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" INSERTION ACTIVITY " IN ELECTROMYOGRAPHY

WITH NOTES ON DENERVATED MUSCLE RESPONSE TO CONSTANT CURRENT

BY

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Introduction

In clinical electromyography the muscle is examined not only in regard to voluntary activity and "spontaneous" activity, but also as regards the response on mechanical stimulation by the exploring needle electrode. According to Weddell and others (1944), the response of the normal muscle consists of a short outburst of action potentials which can be distinguished from normal motor unit action potentials of neural origin only by the mechanical manner of production. They term these action potentials " insertion motor unit action potentials."

In denervated muscle Weddell and co-workers demonstrated that the outburst lasted appreciably longer, and that the action potentials evoked were identical with those of the spontaneously contracting individual muscle fibres of the denervated muscle, that is, the fibrillary action potentials.

In view of the diagnostic importance of the mechanical irritability, we systematically examined it in the normal, and in the denervated muscle, as well as in different forms of muscular dystrophy. Our report includes also an observation on the response of denervated muscle to constant current.

Material and Method

Material.—The observations in this article are based on examinations of a large number of normal cases ; one hundred cases of lower motor neurone lesions of different degree, duration, and ætiology ; and fifteen cases of muscular dystrophy (five cases of the common proximal form, eight cases of a distal form, described by Welander (1946), and two cases of *dystrophia myotonica*).

Method.—Coaxial needle electrodes have chiefly been used, vertically suspended to avoid unnecessary bending and pressure. Occasionally, lacquered sewing needles have been used monopolarly, with a reference electrode on an inactive spot a short distance from the muscle being examined. The action potentials were led off to a one-channel balanced condenser-coupled amplifier (time constant about 1/30 sec.) connected to one beam of a cathode-ray tube, the other beam of the tube being connected to an oscillator which recorded the time. The recording methods have been described in detail elsewhere (Kugelberg, 1947 ; Petersén and Kugelberg, 1949).

The mechanical response of the muscle was tested by gently bending or pressing on the needle electrode. Bipolar stimulation with constant current was used in some experiments. It was not considered necessary to record the form of the current.

Results

Normal Muscle.—On insertion and bending of the needle electrode, the normal muscle responds with a burst of repetitive action potentials (Fig. 1A). Led off with a concentric needle, the amplitude for the latter is, on an average, lower, and the duration shorter, than for ordinary motor unit action potentials, but longer than that of the fibrillary action potential. The mean of the duration of twenty counted potentials, in two different cases was, in the biceps muscle, 4 msec., (the mean for twenty voluntary induced potentials in this muscle ranged between 6·3 and 8·9 msec.; Petersén and Kugelberg, 1949). Many potentials, however, have an amplitude and duration which are identical with either motor unit or fibrillary action potentials.

The frequency of discharge is high at the start, up to 200 per sec. (Fig. 1B). The muscle may then suddenly stop firing without changes in frequency, or with a few irregular or regular beats of lower frequency. The response does not generally outlast the actual shifting of the needle for more than a few tenths of a second. If a light, constant pressure on the needle is applied, the repetitive response may occasionally continue a few minutes longer.

Sixteen subjects without known neuromuscular disorders, between the ages of 20 and 40 years, were systematically examined for mechanical response to the exploring electrode. The extensor group of the forearm, the interosseous muscles, and the biceps were examined altogether at ten different points on each individual. In six of these cases (38 per cent.) it was shown that at one or two points it was possible to elicit activity which, after the needle had been placed in position, lasted from one to ten minutes or longer. Such discharge was mostly irregular, with a frequency of 1-20 per sec. (Fig. 1C and D). The potentials might be ordinary motor unit potentials as in fasciculation (Fig. 1C). They might also have little amplitude and duration, as in fibrillation (Fig. 1D and E). The activity was distinguished from reflex or voluntary discharge in that it was generally irregular even if the frequency was relatively high, 10-20 per second. With the needle in a fixed position, the action potentials have a constant polarity, indicating that they pass the electrode from the same direction. The activity in question cannot be voluntarily controlled. It does not disappear on relaxation, nor does it increase in frequency on slight voluntary contraction. On the other hand, it appears to be influenced by the needle. A slight pressure or bending may increase the frequency while a discharge is going on, start new ones, or reactivate potentials which had stopped.

Denervated Muscles. *Response on Mechanical Stimulation.*—After the muscle is deprived of its motor nerve supply, insertion potentials of the fibrillary type appear somewhat earlier than spontaneous fibrillation. When the muscle is reinervated or undergoes morphological changes resulting in fibrosis, the spontaneous fibrillations disappear and, later on, even the fibrillary insertion response.

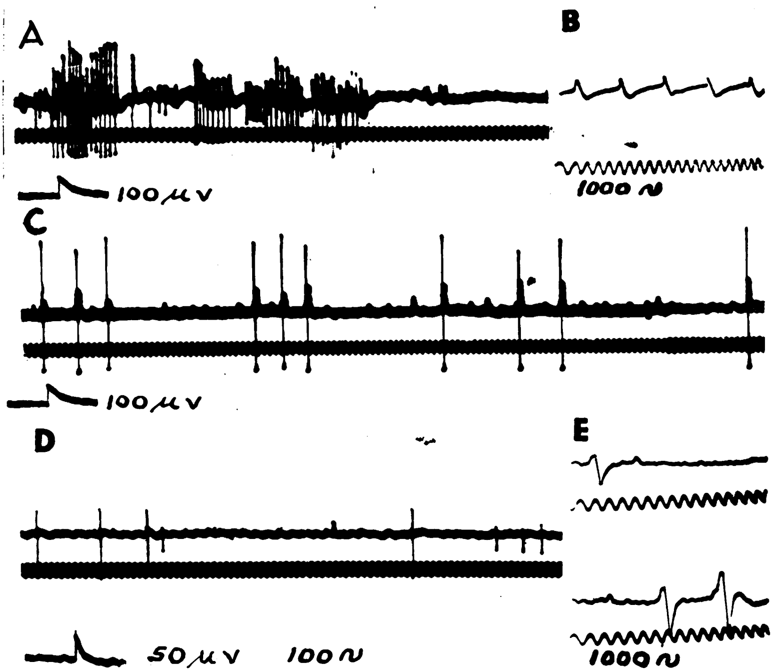

FIG. 1.—Normal muscle. Response on mechanical stimulation. A : Short bursts of repetitive action potentials. B : Detail picture of a burst, with action potentials of 4 msec. duration and frequency of about 200 per sec. C and D: Protracted irregular activity with action potentials similar to ordinary motor unit potentials (C), and fibrillations (D). E : Detail picture of the potentials in D. Amplitude about 100 µ V. Duration 2 and 4 msec.

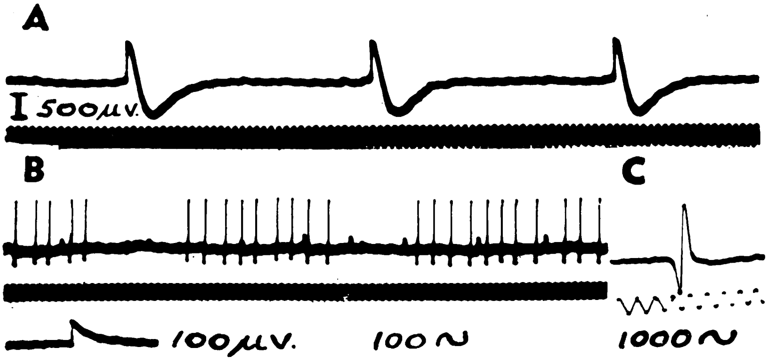

FIG. 2.—Completely denervated muscle. Mechanical response. A : Synchronized activity. Amplitude of potential 1·5 mV. Duration 130 msec. B : The same muscle : repetitive fibrillary activity. C: Detail picture of potential in B.

By the insertion of the needle into an extensor muscle of the forearm in a case with divided radial nerve, a repetitive response of a single fibrillary action potential is evoked (Fig. 2B). The duration is about 1·5 msec., and the amplitude 300 μV. (Fig. 2C). The potential has a duration and amplitude within the limit for the spontaneous fibrillation potentials, and probably corresponds to the activity in a single muscle fibre.

In the same muscle one obtained, however, as a response, potentials of an entirely different appearance (Fig. 2A). A " sharp-rising " phase is followed by long " after-potentials," which are too long to be registered correctly with the type of amplifier used. The amplitude in this case was 1·5 mV and the duration 130 msec. Such potentials occur less often than the insertion fibrillation. They nevertheless constitute a characteristic and common response to

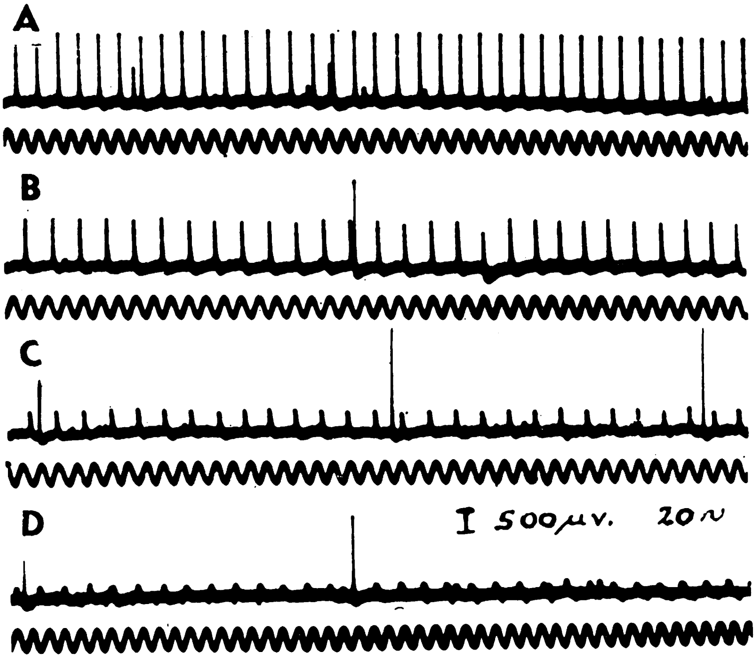

FIG. 3.—Denervated muscle. Repetitive synchronized activity with constant frequency gradually diminishing in amplitude as discharge continues. A : After five minutes. B : After ten minutes. C : After fifteen minutes. D : After twenty minutes.

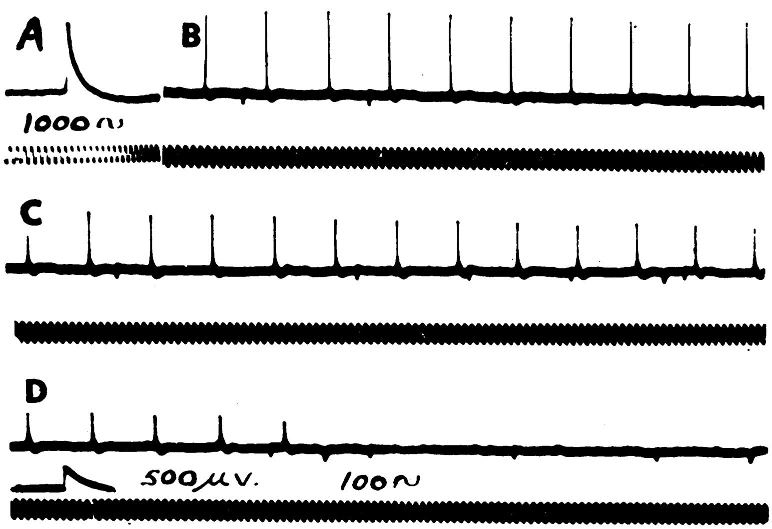

FIG. 4.—Denervated muscle. Synchronized muscle. A : Detail picture of potential in B. Amplitude 1·8 mV. Duration about 16 msec. B, C, and D : Repetitive discharge with constant rhythm, suddenly ceasing

the stimulation of the denervated muscle.

The maximal values observed for amplitude and duration are 4·5 mV and 200 msec. Otherwise we find all transitions down to the size of the fibrillary action potentials. Led off monopolarly, the first phase of the potentials is most often positive, followed by a negative phase.

The frequency of the impulses in a single series is occasionally as low as 1 per sec., or as high as 100 per sec. It usually ranges between 5 and 20. The rhythm is usually regular, but irregular or random discharges may occur. The duration of an impulse series which follows excitation varies within wide limits. Sometimes a single potential can be followed for 30 minutes or more (Fig. 3). Sometimes the potential is repeated merely a few times. An impulse series may suddenly cease, as a rule without slowing down the rhythm (Fig. 4). Several adjacent foci may discharge with independent rhythm (Fig. 5).

The size that the potential reaches, which may be larger than that of the ordinary motor unit discharge, indicates that it is composed of synchronized activity from many muscle fibres. Often the amplitude of a single repetitive action potential decreases continually, indicating that fibres gradually drop out from the beat (Figs. 3 and 4). Gradual decreasing presupposes that the potential has a certain size. If there are merely a few muscle fibres in the focus, the falling out of a single muscle fibre is naturally more noticeable, whence the potential can be seen to decrease abruptly (Fig. 6). This figure shows in a continuous film a repeating action potential which again and again suddenly decreases in amplitude about 50μV, corresponding to the amplitude of a fibrillary action potential. At the same time the frequency diminishes, but reverts to the original rate when the lost component returns. The change in frequency may be explained by spontaneous fluctuation in the excitability of the focus. When the excitability increases, the frequency is raised, and one or more muscle fibres are recruited, falling out again when the excitability diminishes.

Response to Constant Current.—The slow and prolonged contraction of the denervated muscle in response to stimulation with a constant current was suggested by Bremer (1932) to be a contracture accompanied by a non-oscillatory negativity. Doupe (1942) showed, however, that a repetitive response was readily caused by a constant current. He concluded that the galvanotonus had the character of a tetanus rather than of a genuine contracture. He made no attempt to observe the single action potentials, to establish their type or directly follow their repetitivity.

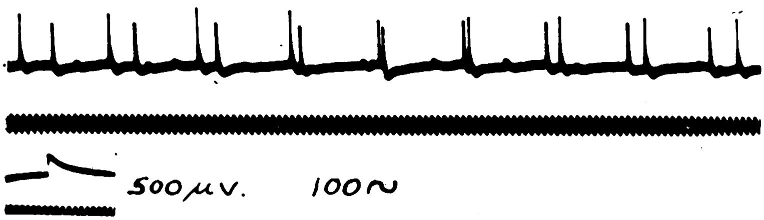

FIG. 5.—Denervated muscle. Two different potentials, discharging independently.

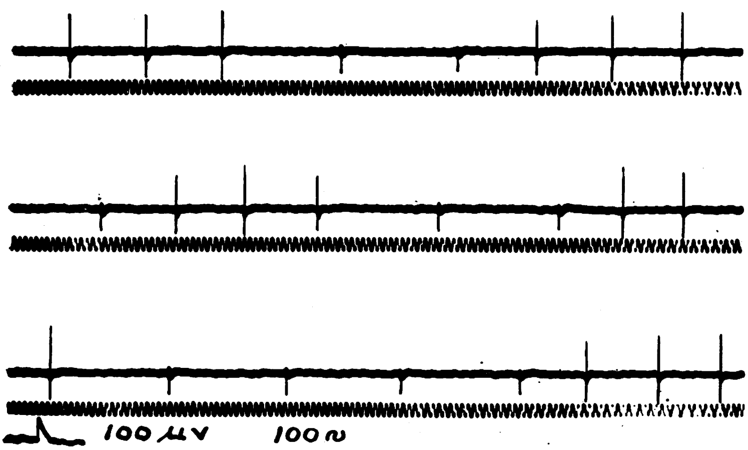

FIG. 6.—Denervated muscle. Repetitive insertion potentials with sudden dropping out of potential components and slowing down of rhythm.

Fig. 7 shows the response to stimulation of the anterior tibial muscle in a case with sciatic nerve lesion leading to complete denervation of the muscle. The strength of the constant current was 10 ma. The activity was led off with a concentric needle electrode 5 mm. distal from the anode, with the cathode proximal to the anode. The current gave rise to a galvanotonus which was accompanied by the same type of activity already described as response to mechanical stimulation, that is, a mixture of fibrillary action potentials and synchronized activity (Fig. 7A). If the current was continued,

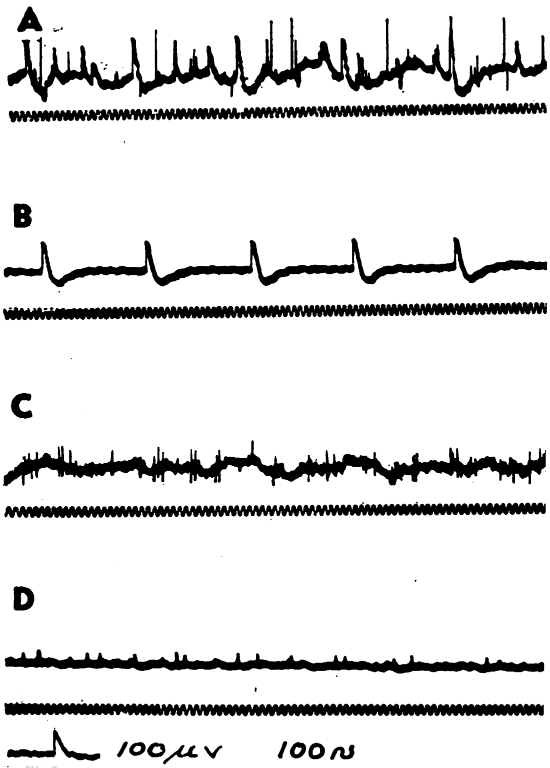

FIG. 7.—Response of denervated muscle to constant current. A : Immediately after closure of current a repetitive discharge of fibrillary and synchronized activity. B : The current still on : After two minutes, only one large potential remains, repeating with almost the same frequency as in A. C and D : The same as A and B, from another muscle, but predominantly of fibrillary type.

the visible muscle contraction gradually subsided, according as one potential after the other dropped out. Finally, merely one relatively large spike (Fig. 7B) remains and goes on repeating with constant frequency, suddenly stopping several minutes later. Sometimes the response is predominantly of the fibrillary type (Figs. 7C and D).

The frequency of the single action potential changes remarkably little, as the contraction of the muscle diminishes owing to its adaptation to the stimulating current. In this way it differs from the reaction of the human motor nerve fibre, which shows a much less rigid response. Under similar conditions in nerve stimulation the frequency changes within wide limits (Kugelberg and Skoglund, 1946).

Muscular Dystrophies.—Irrespective of the type of dystrophy, the mechanical irritability of the muscle tends to diminish according as the wasting increases. The great majority of the potentials that can then be elicited have a small amplitude and duration, thus resembling fibrillary action potentials. The short duration of the insertion potentials may be due to the fact that the number of muscle fibres in the motor units is so reduced by the pathological process that merely a few may be left in each unit. In myopathies the voluntarily induced potentials undergo a similar change (Kugelberg, 1947, 1949).

In muscles where the wasting process has not gone so far, the mechanical irritability differs somewhat in the various forms of dystrophy. In the common proximal form the response resembles that of the normal muscle, except that the fibrillary type of response predominates. A short outburst of high-frequency discharge, or occasionally, prolonged repetitivity is obtained. In the distal form the irritability may here and there be intensified. It may then be considerably easier to elicit prolonged high-frequency or low-frequency responses. Occasionally, as is usual in myotonia, the recorded activity may apparently continue indefinitely after the insertion of the needle. In such cases it is difficult to determine whether the activity has really been initiated by the mechanical irritation or whether it is spontaneous.

In dystrophia myotonica the mechanical irritability, as is well known, is greatly intensified (Brown and Harvey, 1939 ; Denny-Brown and Nevin, 1941 ; Buchthal and Clemmesen, 1941). A prolonged response can be obtained anywhere in the myotonic muscle. A high-frequency response predominates, but prolonged slow, regular or irregular, discharges occur. The action potentials may be of the fibrillary type or, more or less, of the motor unit type. Large repetitive potentials, probably due to synchronized activity from several motor units, may occasionally be seen.

There are thus similarities between the distal form of muscular dystrophy and the denervated muscle as well as myotonia, as regards the mechanical irritability. However, no involvement of the lower motor neurone has been found at autopsy (Welander, 1949), nor any clinical myotonic signs which could explain these similarities. We may therefore assume that during some stage of the dystrophic process the irritability of the muscle may be increased in this disease.

Discussion

The prolonged repetitive activity observed when exploring apparently normal muscles with needle electrodes is probably induced by mechanical stimulation and injury of muscle fibres and intramuscular nerve branches. The phenomenon is of practical importance, as it may be a source of error. The repetitivity, if prolonged for many minutes, may be indistinguishable from either spontaneous fasciculation or fibrillation, depending on the appearance of the potentials. In normal muscles, however, there are but few points from which prolonged repetitivity can be induced in this manner.

The large synchronized activity in denervated muscles which occurs as a response to mechanical and electrical stimulation has not been observed in the normal muscle. A greatly increased irritability is doubtless necessary to bring about this result.

This form of activity almost invariably co-exists with insertion fibrillation, and the frequency of discharge in both is similar. It may be presumed that the synchronized activity is actually a synchronized fibrillation. Its occurrence in completely denervated muscle shows that synchronization, at any rate here, takes place extraneurally, being possibly induced electrically from some fibres acting as "pacemakers." The spontaneously occurring synchronized activity described by Adrian and Gelfan (1933) in frog muscle in the case of calcium deficiency, is closely related. So also is the spontaneous synchronized discharge observed by Harvey and Kuffler (1944) in the denervated muscles of the hypothenar eminence in one patient. In that case the action potentials could be led off with surface electrodes, and the accompanying muscle twitches could be observed through the skin with the naked eye. They assumed that the spontaneous activity may have originated in the region of the motor end plates. However, since the synchronized discharge caused by insertion is a typical and common symptom of the denervated muscle, the spontaneous synchronized activity seems to be rare. Its appearance is of definite diagnostic value.

The electromyographic diagnosis should not be based merely on single factors, such as the type of insertion activity and the occurrence of spontaneous activity, which, though often valuable indications, may not be specific signs. The duration, amplitude and form of voluntarily induced potentials must also be considered, as well as the number of recruited spikes in the picking-up range of the electrode on maximal voluntary contraction, evaluated against the force exerted. When all these factors are judged in relation to the symptoms and signs observed in the clinical examination, electromyography will give exact and conclusive diagnostic information.

Summary

The response of normal, denervated, and dystrophic muscle to mechanical stimulation by the exploring concentric needle electrode has been investigated, as well as the response of the denervated muscle to stimulation by a constant current.

Normal Muscle.—The response consists of a high-frequency discharge of action potentials. The average amplitude and duration is somewhat less than that of motor unit action potentials, though potentials of the same size as motor unit or fibrillary action potentials are common. The response does not generally outlast the actual shifting of the needle by more than a few tenths of a second. An irregular response lasting several minutes, which may be indistinguishable from either fasciculation or fibrillation, occasionally occurs.

Denervated Muscle.—(a) Needle. The response consists of an often prolonged repetitive discharge of the fibrillary type and synchronized activity discharging chiefly at a constant rhythm with a frequency of 1-100 per sec. The synchronized discharge may continue for 20 minutes or more, during which time amplitude and duration generally diminish. The synchronization is brought about extraneurally. (b) Constant Current. The response consists of fibrillary and synchronized repetitive activity which accompanies the galvanotonus.

Dystrophic Muscle.—The mechanical irritability tends to diminish according as the wasting increases. Otherwise, the irritability is rather normal in the common proximal form, while in the distal form it may be increased here and there, and in the myotonic muscle is greatly increased. The action potentials evoked are often of the fibrillary type in all three forms.

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