

DURATION AND FORM OF ACTION POTENTIAL IN THE NORMAL HUMAN MUSCLE

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Introduction

The insight obtained into changes in the electrical activity of the muscle in certain neuromuscular disorders and the refinement of their electromyographic diagnosis have made it necessary to determine more precisely the variations in the form and duration of the action potentials in the normal muscle.

The form of the action potential recorded with a standard electrode (concentric or monopolar needles) is generally stated to be mono-, bi-, or triphasic wave. Polyphasic potentials are occasionally observed, (Denslow and Hassett, 1943; Weddell and others, 1944). Their relative frequency, however, has not been determined.

In the normal muscle the duration of the single motor unit action potential, recorded with concentric needle electrodes and adequate measuring instruments, was found by Buchthal and Clemmesen (1941) to be about 7 to 14 msec. The duration of the first rapid phase of the action potential was subjected to statistical analysis and found to be 4.64 msec., with a standard deviation of 7.4 per cent. The measurements were made from photographic tracings of "lying waves," with a camera transporting the paper at high speed. Owing to the large consumption of paper, however, this method is far too expensive for use in ordinary clinical work. Similar methods were adopted by Weddell and others, (1944), who state that the duration of the action potential in the average limb is 5 to 10 msec. The corresponding figures given by Jasper (1946) are 5 to 8 msec., and by Kugelberg (1947), for the majority of the potentials, 4 to 10 msec. These figures include potentials of less duration than those first mentioned. Snodgrass and Sperry (1941) report the occurrence of still shorter potentials, with a duration of 1 to 3 msec.

It may be seen from the above summary that exact figures for the normal variations in the dura-

tion of the action potentials are lacking. This applies not only to the distribution of the duration in the same muscle, but also as to whether there are any differences in this respect between different muscles and different persons. Nor has any clinically serviceable method for the determination of the duration been tested, nor the effect of the commonly used electrode types on the duration investigated. These are the chief problems discussed in the present paper.

Technique and Method

As a standard electrode, a coaxial needle electrode (platinum wire, 0.20 mm. in diameter, insulated by a glass capillary tube from the cannula of stainless steel with an outer diameter of 0.5 mm.) was employed. The inner core was well centred in the tip of the cannula, care being taken that its end lay in the same plane as the cannula or slightly beyond it. The inclination of the tip was 45 degrees.

A needle with the same dimensions as stated above, but with two platinum wires 0.10 mm. in inside diameter, and with the needle grounded, was also tested. A third type of electrode employed consisted of fine sewing needles (No. 8), insulated by covering with three coats of plastic baking enamel. Though the tip, owing to the surface tension, remains uncoated, it was gently rubbed once against a fine-grained whetstone.

The action potentials were led off to a one-channel balanced push-pull amplifier (time constant 0.3 second) connected to one beam of the cathode-ray tube, the other beam being connected to an oscillator for time recording in milliseconds.

In order to obtain detailed pictures of single action potentials, the sweep was caused to carry the ray horizontally over the screen about three times a second. A camera, taking 120 metres of film paper, simultaneously carried the film vertically in front of the tube, so as to obtain a series of pictures of the several sweeps above one another across the strip of film. The sweep velocity was adjusted each time so as to permit determination on the record of a duration of 0.5 to 5 msec., within an accuracy of about ± 0.25 msec., and for a duration of 5 to 10 msec. within an accuracy of ± 0.5 msec.

The determinations of the duration were made only on potentials with a well-defined beginning and end. The entire duration was measured. The amplification was 100 microvolts, corresponding to 2 mm. on the record. It was necessary for the base line to be stable in order to enable the duration to be determined. For this reason only the three, or exceptionally four, first spikes recruited according as the voluntary contraction increases, have been taken as a basis for the determinations recorded in this paper. On intense contraction the base line will be disturbed owing to distant activity from muscle masses surrounding the needle. Moreover, according as an increasing number of units are recruited, they will often interfere with one another, so that it will be increasingly difficult to distinguish the individual potential. A criterion indicating that we have been concerned with a single functional unit, and not with a temporary coalescence of two or more, is that the unit in question had recurred on the record at least three times with identical form, duration, and amplitude.

Results

Influence of Electrode Type.—In the application of clinical electromyography to neuromuscular disorders, the electrode, without much probing, should give a relatively undistorted single unit response, at any rate to weak contraction. Furthermore, the pain felt on insertion of the electrode should be so slight that the operator can venture to examine each muscle at several points, or to examine several different muscles. The electrode, once placed in the muscle, should cause only slight discomfort and should not interfere with the patient's voluntary contraction. To minimize the pain a concentric needle electrode should not exceed 0.5 to 0.6 mm. in diameter.

The following electrode types are used in human electromyography :

1. The concentric needle electrode of Adrian and Bronk (1929).

2. Fine sewing needles coated except on the tip. They have been used monopolarly with a reference electrode on the surrounding skin, or bipolarly, for example, by Gilson and Mills (1941), Cuthbert and Denslow (1945), and Jasper (1946).

3. Two fine insulated wires inside a hypodermic needle, with the needle grounded (Adrian and Bronk, 1929; Lindsley, 1935). This electrode, being highly selective, has been used in frequency studies in order to follow single action potentials even under strong contraction.

For routine work, types 1, and 2 used monopolarly, have given satisfactory results. In the larger muscles it is somewhat easier to obtain single motor unit action potentials with the lacquered sewing needles than with the concentric electrodes. Little difference in this respect is found in examining smaller muscles, such as the intrinsic muscles of the hands and feet. The concentric double electrode,

on the other hand, takes up activity from a very restricted area. One will, therefore, have to search more in order to find single action potentials. When they are discovered, it is difficult to record them for more than a few moments. In fact a minimal displacement of the needle will suffice to bring the action potentials beyond the picking-up range of the electrode. For this reason the concentric double electrode is not well suited for ordinary electromyography.

Duration determinations with the three different types of electrode (100 action potentials examined at the first dorsal interosseous muscle in ten individuals) yielded the following results :

Type 1.	Mean	7.34 ± 0.21.	Standard deviation	2.1
Type 2.	„	7.29 ± 0.24.	„	2.4
Type 3.	„	2.01 ± 0.10.	„	1.0

There is thus no statistically significant difference between the duration measured with types 1 and 2. Type 3, on the other hand, shows considerably lower figures for the duration.

The amplitudes of the action potentials are, on an average, smallest with type 3, and largest with type 2. The results obtained with types 1 and 2 in this respect are not comparable. No difference in the form of the action potentials has been observed when different electrodes were used.

Form of Action Potentials.—The most common types are bi- or triphasic waves (Fig. 1B and C). Monophasic waves are less common (Fig. 1A). They often have a poorly defined beginning and termination. Deviations from the more symmetrical appearance of the wave forms seen in A-C frequently occur (D-F). This, of course, is to be expected when recording electrical activity spreading in a volume conductor from such a variable structure as the "motor unit."

As has been noticed by Buchthal and Clemmesen (1941), the action potentials are often slightly split up (Fig. 1G). Such potentials, when recorded at a lower speed, have a notch on the spike. If at one or more points on the potentials this disintegration goes further so that it extends over the base line (Fig. 1H-J), they have quite arbitrarily been regarded as polycyclic. The latter are rare in the average limb muscle, occurring to the extent of from only 2 to 4 per cent. among six hundred counted potentials in the first interosseous muscle, and among three hundred in the biceps brachii. As noted by Jasper (1946), polyphasic potentials are commoner in the facial muscles (Fig. 1H).

Duration of Action Potentials.—Duration determinations were made in thirty cases, ten women and twenty men, between the ages of twenty and forty-

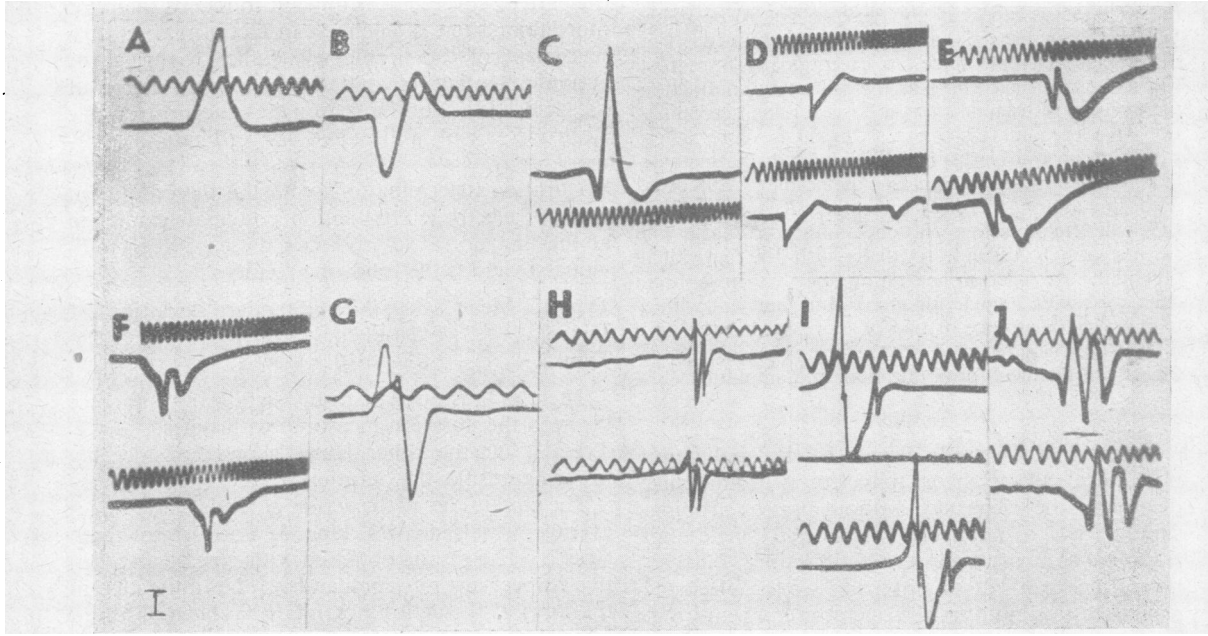


FIG. 1.—Examples of different forms of action potentials in the normal human muscle. G and H are from the facial, the remainder from the biceps and interosseous muscles. Calibration 100 microvolts. Time 1/1000 sec.

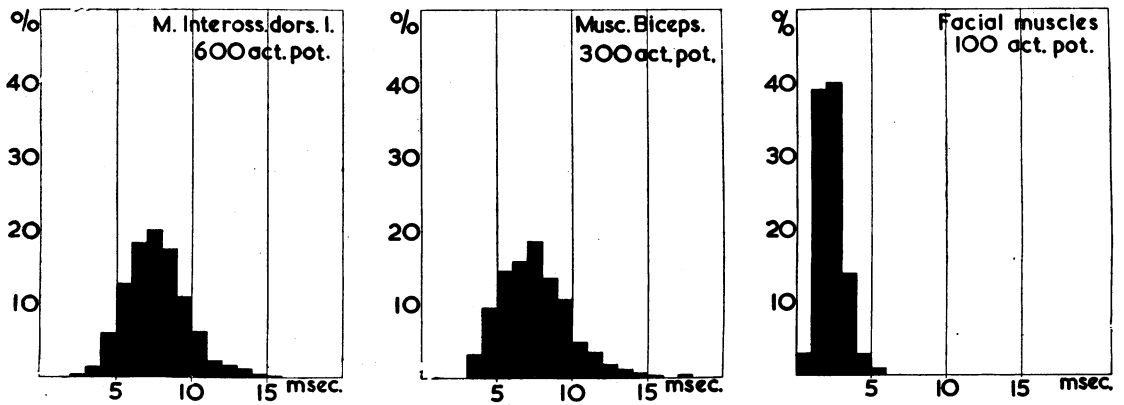


FIG. 2.—Distribution of the durations of action potentials in dorsal interosseous, biceps, and facial muscles.

two years. In each person the duration was computed for twenty action potentials in the first interosseous muscle and ten in the biceps brachii, while a total of a hundred observations were made in the facial muscles. The distribution of the duration of the potentials in the respective muscles is shown in Fig. 2. The extreme limits are between 2 and 16 msec. for the first interosseous muscle, 3 and 18 for the biceps, and 0.8 and 6 for the facial muscle. The much shorter value for the facial muscle is in accordance with the observations of Feinstein (1946).

The differences in the action potentials have been analysed with Fisher's method (1941) in regard to the variation between different persons as well as in each individual person. This analysis of variation shows no significant differences between the different individuals.

The entire number of observations may thus be regarded as a homogeneous unit. The normal limits for the mean value of a given number (n) of determined potential-durations can thus be computed by dividing the standard deviation for the entire series of observations by the square root of n .

The means of the total number of determinations in the different muscles are :

First interosseous muscle	7.68 ± 0.07 .	Standard deviation	2.07
Biceps brachii	7.56 ± 0.14 .	" "	2.37
Facial muscle	2.28 ± 0.03 .	" "	0.30

The standard deviation of the mean for ten and twenty measured potentials and the range of variation for the corresponding means, computed according to 2.5σ on either side of the mean, will consequently be :

First interosseous muscle	$n=10$	0.65.	Range	6.05—9.31
	$n=20$	0.45	" "	6.53—8.83
Biceps brachii	$n=10$	0.75.	" "	5.78—9.34
	$n=20$	0.53.	" "	6.23—8.89

The normal values obtained for the potential-durations in experimental subjects aged 20 to 42 years—a group within which no noteworthy individual differences in respect of sex and age could be ascertained—as compared with those in persons of advanced age, are somewhat shorter. The means of twenty measured potentials in the first interosseous muscle of 5 men aged from 69 to 79 years were 8.5, 8.9, 9.1, 10.9, and 11.3. The three last mentioned values show a significant increase relatively to the normal values in the preceding group. The value 8.9 is statistically probably increased.

Discussion

The method adopted for computing the duration of the action potentials is doubtless liable to give somewhat too short durations, as slow changes in a potential of small amplitude are apt to be masked by slight irregularities on the base line, or may not be observed with the amplification used. On the other hand, if the method is carried out uniformly as regards amplification and recording procedure, it has proved to be quite serviceable in clinical practice. Deviations from normal conditions have been distinctly observed in different pathological material (Kugelberg, 1949). In clinical routine, however, exact measurements from tracings are seldom necessary, but can be replaced with observation of the activity on a large screen with a time scale, or with Bauwens' (1948) ingeniously designed apparatus.

It is evident that the electrode type used affects the recorded duration and amplitude of the action potentials. As regards the duration, the results with the concentric needle electrodes of the same dimensions or thicker than those used here are comparable with those obtained with the monopolar needle. This, however, does not apply to the amplitude. We have also the impression that the concentric needle electrodes should not be too obliquely cut. Some measurements were made. Greatly bevelled electrodes seemed often to produce distorted action potentials of somewhat shorter duration than our standard electrodes. Moreover, they were liable to cause contact defects at the tip, and on some occasions to cut off all action potentials to a few milliseconds.

The very short values obtained with the double electrode may be explained not only by its other physical properties as compared with that of the standard types, but also by the great selectivity of the electrode itself. If the selectivity is sufficiently marked, the electrode will take up activity from a smaller part of the motor unit than a less selective electrode. This because the motor unit has a large distribution, not only lengthwise along the muscle (Cooper, 1929), but also in width, which is due to the fact that the muscle fibres composing the motor unit do not form a close bundle, but are scattered and intermingled with muscle fibres from other units (Wohlfahrt and Wohlfahrt, 1935; Brodal and Refsum, 1942).

It is evident that, in order to obtain comparable results whenever quantitative measurements are made in regard to duration and amplitude, as well as the number of action potentials recruited in the picking-up range of the electrode, the electrode type must be standardized.

The mean of the duration of ten or twenty action potentials shows (within the error of the method) very small differences from case to case among the above-mentioned normal persons between the ages of 20 and 42 years. The duration of the action potentials is evidently a factor in the electromyogram that is well suited for quantitative determinations.

The biceps and interosseous muscles were selected as standard muscles for the purpose of this investigation in view of the fact that they are often subject to pathological changes in different diseases. Moreover, they can be easily examined. The very short values of the facial muscles indicate that the number of muscle fibres in the motor units of these muscles are small as compared with those within the muscles of the extremities and trunk.

A slight prolongation of the duration of the potentials was found at advanced ages. This change may be accounted for on the supposition that the duration of the action potentials had actually become longer. But it may also be merely apparent, being due to the elimination of the action potentials first recruited by the voluntary contraction. In such circumstances the measurements will be made on potentials with a higher threshold for voluntary activation, for the duration of which no normal values are at present available. Seeing that their amplitudes are considerably larger it is plausible to suppose that their durations may likewise be increased. It should be borne in mind that the normal values recorded in this paper refer to the motor units first recruited and which are connected to the nerve fibres with the lowest threshold for a slowly rising current (Kugelberg and Skoglund, 1946), indicating a large fibre diameter. Any process that, more or less selectively, destroys the fibres with the largest calibres will cause the duration determinations to be made on another group of action potentials than that on which the normal values are based. At advanced ages, as shown by Rexed (1944), the calibre spectrum of the dorsal and ventral root fibres shows a tendency to shift to the shorter side, owing to destruction of fibres mainly of large size.

Summary

1. Duration and amplitude of action potentials, as well as the number of recruited spikes in the electromyogram at maximal voluntary contraction, varies with the type of electrode used. To obtain comparable results the type of electrode must be standardized.

2. Some typical forms of action potentials are demonstrated. Polycyclic potentials occur in from 2 to 4 per cent. of the potentials in the biceps and interosseous muscles.

3. The duration of action potentials in the interosseous, biceps, and facial muscles in adults are statistically defined. With old age the duration is somewhat lengthened. Its cause is discussed.

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