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THE RELATION OF THE MOTOR ENDINGS ON THE MUSCLE OF THE FROG TO NEIGH- BORING STRUCTURES.

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With Plates I and II.

It is obviously a matter of some importance in the study of the relation of nerve excitability to muscle contraction, to determine the manner in which the peripheral part of the neurone is related to the muscle fiber. Nor has it been neglected; it has long been a favorite subject for investigation and a prolific field for speculation and debate. At the present time renewed attention is being called to it by the recent works of of APÁTHY, RUFFINI, GRABOWER and others. In these writings special emphasis is being laid on the presence of fine fibrillae, called by RUFFINI ultra-terminal fibrillae, which are projected from nerve endings to various neighboring parts.

From an historical standpoint it is extremely interesting to compare the results of KÜHNE with those of RUFFINI, DOGIEL, HUBER, SIHLER and others, and to observe that as methods and technique improve, a corresponding complexity can be shown in the relation of nerve to muscle. This is well exemplified in the ending of the motor neurone on the frog's muscle. As regards this animal one must acknowledge that the remarks of APÁTHY on nerve endings in invertebrate muscles are not inappropriate:—

“Wenn ich auch hier und da schlechthin von Nervenendigungen spreche, so will ich doch gleich hier von vorn herein betonen, dass ich eine Endigung der leitenden Primitivfibrillen nirgends mit Sicherheit constatiren konnte; ich kann nur sagen, bis wie weit ich eine leitende

Primitivfibrille, oft wohl bereits Elementarfibrille, an einer bestimmten Stelle meiner Präparate zu verfolgen im Stande bin." ¹

In 1877 GERLACH described the nerve endings of the frog as branching dichotomously to form an intravaginal network which runs through the contractile substance of the muscle fiber in close relation to, if not in actual continuity with, the contractile fibrillae. He appears to have been influenced in his deductions by the fact that in staining with gold chloride, he obtained reactions from certain elements of the sarcous substance which were similar to those obtained in nerve endings. In 1889 he repeated these investigations with methylene blue, and claimed that this method substantiated his previous views. Subsequent research by others has not confirmed his results nor upheld his deductions; nor can his own drawings be said to support the claims he attempted to establish. To one conversant with *intra-vitam* staining with methylene blue, it will appear a very doubtful procedure to base results on the similarity of staining reactions. By this *intra-vitam* method one constantly sees fine blue-stained fibers in the intermuscular connective tissue which, taken alone, might simulate nerve fibrillae. At times one observes beautifully stained examples of myofibrillae either as very fine closely arranged points or as continuous structures. On this ground alone, therefore, it is obvious that it would not be possible to deduce a nervous plexus either within or without the muscle-cell. In addition, there must be present an undoubted continuity of structure with an unmistakable nerve fiber, together with any characteristic appearance which one is accustomed to find in corresponding terminals.

In 1896 APÁTHY drew attention to the manner in which the axis cylinder divides in invertebrate muscle fibers. He describes the primitive fiber as entering the muscle cell and there dividing into fine fibrillae (primary fibrils). These, however, do not form a plexus but either send comparatively thick branches (secondary fibrils) to adjacent muscle-cells there to form terminations from which it may be that further branches

¹ *Mittheil. a. d. Zoolog. Station zu Neapel.*, Bd. XII, 1896, p. 505.

(tertiary fibrils) may proceed to other muscle cells; *or* they divide repeatedly into ever finer fibrils till ultimately perhaps, elementary fibrillae result. He often saw very fine nerve fibrillae pass out of a muscle cell into the neighboring connective tissue and it might be, branch there. As to the ultimate fate of the finest fibrillae he is uncertain, but he declares: "Es kommt mir an wahrscheinlichsten vor, das sie mit anderen ähnlichen ein intermuskuläres Elementargitter bilden."¹

The results of APÁTHY led RUFFINI in 1900 to re-examine nerve endings in the human muscle which he had stained by his chloride of gold method. Here he found in some of his specimens fine fibers which he had not previously noted and which he now described under the name of ultra-terminal fibrillae. These are very fine, non-medullated fibrillae which pass out from the motor end-plate. "This fibrilla" (ultra-terminal), he says, "after an unbranched course, more or less long, may terminate in the same muscular fiber on which rests the plate from which it is derived, or, as is often the case, put itself into relation with one of the neighboring striated fibers. From it collaterals may at times come off." It may end in a swelling or in a second small plate (plaquette); in one case from a plaquette another fibre was seen to pass out, but its course could not be followed. Summing up the results of his examination, he says: "The motor plates in man do not represent the true and real terminations of motor nerves, because beyond the plate there exists a well demonstrable anatomical continuity shown by non-myelinated nerve fibrillae of which we do not know the last relations."² This is obviously a statement very closely akin to that given by APÁTHY in the summing up of his results.

Later PERONCITO, working with RUFFINI and using his gold chloride method, describes in *Lacerta muralis* and *Lacerta viridis* the ultraterminal fibrilla as separating itself from the

¹ *Ibid.*, p. 695.

² RUFFINI: *Sulle fibrille nervose ultraterminale nelle piastre motrici dell'uomo. Rivista di pat. nerv. e ment.*, 1900, V. 5.

nerve fiber at the point where it loses its medullary sheath and penetrates the motor plate; from here it may pass to end on a muscle fiber or in a neuromuscular spindle.

In any discussion on nerve endings it is well to recognize the facts that are universally accepted. Thus it is well established that a motor nerve may branch repeatedly before ending, or to put it otherwise, the peripheral ending of a motor neurone is connected with many muscle fibers. This branching occurs at a node. Each branch is a medullated fiber smaller in calibre than the parent stem and it ultimately loses the medullary sheath and breaks up to form a nerve ending usually on one muscle fiber, to which it alone is attached. To this very general statement there are a variety of exceptions. Thus, two or more endings may go to one muscle fiber; or a non-medullated nerve may pass off from a node; occasionally, though more rarely, a non-medullated nerve may be seen leaving a medullated nerve where no node is apparent. To define concisely and yet accurately the term motor nerve ending, either from an anatomical or physiological standpoint, is in the present state of our knowledge by no means easy. For our present purpose a motor ending may be regarded as that peripheral part of the nerve which, on reaching a muscle fiber, loses its medullary sheath and breaks up into more or less numerous non-medullated¹ branches or end twigs which enter into a more or less close relation to the muscle fiber. Having thus defined a motor ending, the significance of the term ultraterminal fibrilla is the better understood; this is a fine non-medullated fibril which passes from one of the twigs of the nerve termination to a region beyond the primary ending. Here it enters into relation with the muscle fiber on which rests the ending from which it originally sprang, or with some adjacent muscle fiber or with a neighboring muscle spindle.

¹ DOGIEL has described a medullary sheath as occurring in the nerve ending (*Archiv f. mikr Anat., Bonn*, 1890, p. 314). This I have never seen, though the dye oozing from the axis cylinder at times gives a resemblance to such.

The following investigations were undertaken by me to determine how the motor nerve endings on the muscles of the frog are related to other structures; and also to ascertain, as far as possible, how the terminal nerve fibrils finally break up and disappear. Especially did it appear necessary to compare the results observed by RUFFINI and others using gold chloride methods with the results obtained by the *intra-vitam* methylene blue method.

Method: The muscles of the frog used were either the M. sartorius, the M. peroneus or the M. tibialis anticus. Into these was injected with a hypodermic syringe, a very weak solution of methylene blue in various salt solutions, for this research has been carried on as a preliminary part of an investigation on the effect of various salts and poisons on motor nerve endings. Grammolecular solutions of the following salts, among others, were used: sodium chloride, sodium carbonate, sodium ammonium phosphate, magnesium sulphate. Nerve endings can be obtained by a solution of methylene blue in distilled water, or with methylene blue in solution with any of the above salts; but the most constant and best results are obtained if sodium chloride is present in the solution. So far as the present paper is concerned, the following solution was constantly employed:

Methylene blue (GRÜBLER'S nach EHRLICH) 0.5% sol.	1 or 2 cc.
Sodium chloride solution, 0.58% sol.	2 cc.
Aqua destil.	17 cc.

This was found to be the most suitable strength of methylene blue to use, though one of half this strength often answers well, especially for sensory endings and sympathetic plexures on blood vessels. The largest and most complex endings were seen when the muscle was injected with the above solution after there had been added to it a few drops of a weak alkaline salt, such as sodium ammonium phosphate, and then a very weak faradic current passed through the nerve trunk for a few seconds.

A few minutes after injecting the solution the muscle is cut out and exposed on a glass slide which has been moistened

with normal salt solution. Within a varying time, usually about five minutes, the nerve endings begin to appear. As soon as these are well marked the muscle is fastened to cork and placed in ammonium molybdate solution (5 %) at a temperature near freezing point. Temperature plays a very important part in the subsequent treatment of the tissues. If it rise at any point of the procedure—e. g. when washing in water or passing through alcohol—the methylene blue dissolves out from the very fine fibrillae. If the tissue has to kept over night in molybdate it is well to place it, especially in summer, in a refrigerator. When passing through alcohol, the vessel should be surrounded by ice-cold water.

The addition of HCl to the molybdate solution is not necessary; I have found it even a disadvantage for the finer results. BETHE in his recent work has abandoned its use.

After removal from the molybdate, the muscle, if too thick, is cut in a freezing microtome, examined in water, and only that part kept which shows traces of nerve endings. The tissue is now passed through 95 % and absolute alcohol, preferably, as stated above, at a low temperature; then from xylol into paraffin. It is important that it remain sufficiently long in xylol to remove the alcohol; otherwise the temperature of the melted paraffin will cause any alcohol present to remove the methylene blue from the fine fibrillae. It remains in paraffin for two hours. The thickness of the section varies with the object aimed at. To get long stretches of nerve endings, it is best to cut from 20 to 50 micra; if one wish to study the relation of the endings to the muscle cell, a thickness of from 5 to 10 micra must be used.

After numerous experiments with various dyes as a counterstain, the following was found most suitable, inasmuch as it dyed the muscle fiber an orange, the sheath of HENLE a rose-pink and the neurilemma a faint pink:

Acid fuchsin	1 g.
Orange "G"	6 g.
Alcohol, absolute,	60 cc.
Aqua destil.	240 cc.

In the frog's muscle the nerve ending has no ground plate in which the branches ramify. The ramifications are not localized but are spread over a relatively large and apparently variable area of the muscle fiber. Usually but one medullated nerve ends in a muscle fiber, though two medullated nerves may be seen at times and three have been described; occasionally two medullated nerve fibers and one non-medullated and much finer fiber may go to the muscle fiber. When more than one nerve goes to a muscle fiber it is often possible to trace the origin of these to the same nerve stem. In no case was there even the suggestion of one of these fibers coming from a nerve whose course lay distinctly apart from the others. If more than one nerve go to the muscle fiber, the places where the nerves enter into contact with the fiber are, if not always, at least most frequently, in close proximity to one another. In short, on the muscle fiber the area to which the entering nerves apply themselves relative to the entire length of the muscle fiber is limited.

Several varieties of motor endings have been described. Thus, there are the four or five types of CUCCATI which RETZIUS would reduce to two; the one exemplified by the branching plate, the other by the broad band. At present, any classification must be but temporary; with equal justification several varieties may be classed as typical by one and rejected by another. For example, one might well wish to add to the types of RETZIUS that more strictly localized variety which DOGIEL has described and which occurs not unfrequently in certain muscles—a variety which closely resembles the branching of mammalian nerve endings only without an end plate.¹

There is, however, one type which is generally recognized as predominating—*das Stangen-geweih* of KÜHNE. In it the nerve after losing its medullary sheath divides more or less dichotomously and spreads itself along the length of the muscle fiber. The band variety is less common; one notes that the better stained the preparation the less frequently it appears.

¹ *Arch. f. mikrosk. Anat.*, 1890, Bd. xxxv.

In the frog the end-arborizations do not terminate necessarily on one muscle fiber. It is not unusual to find that, while the majority of the terminal fibers confine themselves to one muscle fiber and to a certain definite area, one or more fine non-medullated fibrillae pass far beyond the area or to a neighboring muscle fiber. So common is this that in well stained preparations one is ever expectant of finding at least traces of such fibrillae. They are often difficult to observe; but the cause of this is not so much that they do not readily stain, as that it is hard to fix the dye and easy to have it extracted during the stages subsequent to fixation.

Such non-medullated fibrillae may be termed ultraterminal. A convenient way to describe them is to classify them according to the manner in which they end, so far, at least, as such can be traced at present. With this in view, we might describe them as follows :

- (1) Relatively thick, non-medullated fibers which pass to adjacent muscle fibers and divide into endings which resemble more or less closely, though much smaller, the dichotomously branching arborizations from which they spring. These come off very soon after the primary axial fiber loses its medullary sheath and begins to break up (Fig. 1; Fig. 4; Fig. 6).
- (2) Fine fibrillae which pass from the nerve ending into the inter-muscular connective tissue and there cease to be capable of being followed farther (Fig. 1; Fig. 3; Fig. 2).
- (3) Very fine non-medulated fibrillae which detach themselves at various points of the terminations and pass to end in adjacent muscle-fibers in one of the following ways:
 - a) by getting so faint and so fine that it becomes impossible to follow them farther (Fig. 1; Fig. 2; Fig. 3).
 - b) by terminating at what appears as a much thickened knob (similar to Fig. 1, B and C)
 - c) by breaking up into a plexus from which some at least of the fibrillae disappear in the muscle fiber while others continue on (Fig. 2)
 - d) by forming a plexus which enters into close relationship with a typical nerve ending (Fig. 3)
 - e) by breaking up after a relatively long course to form a small localized ending, each termination of which is furnished with a knob (Fig. 6).

At no time have I seen any appearance of an intermuscular nerve plexus formed by these fibrillae. I am inclined to regard the motor fibrillae which pass into the intermuscular connective tissue and there disappear, as either broken fibrillae or fibrillae only partially stained.

The relation of the nerve ending to the muscle fiber.—The relation of the nerve endings to the sarcolemma has been much disputed. Of recent writers who have discussed this question with reference to the muscle of the frog the following only need to be referred to: HUBER-DEWITT,¹ after a careful investigation, come to the conclusion that the terminals lie under the sarcolemma and are devoid of any sheath. SIHLER,² on the other hand, using a method which he finds particularly applicable to this research, considers that the endings lie over the sarcolemma and that the end of fibrils are covered "down to their tips with the sheath of SCHWANN;" further that the sheath of HENLE is open (*verwächst mit nichts*) and does not cover the end fibrils, but that the nerves emerge from it as an arm from a sleeve (*wie der Arm aus dem Aermel*); at the same time, he does not deny that there are points where the nerve substance and the muscle fiber may come into contact.

In fresh muscle fibers in which the nerves have been stained by the *intra-vitam* methylene blue method, I have found that, while the majority of the terminal branches lie in close relation to the muscle fiber, at times a terminal fibril is seen to rise some distance above the muscle fiber, and occasionally such a nerve fibril sends down to the muscle fiber little rootlets comparable to those described by SIHLER. But sooner or later even in such nerve fibrils the ultimate terminals come to lie on the muscle fiber. While the occurrence of such nerve fibrils may be held to prove that the larger fibrils may be epilemmal, there is nothing to show what the relation of the terminal fibrils

¹ HUBER-DEWITT: Nerve Endings in Muscles. *J. Comp. Neurol.*, 1897, VII, p. 185.

² SIHLER: (a) The Nerves of the Capillaries with remark on Nerve Endings in Muscles. *J. Exp. Med.*, 1901, V, p. 511. (b) Neue Untersuchungen über die Nerven, etc. *Zeit. f. wiss. Zool.*, Leip., 1900, LXVIII, pp. 351 and 375.

to the muscle fiber may be. To investigate this a much higher magnification and a more differential stain are necessary than at present are available in the examination of fresh tissues.

By means of the orange G acid fuchsin counterstain above referred to, I have found it possible to distinguish clearly between the nerve fiber (blue), the sheath of HENLE (rose-pink), the faintly stained neurilemma (pink), and the muscle fiber (orange). In thin sections (5 to 7 μ) examined by the 1-12 ZEISS oil immersion lens, where the medullated nerve was observed to lose its medullary sheath and divide into the primary branches, I often clearly saw the primary branches, especially when they were lying in the upper edge of the muscle fiber, enclosed by the neurilemma and by the sheath of HENLE. Moreover these sheaths could at times be traced for some distance on the primary divisions of the ending. The differentiation of the two nerve sheaths was at times aided by the fact that one could distinguish the attachment of the neurilemma to the node, as described by BOVERI and BETHE,¹ while the sheath of HENLE had no such attachment but was continuous over the node. This condition was seen in the section from which Fig. 7 was obtained. Here the neurilemma attached itself to the node where the medullary sheath ceased, and thence was continued over the fibrils. For this research it was not necessary to determine whether at the node the neurilemma was or was not interrupted. Outside of this lay the sheath of HENLE. Each sheath could be followed separately to the muscle fiber, where together they applied themselves to the sarcolemma. When so applied to the muscle fiber, it was not possible to distinguish with accuracy between the pale stained neurilemma and the strongly stained sheath of HENLE. But it was possible to see clearly that the sheath round the nerve was distinct from and was placed outside of the sarcolemma—a distinction which was aided by the fact that here the sheath of HENLE stained at times more strongly than it had previously done and appeared as if it were there thickened

¹ BETHE: *Anatomie und Physiologie des Nervensystems*, 1903, p. 50.

or compressed. As the fibrils subdivided each branch was surrounded by a sheath which became fainter as the nerve fibril became finer.

Occasionally there coiled round a primary terminal branch of a nerve ending another nerve in no way related either to this nerve ending or to its muscle fiber. Thus in Fig. 5 at (2) the nerve (3) curved round a primary terminal division of the nerve termination on muscle fiber A. This is only to be explained by one of two suppositions; either both nerves at that point were over the sarcolemma or under it. The latter supposition is open to many objections; the former will generally be acknowledged to be the more probable, and to me is a confirmation of what I have already stated.

Attention was now directed to two points:

- (1) The relation of terminal fibrillae and of the end knobs to the sarcolemma;
- (2) The relation of the ultraterminal fibrillae to a sheath.

In sections where very fine fibrils were seen, one could trace the blending of the nerve sheath with the sarcolemma. In Fig. 9 the terminal nerve fibrilla rested on an apparently homogeneous substance which was not separated from the contractile muscle substance by any sarcolemma and which was covered by a cap formed by the blending of the nerve sheath with the sarcolemma. In short, it lay under the sarcolemma. When the section from which Fig. 9 was drawn, was carefully examined under the 1.5 mm. ZEISS apochromatic and Oc. 6, the sarcolemma appeared at (*a*) to split into very faint lines. Two of these were seen to project as at (*a*) and disappear in the covering cap. Similarly at (*b*) a line was seen to go off as delineated. The impression formed by the study of this and of other similar sections, was that though the cap over the terminal nerve fibrilla or end-knob was formed by the blending of the sheath which surrounded the nerve fibril with the sarcolemma, the tissue which had principally to do with its formation was the sheath of the nerve fibril.

The relation of the root-like knob to the muscle fiber was sometimes particularly interesting. It seems to lie more in the

sarcolemma than under it, though at times a knob could be observed to penetrate deeper towards the fibrillated sarcous substance. It was noted that in every ending the fibrillated sarcous substance was sharply marked off, so that it was always easy to determine that the nerve terminals did not penetrate within or even as far as the fibrillated muscle substance.

On the ultraterminal fibrillae a sheath could at times be seen. This sheath followed closely the convolutions of the nerve, and could be traced to the neighboring muscle to which the nerve was going; there it blended with the sarcolemma. The nerve terminals and end-knobs differed in no respect from the corresponding parts of the main nerve stem (Fig. 6).

In short the primary divisions of the nerve ending lie over the sarcolemma, and are surrounded by both the neurilemma and the sheath of HENLE; the ultimate fibrils lie in a homogeneous substance within the sarcolemma, and are covered by a cap formed by the blending of these sheaths with the sarcolemma. The open condition of the sheath of HENLE, as described by SIHLER, was not observed.

Conclusions.

The so-called nerve ending of the frog is to be regarded in the first place as the peripheral separation of the contents of the axis cylinder, by which separation it is able to spread itself over a relatively wider area. As a nerve fiber may attach itself to various muscle fibers, so the fibrillae of the ending may likewise reach over to adjacent muscle fibers. Those fibrils which detach themselves near the central point of separation are, as a rule, larger and more easily stained than the more distal ones, and are comparable to the non-medullated fibers which may arise from the medullated nerve stem. One can note that the secondary endings to which they give rise are often comparable in form to the primary endings, though having a smaller number of branchings; this would suggest that the amount of branching which is possible bears a relation to the diameter of the fiber.

A plexus is often formed by the nerve terminations (Fig.

5, Fig. 3, Fig. 6.). Whether this is merely an interlacing or a true anastomosis, it would be difficult to decide. The close approximation of some of the terminals and the way in which they run together (Fig. 6) suggest at least a very intimate relationship between them. By means of this plexus arrangement we can well understand how effective the nerve impulse may become. From this network fibrillae may pass to other muscle fibers (Fig. 3, Fig. 6).

Not only in the fixed but in the unfixed preparations the larger branches of the endings are seen to lie over the sarcolemma and even at some distance from it (Fig. 1, Fig. 7). In fresh preparations one occasionally sees a terminal lying over the paler stained yet clearly outlined muscle fiber, and sending down root-like structures to the muscle fiber. The neurone enters into intimate relationship with the muscle fiber either at the peripheral termination of the ending, where each termination appears as a very fine fibrilla to which an end knob or bulb may be attached (Fig. 1, B & C, Fig. 9) or at the terminal knob of each of those root-like structures which at times are projected from the fibrils of a nerve ending. The former termination, including both the terminal fibrilla and its knob, lies in homogeneous substance under the sarcolemma; it is covered by a cap into whose formation there enters both the nerve sheath and the sarcolemma, though chiefly the nerve sheath. The latter termination is in close opposition to the sarcolemma and may be either in or under it.

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EXPLANATION OF THE DRAWINGS.

I am much indebted to Mr LEONARD H. WILDER for the carefulness and accuracy with which he has prepared the drawings which illustrate this paper.

PLATE I.

Fig. 1. ZEISS D, Comp. occ. 4. The peripheral termination of a neurone, showing Terminal fibrillae with end knobs (1) and (2), Ultraterminal fibrilla ending in intermuscular connective tissue (3), Ultraterminal fibrilla ending on a separate muscle fiber (4).

The medullary sheath, as sometimes happens, is faintly yet distinctly outlined surrounding the continuous and well-marked axis-cylinder. There are three muscle fibers, A, B and C, to which go two medullated nerves, *a* and *b*. The main stem of *a* breaks up on C at 5 into three primary fibrils. In its course there are given off to A two medullated branches, which lose their medullary sheath soon after leaving the main stem and which break up more or less dichotomously. From the one on the left, a non-medullated terminal branch (3) passes beyond the muscle fiber to disappear in the intermuscular connective tissue. The main supply of B is *b*; but the medullated nerve, *a*, while passing over B gives off two very fine, apparently non-medullated branches, one of which ends on B, the other passing to end on C. The termination of the medullary sheath of *a* was close to the breaking up of the axis-cylinder at 5. One of the primary terminal branches on the right gives off a branch 4 which divides dichotomously on muscle fiber B. The others call for no special remark.

Fig. 1, B and C. ZEISS 1-12 oil immersion; Comp. occ. 4. Two forms of endings frequently presented at the terminals of very fine fibrillae.

B. Drawn from (1), shows the fibrillae breaking up into a granular net-like structure.

C. Drawn from (2), shows an elongated broadened club-like body with a marked central axis, imbedded in a well-defined granular mass and surrounded by a homogenous capsule, comparable to cap seen in Fig. 9.

Fig. 2. ZEISS D, Comp. occ. 4. Nerve ending with ultra-terminal fibrillae.

The medullated nerve *a* loses its medullary sheath and breaks up on B at (1). It gives off at (2) a large non-medullated branch which also breaks up on B. The nerve endings send ultraterminal fibrillae to three muscle fibers. The terminal branches to the right could be traced to a distance twice as far as represented. Several of these endings showed knobs similar to those repre-

sented in Fig. 1, B and C. A separate non-medullated nerve (*n*) is shown which forms a small plexus on B, one fiber of which penetrates to a lower plane than the others and ends by forming under the sarcolemma a knob like Fig. 1, B; the other fibers pass on, one to end on B, the other on C.

Fig. 3. ZEISS D, Comp. occ. 4. Three medullated nerves (*a*), (*b*) and (*c*), which pass to three separate muscle fibers, A, B and C, and which have ultra-terminal fibrillae and interlacing of endings. Muscle fiber B is seen only in part.

Fig. 4. ZEISS D, Comp. occ. 4. The type of ultraterminal fibrillae seen most frequently.

Fig. 5, A. ZEISS D, Comp. occ. 4. An ending forming a complex network on muscle fiber C. A nerve coiling round the primary terminal divisions of another nerve (compare page 11 on relation of nerve to sarcolemma). The nerve *n* goes to two muscle fibers, A and C. The nerve 3 on which no medullary sheath was seen divides into two branches; one of these ends undivided, the other separates into two branches which run close together and parallel. At (2) the upper branch coils round a primary fibril of the nerve ending on muscle fiber A; in addition it gives off a fibril which disappears in adjoining connective tissues.

Fig. 5, B. Part of Fig. 5, marked (1), drawn with ZEISS oil immersion 1-12 Comp. occ. 4.

PLATE II.

Fig. 6. ZEISS 1-12 oil immersion, Comp. occ. 4. Sections cut 10 μ . Nerve endings shown only in part, with ultraterminal fibrillae (1), (2) and (3), one of these (1) with sheath. The main fiber is seen at *n*. From it a branch to the right passes off and soon divides; one of these divisions has been cut by the sectioning, the other (1) passes to an adjoining muscle fiber, there to end in a small termination like an end-plate with end knobs. The nerve sheath could only be traced distinctly to the point where the nerve enters into contact with the muscle fiber.

Fig. 7. ZEISS 1-12 oil immersion, Comp. occ. 4. Section 5 μ . Stained in orange G, acid fuchsin. Part of nerve ending lying over sarcolemma. This dye colors the sheath of HENLE rose-pink, the neurilemma pink, and the muscle fiber orange. The medullary sheath was apparent at M just above the node R, where the axis-cylinder divides into three branches which pass to the muscle fiber. The sheath of HENLE (H) is seen continued over R without attachment, and two of its nuclei (Hn) were distinctly outlined. Within the sheath of HENLE and closely applied to the axis-cylinder, lay the neurilemma N, attached to the node R. The primary terminal fibrils surrounded by the sheaths lie over the sarcolemma which is distinctly marked beneath the sheath.

Fig. 8. ZEISS apochromatic 1.5, Comp. occ. 6. Section 7.5 μ . A primary terminal fibril with sheaths. H, HENLE's sheath; N, neurilemma; S, sarcolemma.

Fig. 9. ZEISS apochromatic 1.5, Comp. occ. 6. Section 5 μ . A terminal knob lying under the sarcolemma and covered by a cap which is chiefly composed of the nerve sheath. Fine fibers pass at (*a*) and (*b*) from the sarcolemma to blend with the nerve sheath in the cap.