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ELECTROMYOGRAPHICAL STUDY ON SPONTANEOUS MUSCULAR ACTIVITY

KAZUHIKO HIROSE

1st Department of Internal Medicine, Nagoya University School of Medicine (Director: Prof. Susumu Hibino)

ABSTRACT

An experimental study of rats on the fibrillation potential of denervation and the spontaneous electrical activity of normal muscle was carried out chiefly to find their differential key points.

As the results, fibrillation potentials in denervated muscle on the 21st day after denervation were recognized to be spike potentials with the initial positive phase. But this prescription had to allow the condition that fibrillation potentials would be found only infrequently in normal muscle at rest, so quantitative consideration that these potentials should be found at least in more than two points of a muscle was taken in order to be regarded as a sign of denervation.

In normal muscle, four types of spontaneous electrical activities were recognized clearly. The first type was the irregularity of the base line which was suggestive of negative monophasic activity, and provisionally named the end plate noise according to Buchthal's opinion. The second type was a spike potential with a prominent initial negative phase and called nerve potential according to Jones and supposed to be regarded not as a type of fibrillation potentials but as a normal sign. These two potentials were inferred to be dual under present conditions. The third type was fibrillation potential and the fourth type was so-called myotonic activity. The other activity was seldom found in normal muscle.

It is well known that the spontaneous electrical activity is one of the most important findings in electromyography as well as the motor unit action potential during voluntary contraction. Fibrillation potential is especially a significant one, because it is the only electromyographically visible sign of fibrillation of denervation, which was first studied in detail by Brown[1] and Denny-Brown[2]. But in practice, difficulties have occasionally been experienced to differentiate it from so-called insertion activity of normal muscle, which sometimes occurs and lasts much longer than the actual movement of the electrode, as Kugelberg[3] pointed out already.

It has been generally considered that this prolonged insertion activity, which Jones[4] called nerve potential, has two components: the irregularity of the base line and the spike potential.

廣瀬和彦

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Recently Buchthal[5)6)] reported, however, that the irregularity of the base line was called the end plate noise or ripple by the reasons why this activity was recorded solely in end-plate zones and similar to the miniature end plate potential reported by Fatt and Katz[7)]. Moreover, he stated that it was to be situated newly in spontaneous electrical activities of EMG, and he deduced that the difference between what is called fibrillation potential and the spike potential as a second component of nerve potential was only the difference between the sites of the recording electrode in a muscle at rest, that is, the former was recorded outside the end plate zone, and the latter within the end plate zone. This Buchthal's opinion may be very suggestive but should be scrutinized critically.

Up to this time, fibrillation potentials have been studied generally on the totally denervated muscle, and so easily regarded as a sign of denervation with making little light of its characters as wave form, and frequency or rhythm. But many points remain undetermined on its characters, not to speak of its substance. Therefore, its pathognomonic significance will not be determinative but investigative.

The chief purpose of the study is to clarify what the distinctive characteristics of the fibrillation potential of denervation and its pathognomonic significance in practice are. Furthermore, observations are included of spontaneous electrical activity of normal muscle chiefly in comparison with the fibrillation potential of denervation. In this report, "spontaneous" means that testing muscle is at rest and that a movement of recording electrode stops[8)].

MATERIALS AND METHODS

Adult white rats were used. In EMG activity, rat muscle behaves similarly to various mammalian species including man[16)]. Operations and electromyographic observations were made under Nembutal anesthesia (50 mg/kg intraperitoneally). Denervation was accomplished by resection of the deep peroneal nerve near the fibula by roughly 1 mm.

The exposed normal and denervated tibialis anterior muscle was studied. Observations of the denervated muscle were made on the 21st day after nerve resection, which was most adequate to recording and analyzing of fibrillation potentials of denervation because of the separation of each potential.

Recording electrodes used were conventional single-core needle electrode (concentric or coaxial) and bipolar electrodes. The bipolar electrodes consist of a pair of silver wires of 100 μ diameter, separated by an interval of 1 mm and coated with an insulating adhesive (Araldite), except for a fraction of a millimeter at their tips. For recording the electromyogram, an electromyograph (Electrostimulo-analyzer HM-301 S) and a camera with continuously moving photographic paper (Cannon Photo-Oscilloscope Unit Model-IV No. 10289) were utilized. An electromyograph was set, so that an upward deflection on the cathode-ray oscilloscope might show a change of voltage in the negative direction at the core of coaxial needle electrode or at a proximal electrode of bipolar ones.

RESULTS

1. Wave form of fibrillation potentials recorded from the denervated muscle.

Six rats were examined. The denervated muscle exposed on the 21st day after denervation was in a state of constant fibrillary contraction–fibrillation, which was obviously observed with the naked eyes at the whole surface of the

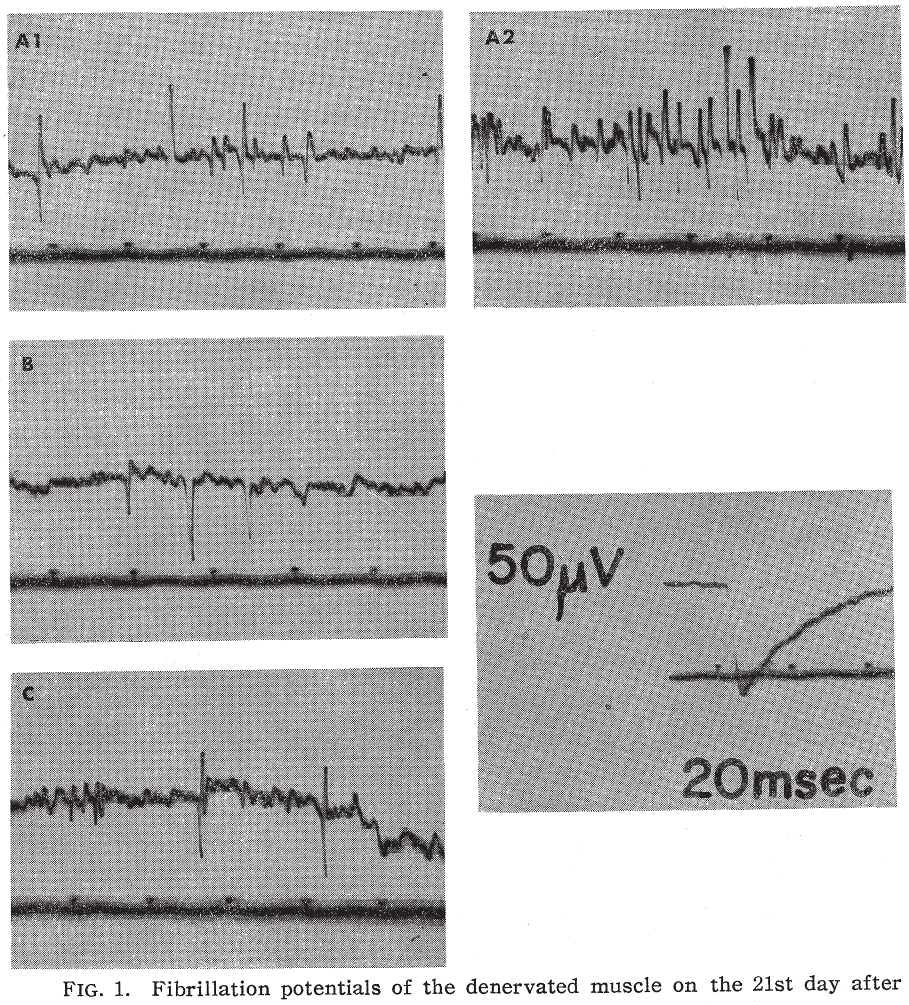

FIG. 1. Fibrillation potentials of the denervated muscle on the 21st day after denervation recorded with coaxial needle electrode:
A 1, A 2, diphasic; B, monophasic; C, triphasic.

muscle in reflected light. The denervated muscle was then explored with concentric needle electrode. A series of spike potentials —fibrillation potentials— were recorded. On analysis of the wave form of these potentials, it was revealed that 75% of fibrillation potentials were diphasic (Fig. 1. A 1, A 2); 20%, monophasic (Fig. 1. B) and 5%, triphasic (Fig. 1. C), on a rough estimate, in spite of a more or less difference in degree according to sites recorded in a muscle. On the other hand, almost all of the fibrillation potentials had initial positive phase regardless of sites recorded, which was found the most characteristic point of the fibrillation potential of denervation (Fig. 1 and Fig. 3).

2. Site of origin of fibrillation potential.

It was easily inferred that the wave form of each fibrillation potential would be closely related to its site of origin, for the shape of an action potential indicates the site of the recording electrode relative to the point of initiation of the potential, and whether it has been conducted to and past the electrode. Hence, the denervated muscle was examined with bipolar electrodes seeking the site of origin and the direction of propagation of fibrillation potentials. This would be determined from a change of the direction of the initial deflection of a series of potentials recorded by bipolar electrodes and the direction itself. Bipolar electrodes were placed in so close contact with the muscle surface parallel to the long axis of the muscle that dimpling of the muscle surface

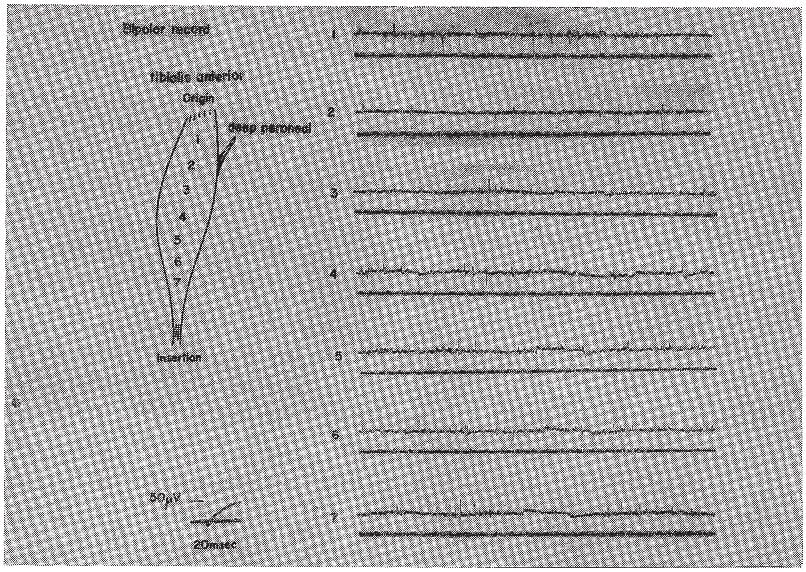

FIG. 2. Fibrillation potentials of the denervated muscle on the 21st day after denervation recorded with bipolar electrodes.

Each number corresponds to the same one respectively.

was visible. Records were taken at 1.5 millimeter intervals in order from proximal to distal along the entire length of the muscle.

An electromyograph was set to have upward deflection, when a proximal electrode of bipolar ones was electrically negative.

Four rats were examined. The reversal of the polarity could not be found. Therefore the site of origin was not settled. It was only supposed that, in general, propagated impulses might be travelling from insertion to origin, for diphasic potentials with an initial positive phase were observed at many sites (Fig. 2).

3. Area of the denervated muscle from which fibrillation potentials were recorded.

Six rats were examined. Each muscle was probed with coaxial needle electrode at many different points. It was obtained from the results that fibrillation potentials could be recorded, wherever the concentric needle electrode might be inserted into the denervated muscle (Fig. 3).

4. Spontaneous electrical activity of normal muscle.

All electrical activities which were found still after the insertion of concentric needle electrode were recorded. The activities were called spontaneous electrical activities. The coaxial needle electrode was inserted and advanced in some steps over the entire part of a muscle.

Five rats were examined. Four types of spontaneous electrical activities

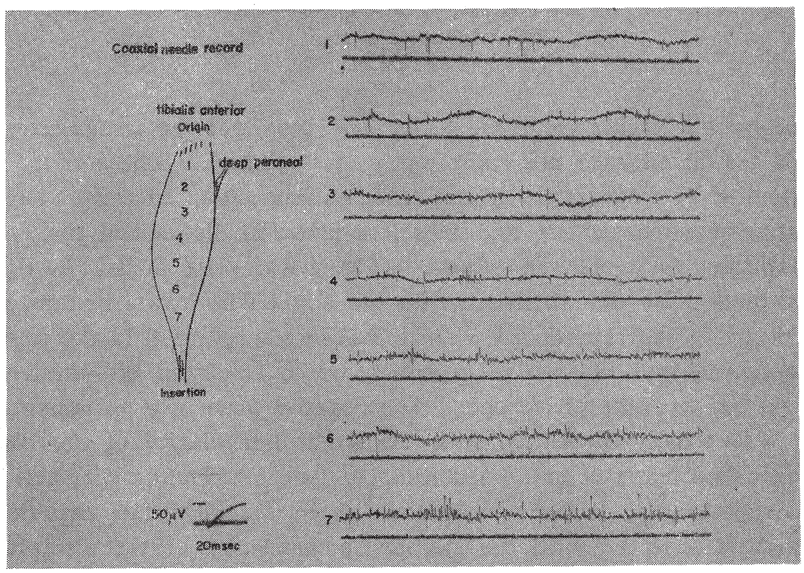

FIG. 3. Fibrillation potentials of the denervated muscle on the 21st day after denervation recorded with coaxial needle electrode.

Each number corresponds to the same one respectively.

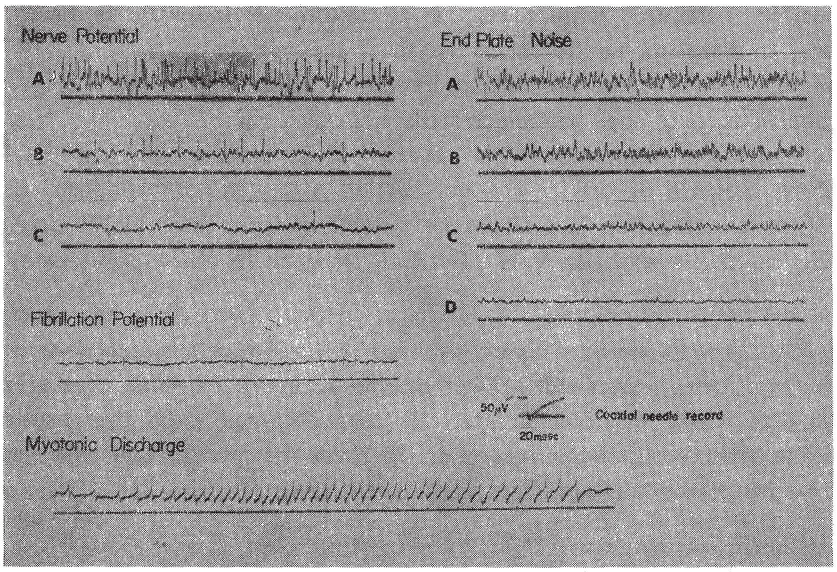

FIG. 4. Spontaneous electrical activities of the normal muscle recorded with coaxial needle electrode.
End plate noise; A: just after it appeared.
B: 1 minute later.
C: 2 minutes later.
D: 3 minutes later.
Nerve potentials; A: just after it appeared.
B: 1 minute later.
C: a few minutes later.

were recognized clearly (Fig. 4). The first type was the irregularity of the base line associated with noise through a loud-speaker. The activity showed attenuation of its frequency and amplitude as time advanced and got suggestive of negative monophasic one and therefore provisionally named the end plate noise according to Buchthal's opinion[5] (Fig. 4 End plate noise: A, B, C, D). The end plate noise was abolished with the slight withdrawal or advancement of the electrode and reproduced when the electrode returned to the same area.

The second type was spike potential, which consisted of initial negative phase and the second positive one. The negative phase was prominent. This activity was usually associated with the slight irregularity of the base line. This was called nerve potential according to Jones[4]. The activity also seemed to be attenuated (Fig. 4. Nerve potential: A, B, C). The fact that the nerve potential was observed with the slightest advancement of the electrode after detection of the end plate noise was sometimes recognized. Therefore, some relationship between them was inferable.

The third type was diphasic spike potential of short duration, of which

TABLE 1. Incidence of spontaneous electrical activity in normal muscle. Number in parentheses shows percentage

No. of Rat	No. of points probed	Fibrillation potential	Nerve potential	End plate noise	Myotonic discharge	Fasciculation potential
No. 1	31	1 (3.2)	3 (9.7)	4 (12.9)	0	1 (3.2)
2	35	1 (2.9)	6 (17.1)	9 (25.7)	0	0
3	22	1 (4.5)	2 (9.1)	3 (13.6)	1 (4.5)	0
4	50	0	3 (6.0)	10 (20.0)	2 (4.0)	0
5	39	1 (2.6)	3 (7.7)	6 (15.4)	0	0
Total	177	4 (2.6)	17 (9.6)	32 (18.0)	3 (1.7)	1 (0.6)

the initial phase was positive. This activity could not be distinguished from the fibrillation potential of denervation mentioned previously and could not help being named fibrillation potential (Fig. 4.).

The forth type was the activity of waxing and waning high frequency with a sound of "dive bomber", through loud-speaker. This was named so-called myotonic activity, because it is customary for electromyography that the activity associated with a sound of "dive bomber" is called myotonic activity or discharge regardless of its wave form (Fig. 4).

The incidence of these four types of activities was shown in table 1.

177 points were tested in the intact muscles of 5 rats. The end plate noise was encountered 32 times, an average occurrence rate of 18.0 per cent. Values ranged from 12.9 to 25.7 per cent in individual rats. The nerve potential was encountered 17 times, an average occurrence rate of 9.6 per cent. Values ranged from 6.0 to 17.1 per cent in individual rats. The fibrillation potential was encountered 4 times, an average occurrence rate of 2.6 per cent. Values ranged from 0 to 4.5 per cent in individual rats. The myotonic discharge was encountered 3 times, an average occurrence rate of 1.7 per cent. Values ranged from 0 to 4.5 per cent in individual rats. The fasciculation potential which was considered to be ordinary motor unit action potential was detected only once. It could not be determined whether this was accidental or erroneous.

DISCUSSION

Weddell[9] termed the action potential, which occurred as a response of the normal muscle at rest on mechanical stimulation by the exploring needle electrode, "insertion motor unit action potentials", because these action potentials were considered to consist of motor unit action potentials. Kugelberg[3] indicated that "insertion activity" consisted not only of ordinary motor unit action potential, but also of those which could be indistinguishable from fasciculation or fibrillation potentials.

Snodgrass[10] had observed action potentials of a very short duration in the muscles of normal human subjects which were similar to the discharges in mammalian motor nerve fibers. Reid[11] and Jasper[12] also observed similar potentials and suggested that these potentials arose from nerve fibers. Jones[4] noted spike potentials of short duration which were recorded during electromyographic examination of normal muscle at rest and found histologically that areas, which these potentials were led off, were closely related with the small intramuscular nerve fibers. Furthermore, he observed that these spike potentials usually occurred with a characteristic irregularity of the base line and called both spike potential and irregularity of the base line "nerve" potentials. Recently, Buchthal[5,6] noticed that the "nerve" potentials have intimate relations to the end plate, and assumed that its site of origin would be the end plate, and named the irregularity of the base line "end plate noise". He also considered boldly that the spike potentials were a type of fibrillation potentials and "nerve" potentials should be dissolved. This interpretation is based on the hypothesis that fibrillation potentials will arise in the end plate zone.

Fibrillation potentials are able to be prescribed by its amplitude, duration, phase, frequency and rhythm, but these parameters are as various as the authors are different (Table 2).

The references on parameters of nerve potentials are poor, but the prescriptions of nerve potentials overlap those of fibrillation potentials in some points (Table 2). The only difference was considered to be in initial phase, as both Jones[4] and Marinacci[18] had already pointed out. The author reaffirmed in the present study that fibrillation potentials of denervation had initial positive phase, when they might be recorded separately without interference with concentric needle electrode in the denervated muscle.

The discussion on the initial phase is deeply related to the problem where the action potentials arise from and which direction they propagate to. Therefore, an experiment was tried seeking for the site of origin and the direction of propagation of fibrillation potentials. No constant results, however, have been obtained yet. On the literature, the site of origin of fibrillation potential has not been decided either, whether it is the end plate[24,25] or the entire muscle fiber[26,27,28,29]. But it is probably fit to be considered that its origin may be along entire fiber according to the textbook[30]. Therefore, the result in the present report that the initial phase of fibrillation potentials was always positive wherever these potentials might be recorded in the denervated muscle will be

TABLE 2. Literature on the Fibrillation Potentials and the Nerve Potentials

Literature on the Fibrillation Potentials

Author and Year	Amplitude (μV)	Duration (msec)	Frequency (per sec)	Rhythm	Phase (Initial Phase)
Brown 1937 (1)	30		2 - 7	irregular, regular	diphasic
D-Brown 1938 (2)	1- 3		2 -10		diphasic
Tower 1939 (13)			2 - 7		diphasic
Weddell 1944 (9)	less than 100	1 - 2	2 -20	rhythmical	mono-, diphasic
Jasper 1949 (12)	50-100 occasionally 500	0.5- 1.5		irregular	mono-, di-, rarely triphasic
Kugelberg 1949 (3)	300	1.5			
Sargant 1950 (14)	50	1 - 2		rhythmical	
Shea 1950 (15)	5-100	1 - 2	2 -20	rhythmical	mono-, diphasic
Landau 1951 (16)		-30		irregular, regular	
Luco 1955 (17)			11	regular	
Jones 1955 (4)				regular	triphasic (positive)
Marinacci 1955 (18)	10-100	1 - 2	2 -20	irregular	mono-, diphasic (positive)
Mayo Clinic 1957 (19)	25-100	0.5- 1.5	2 -10-30	regular, irregular	di-, triphasic (positive)
Hnik 1962 (20)	10-100	1 - 3	2 -30	rhythmical	mono-, di-, triphasic
Inada 1963 (21)	100-650	1.9- 4.1	1.2-10	regular, irregular	di-, triphasic (positive)
Bowman 1964 (22)	-300	1 - 3		irregular	diphasic
Richardson 1964 (23)	20-300	1 - 1.5	2 -30	rhythmical	di-, triphasic
Buchthal 1966 (6)		1 - 5			two or more phases
Literature on the Nerve Potentials					
Snodgrass 1941 (10)					
Weddell 1944 (9)					
Kugelberg 1949 (3)					
Reid 1949 (11)					
Jasper 1949 (12)					
Landau 1951 (16)	-300	1.5-50			
Jones 1955 (4)	10-500	2 - 4		irregular	diphasic (negative)
Marinacci 1955 (18)	-300	1 - 3	30 -	regular	monophasic (negative)

accepted more easily.

It would be admitted that fibrillation potentials of denervation have the initial positive phase which is the most significant point to differentiate it from spontaneous electrical activities of normal muscle. This prescription, however, must allow the condition that fibrillation potentials will be found only infrequently in normal muscle at rest. Then, what is the conclusive factor of pathological fibrillation potentials? Not qualitative but quantitative consideration should be taken, because fibrillation potentials in normal muscle are encountered only 4 times in 177 points probed, on the other hand fibrillation potentials in denervated muscle are encountered wherever the totally denervated muscle may be probed, without reinnervation or sufficient degeneration[30]. When a thorough search reveals the potentials in a single region, their pathognomonic significance is unable to be decided, because they may be accidental. But it could be supposed that they may be regarded as pathological when they are found in two or more points of a muscle. Thage[31] adopted the similar criteria on the pathological meaning of fibrillation potentials, which were considered to contain wider range of potentials including normal activity than those described in this report.

Moreover, in general, it is presumed that, in the present state of electromyography in practice, an easily detectable spontaneous electrical activity in any explored muscle is regarded to be pathological whatever activity it may be. It seems true, but it would be securely accepted to be pathological on the fibrillation potential, if consideration were also given to the wave form.

Jones[4] indicated that nerve potentials have two components which consist of the irregularity of the base line and the initially negative diphasic spike potentials, and that most often these two components are combined. But the present experimental study revealed that the first component frequently occurred alone. Therefore, these components should be considered to be tentatively dual. It could be appropriate to call the first component "end plate noise" and the second, "nerve potential", although it must be scrutinized whether the names are adequate or not.

The nerve potentials should be recognized distinctively from the view point of the wave form which consists of an initial prominent, negative phase and a second positive one. These potentials may be able to be detected only in normal muscle. Therefore, if these potentials can be observed in any paralysed muscle, the muscle will be inferred to have some normal parts. Hence, the nerve potentials should be regarded to be very significant not as a type of fibrillation potentials but as a normal sign under present conditions, even if the elucidation of the substantiality of the fibrillation potential would be indispensably needed for the determinative opinion.

Besides the activities which were mentioned previously, in normal muscle, Goodgold[32] first observed so-called myotonic discharges and Bonsett[33] revealed histologically that so-called myotonic activities were found when the tip of the moving needle activated the muscle spindle. The author found the same activities in normal muscle on 1.7%. This so-called myotonic acivity or discharge may not be pathological but normal, therefore quantitative consideration which was taken as to fibrillation potentials might be also necessary for a pathological meaning of myotonic activity.

The other activity was seldom found in normal muscle.

Including the term of so-called myotonic activity, terminology in electromyography has not been standardized yet, so each electromyographer tends to use a self-satisfied term which may mean a same activity[34]. The terms used by the author may be self-willed, but what they mean will be understood by reference to figures and the text.

The author will conclude from present informations as follow:

1. Fibrillation potentials are spike potentials with the initial positive phase when these are recorded separately without interference and these should be found at least in more than two points of a muscle in order to be regarded as a sign of denervation.

2. In normal muscle at rest, electromyographically, end plate noise, nerve potential, fibrillation potential and so-called myotonic discharge are recognized.

SUMMARY

1. White rat tibialis anterior muscle, on the 21st day after denervation, and in normal state, has been studied with single-core concentric needle electrode and bipolar electrodes.

2. Fibrillation potentials of the denervated muscle recorded with concentric needle electrode were often diphasic, occasionally monophasic and rarely triphasic.

It was the most characteristic point as well as the key point for differentiation from so-called insertion activity of normal muscle that these potentials had always initial positive phase.

3. The site of origin of the fibrillation potentials was searched with bipolar electrode, but not settled.

4. End plate noise, nerve potentials, fibrillation potentials and so-called myotonic discharge were recognized in normal muscle.

5. The pathognomonic significance of the fibrillation potentials were discussed.

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