ELECTROMYOGRAPHY IN MUSCULAR DYSTROPHIES

DIFFERENTIATION BETWEEN DYSTROPHIES AND CHRONIC LOWER MOTOR NEURONE LESIONS

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Introduction

In a recent issue of this journal (Kugelberg, 1947) the electrical activity of voluntary muscle was studied in various forms of muscular dystrophies and lesions of the lower motor neurone, with special regard to differentiation between them.

The electromyographic differential diagnosis between muscular dystrophies and atrophies was formerly based on the finding of Buchthal and Clemmesen (1941) that "single discharge" on maximal voluntary contraction was not observed in genuine myopathy, even in extremely severe cases. In neurogenic lesions, on the other hand, "single discharge" occurred even when the weakness was moderate.

The observation that a decrease in the number of spikes relatively to the muscular power exerted occurs much later in myopathies than in neurogenic lesions, was confirmed (Kugelberg, 1947). "Single discharge," however, was regularly observed even in myopathy, provided that the changes were sufficiently advanced. As no diminution in the number of spikes could be observed in mild cases of myogenic and neurogenic paresis, and as both may show "single discharge" when the weakness is extreme, the need of more specific signs of myopathy in the electromyogram became acute. Moreover, it is always unsatisfactory in intermediate degrees of weakness to diagnose the case as myopathy, on the ground that "nothing abnormal can be seen."

A positive symptom of myopathy was found, however, in the occurrence of action potentials of short duration (1 to 2 msecs.). They increase in relative number according as the weakness advances. As regards the material examined, the action potentials observed in the myogenic "single discharge" were invariably of this type. Thus a reliable differential diagnosis could be made in all but the mildest degrees of weakness, being more and more easily determinable as the weakness advanced.

It had been assumed that the characteristic rapid spikes in myopathies were produced by a shortening of the duration of the normal spikes; this and the other changes being accounted for by a process which, more or less diffusely, gradually reduces the number of fibres composing the different motor

units until at length they are completely put out of action.

To test this view, and further to establish the electromyographic picture in muscular dystrophies as well as to differentiate it from diseases of the lower motor neurone, changes in the form of the action potentials have been studied, and measurements of their duration have been made, as reported in this paper. The significance of such measurements can be evaluated quantitatively, as the form and duration of the action potentials in the normal muscle have now been defined (Petersén and Kugelberg, 1949) with the same technique as adopted in the present investigation.

Methods

Concentric needle electrodes were used (platinum wire 0.20 mm. in diameter insulated from a cannula having an outer diameter of 0.5 mm.). The recording procedure has been previously described (Kugelberg, 1947; Petersén and Kugelberg, 1949).

The muscles were examined for (1) the occurrence of spontaneous activity and intensification or lessening of the response on mechanical stimulation by the exploring needle electrode; (2) the form, duration, and in some cases amplitude of the action potentials; and (3) the number of recruited spikes within the picking-up range of the electrode on maximal voluntary contraction compared with the strength of the muscle.

Results

Electrical Activity in Muscular Dystrophies: Proximal Forms.—Seven adults (Cases 1 to 7) and one child (No. 8) with the common proximal forms of muscular dystrophy were examined. In the first place the biceps muscle, in regard to which variations in the duration of the action potentials had previously been determined in normal cases, was examined. Different degrees of weakness were represented: (a) maximal atrophy (Case 1) or pseudohypertrophy (Case 2) with no palpable or clinically observable response to attempts at voluntary contraction; (b) severe atrophy and the bare capacity to flex the joint against gravity (Case 3); (c) severe atrophy and capacity to flex the joint against gravity plus slight active resistance (Cases 4 and 5); and (d) no atrophy, and slight but definite paresis (Cases 6 to 8).

TABLE I
PROXIMAL DYSTROPHY
(Biceps Brachii)

Case	Action potentials counted	Mean	Polycyclic percentage	Duration less than 3 msecs. percentage
1	10	2.4	—	80
2	25	3.3	16	40
3	50	2.3	32	80
4	30	2.8	7	70
5	25	2.7	16	68
6	50	3.9	20	44
7	20	3.9	10	25
Normal values	10	5.8-9.3	4	approx. 1

1. Spontaneous fibrillation did not occur in any case.*

*Particulars of the mechanical response on stimulation by exploring electrode will be published in a later article, and compared with the response in the normal and denervated muscle.

FIG. 1.—The distribution of the duration of action potentials in the biceps muscle in cases of proximal dystrophy. The portions shaded with oblique lines indicate polycyclic potentials.

2. The distribution of the duration is recorded in Cases 1 to 7 (Fig. 1 and Table I). It shows a considerable shift towards the short side relatively to the normal biceps. As expected, action potentials with a normal duration were most numerous where the biceps was clinically least affected (Cases 6 and 7). In other cases there was no strict correspondence between the reduction of the average duration and the degree of weakness. It is also evident that action potentials of normal duration may occur even in advanced stages of the disease. Moreover, in Case 2, with clinical paralysis of the biceps, there were no potentials with a maximal reduction to 1 or 2 msecs. The average duration, however, as in the other cases, was statistically significant, well below the normal limits. The absence of 1 to 2-msec. spikes in muscles with clinically advanced changes is rare, not being observed in any other case. In the same patient they were numerous in other muscles examined.

Owing to the occurrence of action potentials of relatively long duration (4 to 5 msecs.) even in cases of advanced changes, "single discharge," consisting

of normal potentials, may be obtained exceptionally at certain positions of the needle. In such cases it becomes a statistical problem to work out a pathological reduction of the duration of the potentials, as it becomes necessary to sample action potentials from several different needle positions.

Some polycyclic action potentials in muscular dystrophy were observed in one case by Bowden and Gutmann (1946). They also occur normally, however (Denslow and Hassett, 1943; Weddell and others, 1944), to the extent of from 2 to 4 per cent. in the biceps muscle (Petersén and Kugelberg, 1949). An increase in their frequency, or differences in their form and duration, will therefore have to be shown if any significance is to be attached to the findings in dystrophies. Normally the duration is rather long, 8 to 12 msec.

The frequency of polycyclic action potentials was significantly increased in four out of seven cases (Table I). In Case 1 none was discovered. Here the muscle was very severely affected. Only ten different potentials could be found, most of which were of such short duration that no further disintegration could be expected. As shown by the histograms, the duration is mostly below the average for that of the normal action potential, down to 3 msec.

Some typical polycyclic potentials (from Case 6) are shown (Fig. 3). Most of them consist of components of very short duration. They are arranged (C-E) so as to show tentatively how the normal action potential B is broken up, and finally, through the rapid action potential G, is reduced to a potential H, resembling the fibrillary spike (duration about 1 msec. and amplitude about 150 microvolts). (See the discussion.)

3. Patients with extreme paresis (Cases 1 and 2)

find it difficult to maintain a voluntary contraction. The frequency of the individual units as a rule falls rapidly, and the maximal number recruited can be brought into operation for only a few moments. The number of spikes recruited in the picking-up range of the electrode in the attempt at maximal contraction in Cases 1 and 2 was at most four or five, giving rise to typical "single discharge" records (Fig. 4A). The greater part of the muscle in these cases was electrically silent. Here and there one could find individual units and, in places, also streaks with greater activity. When led off to some distance, this activity is of non-characteristic appearance, but suddenly breaks up into distinct spikes if the position of the needle is correct. Shifting of the point of the needle by a fraction of a millimetre will often suffice to bring the activity in or out of "focus."

At the next stages (Cases 3 to 5) there may still be areas which are silent or show "single discharges." In the latter case spikes of pathologically small amplitude usually occur, as well as other activity picked up from some distance; this gives the base line a disturbed and fluffy appearance unlike "single discharges" in neurogenic disorders. The pathological process in advanced cases is apparently not uniform over the whole muscle, but often shows rather patchy distribution in regard to the extent to which the electrical activity is reduced. However, even in such severe weakness, as in Cases 4 and 5, large areas show the massed interference curve of the normal muscle. In Cases 6 to 8 the muscle everywhere showed that type of activity (Fig. 3A).

Late Distal Hereditary Myopathy.—Besides earlier ones (Kugelberg, 1947), eight additional cases (Nos. 9 to 16) of this interesting disease, which has been briefly described by Welander (1945, 1946)

FIG. 2.—The distribution of the duration of action potentials. The portions shaded with oblique lines indicate polycyclic action potentials. Cases 9 and 16, interosseous muscle in distal dystrophy, showing the shifting of the duration to the short side, in contrast to the case of Charcot-Marie-Tooth disease, with shifting of the durations to the long side.

have been examined. The cases are included in material serving as a basis for a monograph on the disease in course of publication (Welander, 1949).

As distal myopathy, "myopathia distalis tarda hereditaria," is a hitherto little-known disease, it seems desirable to give a short summary of Welander's description. Distal myopathy, as shown at autopsy, is a primary muscular disease. The heredity is dominant. The onset may occur at any age between 30 and 82, but most commonly between 40 and 50, with gradually increasing weakness and wasting of the hands, and later also of the feet. Predominantly it is the intrinsic muscles and the extensors of the distal parts of the extremities that are involved. The disease progresses very slowly and seldom affects muscles proximal to the elbow- or knee-joints, even after a duration of 30 to 40 years.

TABLE II
DISTAL DYSTROPHY
(Interosseous Muscles)

Case	Action potentials counted	Mean	Polycyclic percentage	Duration less than 3 msecs. percentage
9 (161)*	25	2.6	32	64
10 (23)	25	2.4	24	76
11 (7)	26	2.6	46	65
12 (75)	25	2.2	12	80
13 (30)	50	3.9	24	36
14 (157)	25	2.3	36	80
15 (34)	50	4.1	24	26
16 (159)	45	3.8	24	33
Normal values	20	6.5-8.8	4	approx. 4

*The case numbers in parentheses are those in Welander's monograph.

It seems scarcely necessary to enter into details regarding the electromyogram in distal myopathy, as it shows essentially the same features as the proximal forms. The average duration of the action potentials, the percentage of rapid spikes, and also the percentage of polycyclic action potentials are shown in Table II. The result, as we see, is much the same as in the proximal dystrophies. A statistically significant reduction of the average duration is observable.

In Cases 9 to 15 the interosseous muscle was severely atrophic and paretic. In Case 16 neither atrophy nor weakness of this muscle could be definitely ascertained. The patient had a strong hereditary predisposition to the disease and an undoubted weakness in the extensors of the fingers, whence it might be expected that the first interosseous muscle would also be affected. The clinical examination gave no reliable guidance in this respect. Quantitative determination, however, showed a statistically significant reduction of the

average duration, as also a pathological increase in the number of polycyclic potentials and of potentials with a duration of less than 3 msecs. (Table II and Fig. 2.) Thus, though the diagnosis of "myopathy" can usually be made solely after inspection of the activity on the screen, it may be extended by quantitative determinations of the duration so as to cover even very mild cases of weakness.

Some polycyclic action potentials are shown in Fig. 5 (B-E). C-D are examples of the double spike commonly observed in dystrophy, with components of very short duration. Types C-D are hardly ever seen in the normal interosseous muscle, and very rarely in the large muscles of the extremities, but are not uncommon in the facial muscles, where the action potentials even normally have a short duration.

The interval from the beginning of the first action potential to the beginning of the second in the group is usually less than 4 msecs. In regard to the same double spike the interval is as a rule constant, though minor variations may occur. At different positions of the needle, however, the variations are considerable; sometimes the two components can be brought approximately to coincide if the position of the needle is shifted. The components may differ in amplitude, form, and duration, or they may be rather similar, as in the Figures.

Differential Diagnosis

The differential diagnosis between muscular dystrophy and lesions of the lower motor neuron in acute stages or during re-innervation is, clinically speaking, comparatively easy, and will not be discussed here. It is usually indicated by the case history. The differential diagnosis from chronic lesions such as degenerative diseases of the lower motor neuron may, however, be very difficult in certain clinically atypical cases. Here the electromyogram may be of decisive importance. In particular, it may be difficult in the routine clinical examination to distinguish proximal spinal muscular atrophy from the proximal forms of dystrophy, as also the Charcot-Marie-Tooth type of neural atrophy from the distal forms of myopathy.

No less than 142 cases of chronic lesions of the lower motor neuron have been investigated. Among these cases, nineteen represent the Charcot-Marie-Tooth type of progressive muscular atrophy, thirty-eight amyotrophic lateral sclerosis, four proximal spinal atrophy, fourteen anterior horn-cell lesions due to other causes, six multiple neuritis, etc. The electromyographic change, in almost every respect, differed from those in muscular dystrophy being marked by:

FIG. 3.—Muscular dystrophy (Case 6). Records from the biceps brachii.

A. Activity of voluntary contraction gradually increasing in strength, showing on strong contraction the interference activity of the normal muscle. Time 1/100 sec.

B. Collected action potentials with different forms and durations which are arranged B-H, to show tentatively how the normal action potential B is broken up and at last reduced to a potential H resembling the fibrillatory spike. Calibration in this and the following records, 100 microvolt. Time 1/1000 sec.

FIG. 4.—Muscular dystrophy (Case 1). Records from the clinically paralytic biceps muscle.

A. Activity at maximal voluntary contraction. Only two different action potentials are recruited. Time 1/100 sec.

B. Detail pictures of these potentials. Time 1/1000 sec.

FIG. 5. Muscular dystrophy distal form (Case 10), showing different action potentials of dystrophy type. Described fully in the text. Time 1/1000 sec.

1. spontaneous fibrillations as well as greater response on mechanical stimulation by the exploring needle electrode (Denny-Brown and Pennybacker, 1938; Weddell and others, 1944; Jasper, 1947; and others);

2. greater duration (Buchthal and Clemmesen, 1941) and larger amplitude (Denny-Brown and Pennybacker, 1938; Kugelberg, 1947) of the action potentials.

3. even in cases of moderate weakness a marked reduction in the number of spikes on maximal contraction (stressed especially by Buchthal and Clemmesen, 1941, 1943; also observable with the plate electrode technique, see for example, Richter and Ford, 1928, and Altenburger, 1937).

Spontaneous fibrillation and greater mechanical irritability has always been observed in the present material during the first year after the onset in cases of extensive denervation due to acute or rapidly progressive lesions. On the other hand, such fibrillar contractions have often been lacking in cases of slight partial damage or extensive lesions of long duration where the muscle has become indurated, a symptom which is felt on penetration by the needle.

A more or less prolonged average duration as also a greater amplitude of the action potentials is a common observation in chronic neurogenic lesions, as exemplified by the histogram from Case 128 (Fig. 2) of the Charcot-Marie-Tooth type. In long-standing cases of advanced atrophy with the muscle in a bad condition, the duration and amplitude of the potentials are often normal; or else the amplitude may even be, on an average, smaller than normal. The duration in such conditions may very rarely also be shorter than normal. This may be

due to secondary changes of myopathic type due, say, to inactivity or ischaemia.

Polycyclic action potentials are common in cases of muscular atrophy (Jasper, 1947; as regards poliomyelitis, see for example, Rohmer and others, 1947). The polyphasic potentials usually have a rather long duration (see the histogram),

A marked reduction in the number of recruited spikes is clearly observable even in cases of moderate weakness. If, for example, the muscular force is reduced by 50 per cent., the number of spikes, roughly estimated, will have been reduced in the same proportion. One will then obtain records where the potentials cover the base-line but are definitely reduced. In certain lesions of long standing but with good functional repair we note that, despite only a slight loss of muscular force, the number of potentials is greatly reduced. Evidently the force which the average individual potentials represent has increased relatively to that which they represent in the normal muscle. The amplitude and duration in such cases are particularly marked.

By duly observing the characteristics now enumerated, it has been found possible to differentiate with certainty between muscular dystrophies and atrophies. One should, however, systematically examine the muscle, part by part, with careful observation of the activity on the screen, beginning with the muscles most affected. Should it occasionally happen that a characteristic picture of the muscle cannot be obtained, it is advisable to pass over to other muscles in different stages of disease.

Discussion

In the dystrophy cases examined, the electromyogram is characterized mainly by the following features:

1. The average duration of the action potentials is diminished, and the number of potentials with a duration of 1 to 3 msecs. is increased.

The form of the action potentials is changed in that in most cases a pathological number of polyphasic potentials is observed. They usually have a shorter duration than the average normal action potential. A diminution of the spike amplitude may be ascertainable.

2. Even if the paresis is considerable, the interference activity of the normal muscle is still found. Approximately when the muscle is just able to produce a movement in the joint, single discharges are observed.

There can be little doubt that these changes are due to a process which more or less diffusely reduces the number of muscle fibres in the different units until they are put out of action.

The action potential of the single muscle fibre, as seen in fibrillation, has a duration of 1 or 2 msecs., and an amplitude of 50 to 100 microvolts (see for example, Weddell and others, 1944). The action potential of the normal motor unit is of considerably longer duration (3 to 15 msecs.) and of larger amplitude. The generally accepted explanation of the longer duration of the latter is that not all the muscle fibres in the unit picked up by the electrode are acting in phase. The synchronization is not complete. A gradual diminution in the number of fibres composing the unit should thus, as is the case in dystrophy, tend to reduce the duration of the action potentials, and, in a minor degree, the amplitude. The reduction in the number of fibres may proceed until only a single one is left in the unit. The action potentials at this stage should be similar to those in fibrillation. In fact such potentials are by no means uncommon (Fig. 4b).

A reduction in the number of fibres composing the "motor unit" should, however, not only diminish the duration and amplitude, but also modify the form of its potential. It may, in fact, be presumed that the muscle fibres are put out of action in the unit in an irregular way—now one participating in the formation of the potential at the outset, now one acting in the middle or just at its termination. If the activity happens to be sufficiently reduced by elimination of muscle fibres except at its very outset or termination, the potential would be split up. We should then expect polyphasic action potentials. The duration of the latter, as is the case in dystrophies, should usually be shorter than that of the normal action potentials, seeing that, at all stages down to those where the unit is composed merely of a few synchronously acting fibres, they may be disintegrated in this way.

Slight polyphasicity may also result from a functional disintegration of the action potential, due to disturbances in the transmission of the impulses to or through the degenerating muscle fibre. The occasional elimination of one component in a polyphasic complex indicated the existence of such disturbances. The double or triple spikes shown in Figs. 3 and 5 might also be explained by a repetitive response in the muscle fibre or end-plate. Seeing that the mechanical and electrical irritability is reduced in the dystrophic muscle, this explanation is not very convincing, but may possibly hold good in myotonia. Nor are these spikes identical with the double spikes which sometimes occur under normal conditions (Gilson and Mills, 1941; Denslow, 1948) and regularly in tetany (Turpin and others, 1943; Kugelberg, 1948a) or in ischaemia (Kugelberg, 1946, 1948b), being due to repetitiveness in the motor neurone or nerve fibre (Kugelberg, 1948a and b). These spikes, unlike those observed in dystrophy, become single when the frequency rises, and the interval between them is considerably longer, about 7 msecs. The polyphasicity of the action potentials is due mainly to an anatomical disintegration of the motor unit.

The marked diminution of the muscular force despite the relative maintenance of the number of action potentials indicates that the force represented by the individual potential has been reduced. This, of course, is also due to the diminution in the number of muscle fibres in the different units. The immense reduction of the average force in the units can be most clearly observed in cases of distal myopathy. Electromyographically the small hand muscles can, in fact, be far more easily surveyed and accurately controlled than the larger muscles. In order to make a minimal adduction of the second finger, only a few potentials in the first interosseous muscle need normally be brought into operation. In the diseased muscle, however, twenty, thirty, or more potentials will perhaps have to be mobilized in order to attain the same result.

The area of distribution in the dystrophic muscle of the unit represented by the action potential is moreover much smaller than in the normal muscle. If one tries to survey the area from which the dystrophic potential (1 to 2 msecs.) can be recorded, we shall find that minimal shifting of the needle will reduce the amplitude to zero. In order to get such a result in the normal muscle, the needle would have to be shifted about 1 cm. (Denslow and Hassett, 1943).

To sum up: the fact that the dystrophic process operates on the muscle fibres is the basis of the changes described in the duration, form, amplitude, distribution, and force of the action potentials.

These changes are not specific for dystrophy: they occur also in other conditions of myopathy. As has been shown, however, they give a firm basis for differential diagnosis from chronic neurogenic disorders, which do not primarily operate on single muscle fibres, but on nerve fibres, and thus on whole units.

Summary

Muscular dystrophy (eight cases of the proximal type, eight of a distal type) and various forms of chronic motor neurone disorders (142 cases) have been subjected to electromyographic analysis, with the following results.

A. The dystrophies show:

1. (a) The distribution curve for the duration of the action potentials is shifted towards the short side. In all recorded cases the mean of the durations showed a significant decrease, whereas the relative number of action potentials with a duration of less than 3 msecs. had increased.

(b) The relative number of polycyclic action potentials showed a significant increase in twelve out of fifteen cases. They usually have a shorter duration than the action potential in the normal muscle.

(c) A decrease of the spike amplitude may be ascertainable.

2. The interference curve of the normal muscle on maximal voluntary contraction is found also in cases of severe weakness. Roughly speaking, when the muscle is just able to perform a movement in the joint, "single discharge" is observed. The reduction in the number of spikes in advanced cases shows a patchy distribution in the muscle.

3. The strength represented by the dystrophic 1- to 3-msec. action potential, and the area from which the action potential can be recorded, are greatly reduced as compared with normal muscle.

All these changes are due to a process which, more or less diffusely, reduces the number of muscle fibres contained in the individual functional units represented by the action potentials.

B. The chronic lesions of the lower motor neurone show one or more of the following characteristics:

1. Spontaneous fibrillation. Greater response to the exploring needle electrode.

2. Greater duration and larger amplitude of the action potentials. Polycyclic potentials may occur.

The latter usually have a longer duration than the average action potentials in the normal muscle.

3. The number of spikes is more or less reduced in proportion to the diminution of the muscular force. In some cases with good functional repair, however, the reduction in number is far more pronounced than the weakness. Single discharge thus occurs in moderate paresis, and in the latter case even when it is slight.

The changes in chronic lesions of the lower motor neurone are thus entirely different from those in myopathies, which is due to the fact that neurogenic disorders operate on nerve fibres and thus on whole motor units, instead of primarily on single muscle fibres and parts of units. Electromyography facilitates a reliable differential diagnosis between the two.

The Editor wishes to take this opportunity to apologise for an error which occurred when the illustrations to the article by Kugelberg published in this Journal in 1947 (see references) were being prepared for press. The electrical tracings were unfortunately allowed to be touched up by hand, and this circumstance was not discovered until after the Journal had gone to press.

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