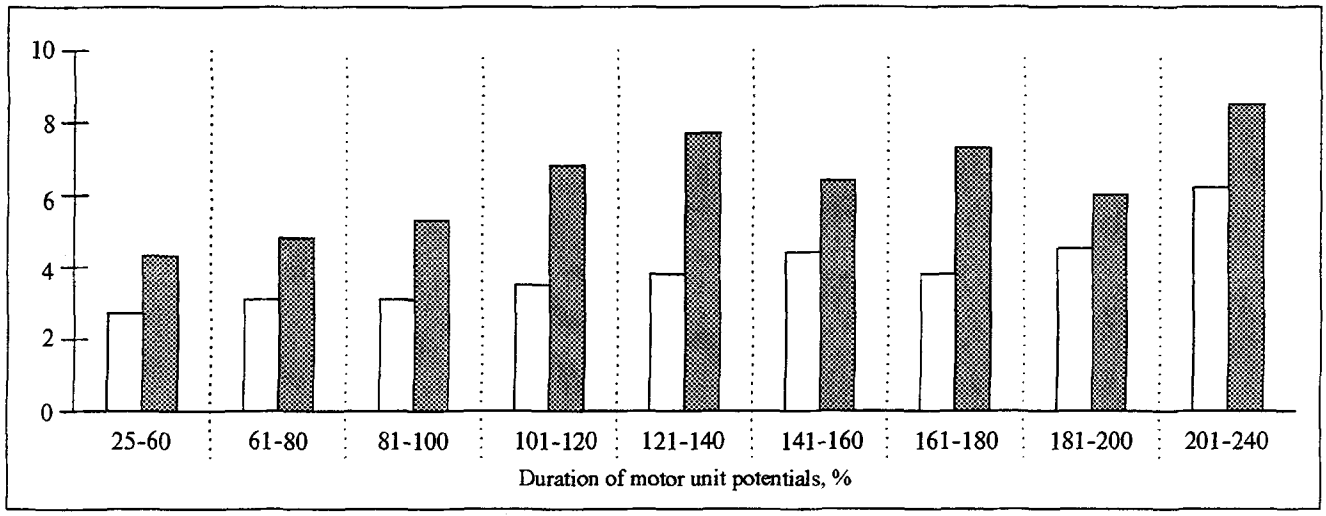


**Fig. 2.** Mean muscle fiber densities in muscle MUs (white bars) and the number of turns (black bars) in potentials of different durations, as expressed in % relative to their normal duration. Ordinate: mean fiber density in MUs and the mean number of turns in potentials of a given duration.

organization of MUs, for such analysis can provide very useful information. Increased amplitude of the MC is a much earlier indicator of MU abnormalities than the traditional measurement of MUP duration, while the determination of MC duration permits detection of such abnormalities in the region of normal MUP values, which adds substantially to the capabilities of clinical electromyography.

Analysis of MC parameters thus yields new information that can modify to some extent our understanding of the morphofunctional organization of MUs in human skeletal muscle in various neuromuscular diseases [2,12,14].

As demonstrated by mathematical modeling of MUPs, MUP parameters depend on the number and size of muscle fibers contiguous with the leading-off surface of the electrode or located at a distance of not more than 500 μ from it [5]. The remaining fibers, located further away, form the slow component of the MUP preceding or following its spike component. The results of scanning electromyography also indicate that only a small fraction of MU fibers form the spike component (MC) of the MUP [11]. This makes it clear why parameters of this particular component change first. The earliest changes in the MC are increases in its amplitude and duration in the number of its turns, and there is a reasonably high degree of correlation between these changes.

There is also a good correlation between the change in fiber density in a MU and the increase in the number of turns exhibited by the MC. In our

**TABLE 2.** Number of Turns in the Main Component (MC) of Different Durations and Amplitudes in Healthy Subjects and Patients with Diseases of Motoneurons or Their Axons (*M*±s)

| MC duration, msec | Healthy subjects | | | Patients | | |
|---|---|---|---|---|---|---|
| | number of MUPs | number of turns* | MC amplitude, mV* | number of MUPs | number of turns* | MC amplitude, mV* |
| <1 | 10 | 1.2±0.3 | 0.78±0.3 | 12 | 1.7±1.6 | 2.5±1.4 |
| 1-1.9 | 134 | 1.3±0.5 | 0.77±0.3 | 122 | 2.5±1.9 | 2.7±2.4 |
| 2-2.9 | 84 | 1.4±0.4 | 0.76±0.4 | 175 | 2.4±1.4 | 2.2±1.8 |
| 3-3.9 | 12 | 1.0±0.3 | 0.58±0.3 | 97 | 3.5±1.7 | 2.2±1.7 |
| 4-4.9 | - | - | - | 41 | 5.7±2.4 | 2.4±0.9 |
| 5-5.9 | - | - | - | 21 | 5.8±2.9 | 1.8±0.9 |
| 6-6.9 | - | - | - | 9 | 5.6±1.9 | 2.3±1.3 |
| 7-7.9 | - | - | - | 4 | 3.2±2.3 | 2.4±0.2 |
| >7.9 | - | - | - | 3 | 5.1±2.1 | 1.1±0.6 |

**Note.** *$p<0.001$ for all values in the column.

previous study, the mean density of muscle fibers in a single MU of healthy subjects, measured in relative units, was 1.47±0.3 (range, 1 to 3) [3], and the mean number of turns in the MC of those subjects was similar (1.28±0.6). Similar results have been reported by other authors [7,10,13].

By studying the MC and determining the number of its turns, it is possible to follow alterations occurring in a human muscle at different stages of the denervation-reinnervation process and to show that the concentration of fibers within a single MU increases in some regions of the muscle at the initial stage of this process. The synchronous activity of MUs and the summation of potentials generated by individual closely adherent muscle fibers results in an increased amplitude of the MC, and this increase precedes that in the duration of the MUP. Even a slight desynchronization of potentials generated by individual MU fibers leads to an increased number of turns reflecting the number of fibers involved in generating the MC.

In summary, the results of our investigation show that analysis of the spike component (MC) of MUPs along with measurement of the MUP amplitude and duration is a highly sensitive test for detecting denervation and reinnervation processes, and that counting the number of turns gives an indication of how many muscle fibers the MU under study contains, which makes it possible to dispense with a painful and time-consuming investigation to determine muscle fiber density in the MU.

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