

Motor unit fibre density in the extensor digitorum communis muscle

Single fibre electromyographic study in normal subjects at different ages

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SYNOPSIS A single fibre EMG study is presented from extensor digitorum communis muscle in subjects aged 10 to 89 years. The average number of single muscle fibre action potentials generated by muscle fibres in the same motor unit within the uptake area of the electrode is used as a measure of the motor unit fibre density. The fibre density increases slowly during life with a faster progression after the age of 70 years. The number of recordings indicating impaired nerve or neuromuscular impulse transmission increases at the same time. The findings indicate degenerative loss of motor neurones with aging, compensated for by reinnervation. The changes are relatively slight in the extensor digitorum communis muscle as compared with other muscles, permitting early pathological changes in this muscle to be recognized independently of age factors.

It is known from clinical experience that certain muscle groups show atrophy at older ages. These atrophies cannot be regarded simply as disuse atrophies. Electromyographic (EMG) investigations have shown an increased duration of the recorded motor unit potentials at the older ages (Sacco *et al.*, 1962). There is also a reduced number of motor units recruited at maximal contraction, especially in extensor digitorum brevis muscle (EDB) and in the small muscles of the hand. Jennekens *et al.* (1971) showed fibre grouping in histological preparations from the age of 30 years in the EDB and from the age of 60 years in flexor digitorum brevis muscle. Campbell *et al.* (1973) showed, with a particular electrophysiological technique, a reduction of active motor units from the age of 60 years in the EDB. In the thenar muscle Brown (1972) found a similar reduction of number of motor units from the age of 60 years.

The purpose of the present investigation is to study healthy subjects of different ages concerning fibre density in the extensor digitorum communis muscle (EDC). This muscle has been

the preferred one for single fibre electromyographic investigations in normal and pathological conditions.

METHODS

The investigation was performed on 152 subjects without signs or symptoms of present or past neuromuscular disorders. No earlier EMG or SFEMG investigations were performed in the muscle which they studied, because of the changes occurring with repeated electrode insertions. Five subjects were receiving carbamazepine or phenytoin for epilepsy but had no neuromuscular symptoms. The EDC muscle was studied exclusively in this investigation.

TECHNIQUE *Fibre density* In order to study the muscle fibre distribution within the motor unit and impulse transmission in peripheral parts of the motor unit, single fibre electromyography (SFEMG) was performed according to the general principles described by Ekstedt and Stålberg (1973) and Stålberg and Ekstedt (1973). Needle electrodes with leading off surfaces 25 μm in diameter, mounted in the side of the needle, were used. Recording was made between one of these surfaces and an indifferent surface electrode. Because of the small size of the electrode, action potentials from single muscle

fibres can be recorded. For recording, conventional EMG equipment (DISA, Medelec) or special amplifiers were used. The filters were usually set to 500 Hz and 20–40 kHz (12 dB).

The needle electrode was inserted in the slightly voluntarily activated muscle. It was positioned as close as possible to the first muscle fibre action potential recognized after insertion—that is, the action potential from this muscle fibre was made maximal in amplitude, usually 2–10 mV.

This action potential was used to trigger the sweep of the EMG apparatus or of a dual beam oscilloscope (Tektronix 565). Other action potentials belonging to the same motor unit as the triggering one appear then at a nearly constant position related to the triggering potential. Action potentials from other motor units occasionally appeared on the oscilloscope screen, but at randomly varying positions along the sweep. Therefore more than 20 consecutive discharges were studied. In order to detect also early action potentials with low amplitude, the trigger level was set to allow action potentials exceeding 200 μV to start the sweep. Furthermore, a delay line (Medelec, 5 ms) was used. Analysis was made either from oscilloscope photographs or visually from a storage oscilloscope

(Tektronix 549, D5010). The number of muscle fibres from one motor unit recorded at a single needle position was estimated by counting the number of single fibre action potentials (Fig. 1). The criteria for accepting an action potential was a total amplitude of 200 μV and a biphasic shape with a maximum-to-minimum rise time of less than 300 μs , giving the action potential a relatively spiky appearance at a sweep speed of 0.5–1 ms/cm. The shape should be constant at consecutive discharges when a sweep speed of 100 $\mu\text{s}/\text{cm}$ is used. Twenty needle insertions, usually into three to five different parts of the muscle, were made in each subject. The results are expressed as the relative frequency of one, two, three or more components and as the average number of recorded fibres of an individual motor unit/recording site.

Other SFEMG parameters The maximal duration of the action potential complex—that is, the time between the zero intersection points between the fast rise phase of the first and the last spike components—was measured in the recorded multiple potentials.

The impulse transmission in the peripheral parts of the motor unit was studied by means of *jitter*

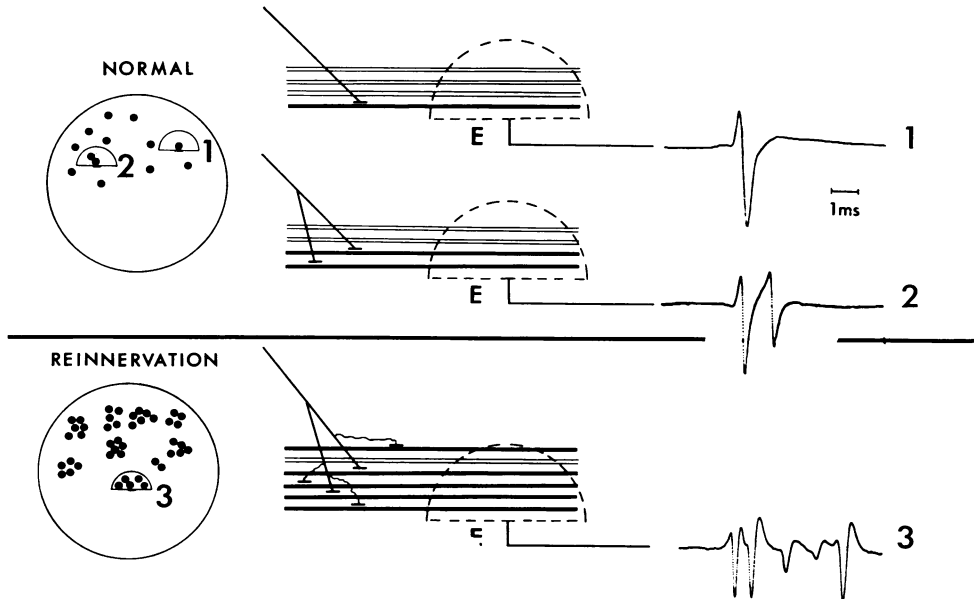


FIG. 1 Single fibre EMG recordings in normal and reinnervated muscle. The filled circles indicate muscle fibres from one motor unit in a muscle cross-section. The number of fibres within the uptake area of the electrode (E) is indicated within a semicircle in cross-section and longitudinal section. In the normal (1 and 2) action potentials from one or two fibres are recorded. In reinnervation (3) many fibre action potentials are recorded due to increased fibre density.

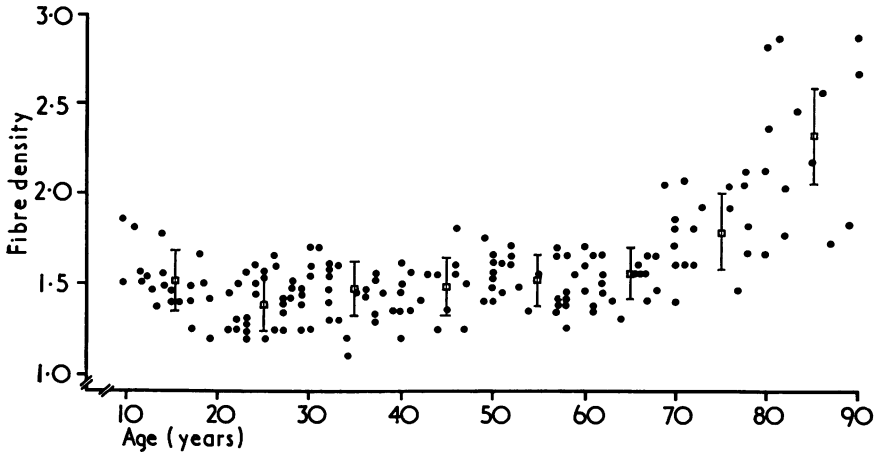


FIG. 2. Fibre density values in EDC for different ages. Each dot represents the mean number of muscle fibres/uptake area of the electrode belonging to the same motor unit in one subject. Mean values and standard deviation for each decade indicated.

TABLE
NORMAL MATERIAL

Age groups (yr)	No.	Fibre density (mean SD)	Difference in fibre density between age groups (yr) (degree of significance)								Increased jitter (%)	Blockings (%)
			10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89		
10-19	20	1.50 ± 0.17	—	*	—	—	—	—	‡	‡	0.33	0.33
20-29	20	1.38 ± 0.15	—	—	—	—	†	‡	‡	‡	0	0
30-39	20	1.47 ± 0.15	—	—	—	—	—	‡	‡	‡	0	0
40-49	20	1.48 ± 0.16	—	—	—	—	—	‡	‡	‡	0.33	0
50-59	20	1.51 ± 0.14	—	—	—	—	—	‡	‡	‡	0.6	1.0
60-69	20	1.55 ± 0.14	—	—	—	—	—	‡	‡	‡	1.6	1.3
70-79	20	1.78 ± 0.21	—	—	—	—	—	—	‡	‡	2.81	0.3
80-89	12	2.32 ± 0.26	—	—	—	—	—	—	—	—	—	—

* 0.01 < P < 0.05.

† 0.005 < P < 0.01.

‡ P < 0.001.

determinations—that is, the interpotential interval variability in consecutive action potentials from muscle fibres of the same motor unit. This jitter is due mainly to a short term variability in the neuromuscular delay (Stålberg *et al.*, 1971). When the neuromuscular transmission is disturbed the jitter increases until impulse blocking occurs. In pathological conditions—for example, at early reinnervation—disturbed impulse transmission also may occur in the nerve twigs (Stålberg and Thiele, 1972; Hakelius and Stålberg, 1974; Thiele and Stålberg, 1974). In this investigation, the numerical value of the jitter was not calculated in all potentials but was judged normal or increased by visual inspection of the oscilloscope screen. The occurrence of blocking was determined in the same way.

RESULTS

FIBRE DENSITY The fibre density values of EDC muscle in all the subjects investigated in this study are shown in Fig. 2. A mean value of fibre density was calculated for the consecutive decades of age, beginning with 10 to 19 years. From 20 years these mean values of fibre density show a slight progressive increase up to the age of 60 years and a faster progression in those over 70 years (Table). In subjects between 10 to 19 years of age, the fibre density values were higher than in the next older group. This difference was significant ($P=0.025$). The relative frequency of single, double, and multiple spikes summed for

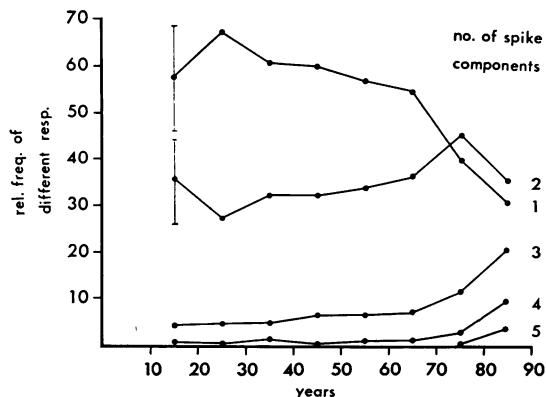


FIG. 3 Relative incidence of numbers of spike components for each decade. Age groups on the abscissa, incidence of number of spike components on the ordinate. The standard deviation is only indicated for the single and double potentials for the first decade being relatively constant for all age groups.

each age group is shown in Fig. 3. In most recordings about 60–65% were single potentials, 30–35% double potentials, 5% were triple potentials, and more than three components were very rare in lower age groups. Over the age of 70 years an increase in relative frequency of multiple potentials was observed. In the age group 10–19 years, double potentials were seen relatively more often than in adults but there was no relative increase in more complex potentials.

DURATION OF MULTIPLE POTENTIALS In adults up to the age of 50 years more than 70% of the recorded multiple potentials had a duration below 1.0 ms and potentials with duration beyond 3 ms were rarely seen (Fig. 4). Over this age an increased number of prolonged action potentials was recorded. These long potentials (over 5 ms) were in most cases double potentials. Multiple potentials containing four or even more

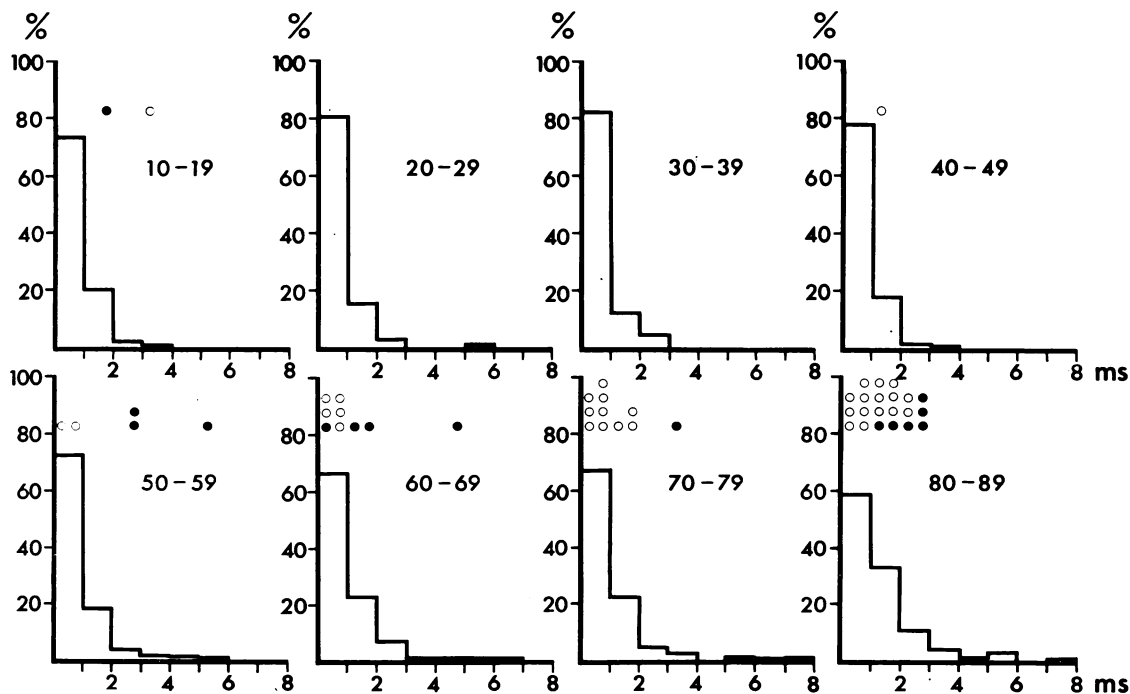


FIG. 4 Duration of the recorded multiple potentials for different ages. Duration on the abscissa, percentage of incidence on the ordinate. Beyond the age of 50 years there was an increasing incidence of duration over 3 ms, which is rarely seen in younger subjects. Individual potentials with increased jitter (○) and with blockings (●) are indicated for the respective duration in the upper part of each histogram.

components usually had a shorter duration, about 2–4 ms.

NEUROMUSCULAR TRANSMISSION Increased jitter and blocking were extremely rare in adults between the ages of 20 and 60 years. Above this age an increased jitter ($> 50 \mu\text{s}$) was seen in about 2% of multiple potentials, independent of the potential duration. Blockings occurred in about 1% of the multiple potentials, predominantly in the late components in long duration potentials (Fig. 4).

DISCUSSION

The method presented gives a measure of the number of muscle fibres belonging to one motor unit within the pickup area of the electrode. The following criteria were established for accepting an action potential for measurement:

1. The action potential should have an amplitude exceeding $200 \mu\text{V}$. Earlier investigations of the volume conduction of the single fibre action potential have shown that when the amplitude is about $200 \mu\text{V}$ the electrode to fibre distance is 150–350 μm (mean 270 μm) (Stålberg, Schwartz, Thiele, and Schiller, in preparation).

2. The action potential should be biphasic, with max–min rise time less than 300 μs and have constant shape with consecutive discharges. If two or more action potentials from fibres belonging to the same motor unit close to the electrode interfere, a complex potential will be recorded. Usually the different spike components are discernible because of the jitter and the number of generators can still be measured. If recordings be obtained from two or more muscle fibres at a distance exceeding 200 μm from the electrode, synchronous action potentials could superimpose and give a broad, often monophasic potential of variable shape with an amplitude which could exceed $200 \mu\text{V}$. Because of the rounded and variable shape, this activity is not accepted for measuring. It should also be stressed that the accepted individual spike components in multiple potentials must occur with fairly constant time relation, tested for at least 20 discharges.

Action potentials of fibres of especially large diameter have a higher amplitude and can be recorded at longer distances giving a larger

electrode uptake area than action potentials from smaller muscle fibres. In cases of the large fibre diameter, however, there are fewer muscle fibres per mm^2 . These two factors can counteract and the number of recorded fibres/uptake area could remain fairly unchanged. Similarly, when the average muscle fibre diameter is small, an increased number of fibres are present per mm^2 but their small action potentials are conducted over a shorter distance and the electrode uptake area is reduced. Thus the number of muscle fibres/uptake area may again be unchanged. It cannot be predicted how exact this counteraction may be and whether it will bias the measured values in opposite directions for atrophic and hypertrophic muscles.

The increased fibre density before the age of 20 years and after the age of 60 years might be due to different factors which will be discussed shortly.

GENERAL MUSCULAR ATROPHY In old age the reduction of fibre sizes is of the order of 20%. This is unlikely to be the main explanation for the increase in fibre density, by far exceeding that found in young children where the fibre size is 50% or less of the adult size (Brooke and Engel, 1969).

SELECTIVE MOTOR UNIT LOSS In some muscle disorders selective loss of motor units without parallel reinnervation has been described (Warmolts and Engel, 1973). If this be the case also in normal aging and no fibrosis or other changes take place, a reduced territory of the surviving motor unit is expected. No histological evidence for selective motor unit loss is reported in the aging muscle.

PERIPHERAL NERVE SPROUTING The third possibility is peripheral nerve sprouting where denervated muscle fibres have been reinnervated and incorporated into the motor unit. In cases with pronounced reinnervation—for example, after muscle transplantation (Hakelius and Stålberg, 1974) where fibre grouping takes place as shown with histochemical methods—the fibre density increases to as much as 10–20 fibres/electrode surface. The present finding with

an increased fibre density may thus be a sign of reinnervation. Another sign of denervation and reinnervation is the increased duration due to either slow impulse conduction in newly formed nerve sprouts or to slow impulse conduction in atrophic muscle fibres. Increased jitter and occasional blockings found in this material indicate an uncertain nerve or neuromuscular transmission.

The fibre density values in the age group of 10 to 19 years were slightly higher than during the next decade. It seems unlikely that this is due to degenerative changes. A smaller muscle fibre diameter may play a role, especially in the younger subjects in this age group (Brooke and Engel, 1969). Also, differing amounts of connective tissue, fat, and water may contribute to altered recording conditions. But the volume conduction characteristics are similar in this age group and in older people when action potentials of the same amplitude are studied. Thus, there may be a difference in the motor unit anatomy in lower ages.

In earlier investigations comparing subjects of different ages, a loss of motor units was found beyond the age of 60 years up to 50% in the small muscles of the foot and of the hand (Campbell *et al.*, 1973; Brown, 1972, 1973). O'Sullivan and Swallow (1968), found in peripheral nerve biopsies that the number of nerve fibres per mm² was only one-half to one-third in older ages compared with younger adults. In muscle biopsy studies the incidence of fibre grouping varied in different muscle groups, being more pronounced in the small foot muscles than in the gastrocnemius and tibialis anterior muscles (Jennekens *et al.*, 1971, 1972).

A number of possible factors responsible for the reduction in number of motor units have been discussed in the literature, such as general loss of neurones, nerve trauma, muscle ischaemia, and toxic ones. It is of interest in the present investigation to note that even at old ages there is a considerable regenerative capacity in surviving motor neurones.

There is apparently a great variation relative to age, in different muscle groups. In the present study there is only a slight change up to the age of 70 years. Muscles lying distally are probably more exposed to trauma and demonstrate

changes at an earlier age, making it more difficult to assess early pathological changes. In the EDC muscle the motor unit physiology remains relatively unaffected until senescence, permitting early pathological changes to be recognized independently of age factors.

The investigation was supported by the Swedish Medical Research Council (Grant No. 04X-135). Kerstin Mellqvist is acknowledged for her technical assistance. Gösta Lovén constructed the SFEMG electrodes.

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