

Effect of the Method of Leading on the Recording of the Nerve Fiber Spectrum

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ABSTRACT A study has been made of the modifications of the shape of a nerve action potential dependent upon the placement of the two electrodes, always necessary for a lead. In a classic diphasic lead separation of the electrodes brings out, in addition to a separation of the phases, the appearance of a positive deflection traceable to the passage of an impulse between the electrodes. This phenomenon, called the lead separation effect (l.s.e.), must be considered as an expression of a feature of normal nerve fiber biophysics. It regularly appears and it can be analyzed with respect to the position of the sink maximum. Also it cannot be eliminated by a block at the second electrode.

The advantage of approximating the leads was shown by the absence of a l.s.e. following spikes recorded by electronic integration of tangents, which with validity can be derived from threshold fibers. Since tangent leads are not adaptable to recording a spectrum, a block at the second electrode is required. The making of such blocks and the configuration of records obtained with them are described. Conditions for an optimal lead, but not an ideal lead, were delimited. In an optimal lead only two major elevations appear in the spectrum of a skin nerve: those known as alpha and delta. A reference to maps of fiber size analyses shows that the fibers in the delta elevation have velocities of conduction slower than they would have if following in linear sequence the fiber diameters belonging to the alpha elevation.

In spite of the fact that the use of two electrodes is inevitable in every lead from nerve, neurophysiologists have idealized a fiction, the rate of change at a point of the potential with respect to time. An early step toward this aim was suppression of the action at the second electrode. From time to time technical precautions have been delineated without, however, attainment of a procedure operationally satisfactory. Witness the ambiguity that still surrounds the configuration of the ending of the spike. More than academic interest is attached to this shortcoming as it has introduced artifacts into records of temporal dispersion on conduction, inductive of misinterpretations

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of the content of the fiber spectrum. To learn what these are a new inquiry has been made into the consequences of leading with two electrodes.

The simplest lead is two electrodes applied to the side of a nerve. If the ends of the nerve are floating it has the merit that one knows the locations of the sites of leading. To an appropriate recording device the electrodes report the differences of the potentials between them induced by a passing impulse. There is then left for interpretation the genesis of the differences. What is contributed by changes at each of the two electrodes? How much must be attributed to the passage of the impulse between the electrodes?

THE DIPHASIC LEAD The classical diphasic lead obtained with two electrodes had at hand a ready explanation. The nerve impulse, signaled by a negative variation, would produce in turn negativity at the two electrodes. With reference to the direction of the deflection produced by negativity at the first electrode, negativity at the second electrode would produce one in the opposite direction. An actual record would be determined by the algebraic sum. Record 1A (l.s. 20) is consonant with such an interpretation. But, if the interpretation were sufficient, it would follow that at an electrode separation long enough to encompass a whole wave length a monophasic record could be led from the first electrode. Trial of the experiment, instead of confirming the prediction, succeeded only in revealing the insufficiency of the interpretation. As the phases were separated conditions came to light favorable for demonstrating that the potential difference between the electrodes is determined not only by the changes at the electrodes produced by a passing impulse but also by an effect of the impulse as it passes between the electrodes. The evidence is illustrated in Fig. 1.

An experiment was set up in order to obtain a series of diphasic records revealing the effect of making the lead separation (l.s.) the only variable. Nerves suitable for the employment of a long lead separation are notoriously hard to prepare on account of the propensity of any irregularity between the electrodes to yield a false lead (Bishop *et al.*). This preparation of the saphenous nerve of the cat was a particularly successful one. After the velocity had been measured at a conduction distance (c.d.) of 52 mm. the first electrode (E_1) was set in a constant position; then the lead separation was determined by moving the second electrode (E_2). As a group of fibers had to be used for representation of a single fiber, the aim was to keep the fiber group optimally homogeneous by using as weak a shock as possible. In practice, since an exaction of the experiment was constancy of the size of response, the shock strength had to be increased above the level of play at a sacrifice of fiber homogeneity. A consequence was the obvious dispersion in the second phase when the l.s. became long. Calculated on the basis of the velocity of the crest from the first to the second phase, fibers with conduction velocities ranging between 83 and 53 m.p.s. were actually involved. Dispersion in the first phase was minimized by selecting a short c.d. The series, like all long series requiring maintenance of the nerve in a constant condition,

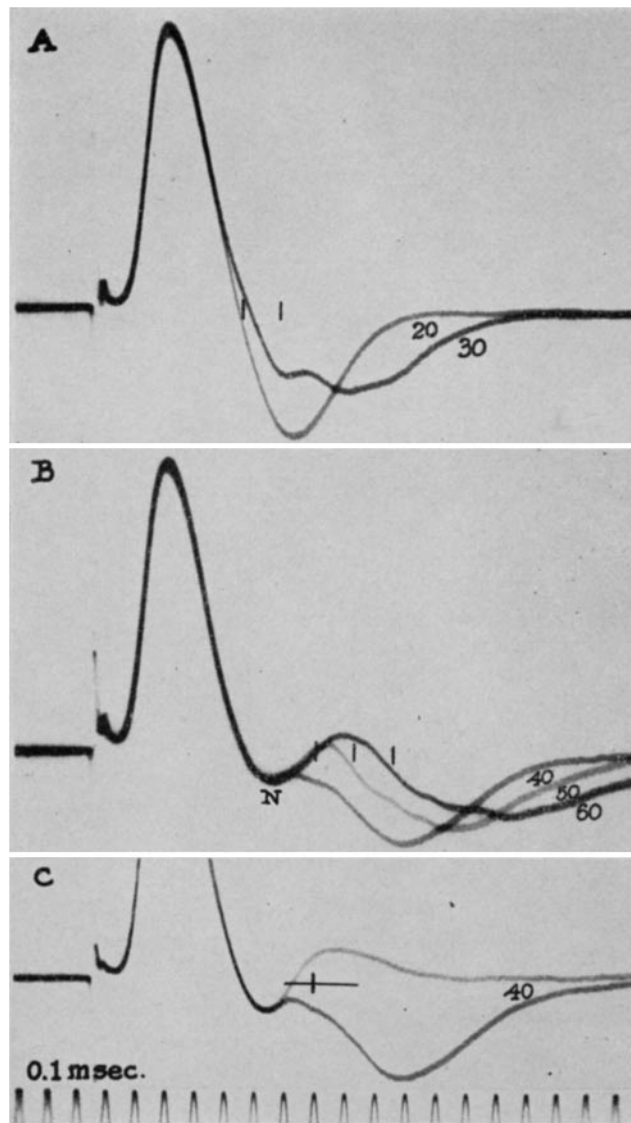


FIGURE 1, A and B. Series of diphasic records from the saphenous nerve of the cat at the lead separations (l.s.) marked on the records in millimeters. Shock constant, 6.5 volts for 0.01 msec. Conduction distance (c.d.) 12 mm. Nerve in oil, equilibrated with 5 per cent CO_2 in O_2 . 37.4°C . To facilitate comparison, the individual tracings are presented as prints through registered enlargements on film. A, l.s. 20 mm. on l.s. 30 mm. B, l.s. 40 mm. on l.s. 50 mm. and on l.s. 60 mm. N, positive notch. C, the diphasic record at l.s. 40 mm. on one with a xylocaine block with a sharp border established at 40 mm. from E_1 . E_2 was 15 mm. beyond the edge of the block. On all the records vertical lines mark the position of the sink maximum. On C the duration of the sink is also marked.

had to be performed in oil. At its end the nerve was bathed in Krebs' solution. Then, according to a method to be described later, a block was established with its border 40 mm. from E_1 .

In a quick survey of Fig. 1, it is seen that a positive notch appears at l.s. 30 mm. Its maximum reaches a constant size and position at the longer separations (Fig. 1B N). Its duration increases with the l.s. which determines the intervention of the second phase. Neither its size nor the position of its maximum is affected by a block at E_2 (Fig. 1 C). Since the manifestation of the notch varies with the l.s., and frequent references must be made to it, it will be called the lead separation effect (l.s.e.).

The most illuminating clue to the interpretation of the series of records was found to be consideration of the spatial changes of the position of the maximal sink with respect to time. To do so involves the potential-distance curve, which has the same shape as the potential-time curve but reads from right to left. The sink enters the interelectrode region at the beginning of the inflow current. At E_1 it starts at the first inflection of the potential-time curve and there reaches its maximum at the potential crest. Thus one position of the sink maximum is located. A time for it can be calculated from the conduction distance, 12 mm., and the velocity separately measured, 83 m.p.s. On the basis that the potential crest is propagated at the same rate as the start the time turns out to be 0.145 msec. A time for location of another position of the sink maximum is required. In accord with an hypothesis that the time of the maximum of the positive notch (N) is also concurrent with the time of a sink maximum the time can be read on any of the records in Fig. 1B, better from the last two, which yield a reading of 0.364 msec. after the crest. At a conduction time of 0.509 msec. the distance becomes 42 mm., or 33 mm. beyond E_1 . Alternatively the location of the sink maximum can be determined from measurements made directly on the records: from the crest time and the latter plus the conduction time increment at the maximum of N. The penetration then becomes 28.5 mm. which corresponds to a velocity of 78.4 m.p.s. In recognition of the temporal dispersion involved, this velocity was considered to be a more realistic one. It was used for marking the positions of the sink maxima on the records in accord with the lead separations at which they were made.

Attention is called to the fact that none of the vertical marks indicating the positions of the sink maxima fall at the maximum of the positive notch (N) in Fig. 1B. Coincidence between the two maxima occurred at the time at which the sink maximum passed the notch maximum. That time is constant in all three records, hence its selection for the temporal location of a sink maximum. When the lead separations are extended to 40, 50, and 60 mm. the sink maxima pass beyond the time of the notch maximum in the course

of the records. At l.s. 30 mm. in Fig. 1A the mark of the position of the sink maximum is above the notch which is being formed and is being recorded in summation with the beginning of the second phase.

Whatever effect the sink has at a short l.s. is obscured by the first phase. At l.s. 30 mm. it distorts the second phase. At l.s. 60 mm. the maximum comes about half-way between the electrodes. As it approaches E_2 its effect is prolonged but decreased in size; and at this separation it actually changes sign before the intervention of the second phase. This unanticipated sign reversal is brought out on suppression of the second phase (Fig. 1C). In interpretation of this record the duration of the sink enters into the reckoning. As measured on the first phase it lasts from 0.09 msec. before the maximum to 0.15 msec. after it (second inflection). The duration without allowance for dispersion is marked on the record. Its fit is sufficient to indicate that a sink while proximal to E_2 affects the lead differently than when it is passing.

In the experiment just described the behavior of a potential manifestation has been analyzed. This manifestation was first differentiated from other manifestations by Lorente de Nó. After careful consideration he came to the conclusion that it must be attributed to structures in the core, polarizable by longitudinal currents. Recently P. Mueller has, indeed, demonstrated longitudinal polarization of the axons of single fibers. In whatever measure this explanation applies, it is consistent with an important general conclusion: that the manifestation is an expression of normal nerve biophysics. Its regular appearance in normal nerve, its definite department, its apparent correlation with the membrane current, and its inaccessibility to a cocaine block at E_2 , all point in the same direction. So interpreted, it would be indicated to consider the possible role of the process in the mechanism of normal conduction, rather than to dismiss the manifestations as an artifact. Therefore, it was given the non-committal appellation, lead separation effect, the adjectives in deference to the most effective method for its revelation. If the l.s.e. is brought out by separation of the electrodes, conversely a lead in which it is minimally present should be obtained by approximating the electrodes. Such a lead is usually considered to record the longitudinal current.

INTEGRATION OF THE TANGENT In another view a longitudinal current lead records the tangent of the action potential. Valid tangents are obtainable from spikes of threshold fibers with a wave length of 50 mm. They can be led at long distances from cut ends of the nerve and they can be integrated electronically.

For the apparatus with which integration was accomplished I am indebted to the kind cooperation of J. P. Hervey and P. F. Smith, who constructed for me an "analogue integrator operating in real time," suitably adapted to the time constants of the tangents to be integrated, and equipped with an adjustable delay triggered by

the stimulus shock so that integration could be started at a time when the shock artifact would not be included. The integrator panel is installed so that according to need it can be connected to, or disconnected from the rest of the circuit leading to the oscillograph. Through a by-pass on the integrator, itself, alternate readings of the tangent and its integral can be made. Amplification is D.C. An increase is needed for the integration, usually tenfold. A difficulty in the use of the integrator is its high sensitivity to an input imbalance, which it integrates to produce a change of direction of the base line. In fact, this sensitivity, causing a kink in the base line changing between upward and downward slopes, affords a delicate index of the extent to which the resting potential is continuously subject to slight fluctuations. In operation a tangent is recorded, the by-pass is removed, and the base line watched for a steady period in which to start the integration. After an initial base line the integral is recorded; and it is succeeded by a second base line for assurance that the balance has not significantly changed during the procedure. Usually a number of attempts must be made before a successful sequence is obtained.

In operation some optima had to be ascertained by observing the tolerance of variation in the experimental conditions not resulting in observable differences in the records. Triggering was so rapid that it could be effected within the conduction time for 10 or 11 mm. Short conduction was imperative to avoid temporal dispersion resulting from the departure of the fibers from homogeneity, imposed by the shock strength necessary for steadiness of response. Fortunately, in the tangent lead, with its proximity of the second electrode to the first, heterogeneity does not have any long distance in which to display its effect such as it had in the experiments described in the previous section. Thus, the group becomes far more representative of a single fiber. Leads were made with thin heavily chlorided silver wires. But no advantage was observed over wires of heavier gauge used in the earlier experiments. The lead separation (measured between the inner edges of the wires) was not notably critical. A separation of 2.0 mm. was mostly used. Greater separations were within tolerance. Shorter ones showed no advantage and necessitated increasing the gain for integration in a way to make balancing more difficult.

An integration is illustrated in Fig. 2, together with reproduction of the attendant records in the sequence of recording. The closeness of the match of the integral to the theoretical integral of the tangent supports the validity of the electronic integration. The striking feature of the spike is the smooth relaxation of the falling phase. Not a trace of l.s.e. is visible. The picture corresponds to the one that has been idealized for the monophasic action potential. Comparison with the measurements of spikes in single fibers in the saphenous nerve, made by Gasser and Grundfest twenty years ago, shows that the dimensions come extraordinarily close to being representative of a single fiber.

The experiment of Fig. 2 was selected for illustration on account of the

lack of complication by visible negative after-potential. The tracing is somewhat exceptional in an experiment performed according to routine in an atmosphere of 5 per cent CO_2 in O_2 . Usually a negative after-potential (N a-p) is encountered, as exemplified in Fig. 3. The size seen in Fig. 3A is frequently observed, and larger ones are found in nerves presumably normal (Fig. 3B). Two aspects of the observations are noteworthy. One is the eventless junction of the spike and the N a-p. The other is that with the aid of the tangent the origin of the N a-p can be traced back to as early as the spike crest. The evidence is contained in the reduction of the area of the second phase of the tangent below that of the first phase, causing failure of the integrator con-

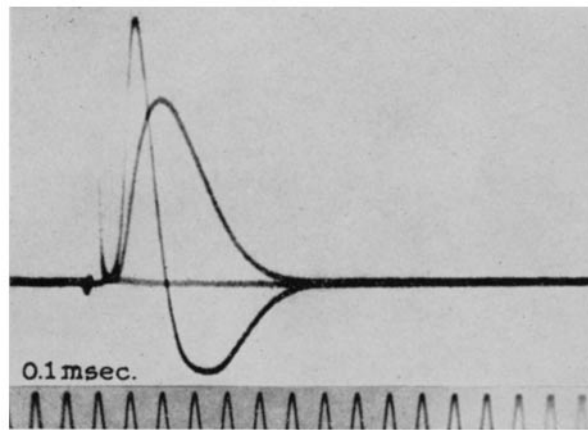


FIGURE 2. Cat saphenous nerve. Superimposed record of an integral with its base line upon the corresponding tangent. Gain for integral 10 times that for tangent. Stimulus shock duration, 0.01 msec. Integration delay 0.04 msec. C.d., 11 mm. l.s., 2.0 mm. 37. 3°C.

denser to empty for a return to the base line. The N a-p is discernible on the tangent, itself, in Fig. 3B.

In the problem of recording the fiber spectrum the contribution of the integration of the tangent ends with the demonstration of the nature of the spike termination and the provision of a model of a "monophasic lead." Two inadequacies prevent extension of the integration procedure to the spectrum. Integration of the N a-p produces a gross distortion of it. And the wave lengths of the spikes of the small fibers are too short for tangent leads. A resort to a lead with a block at the second electrode is inevitable. In view of the significance of the lead separation, there is a directive toward exploring means for making it as short as possible.

The shortness of the l.s. attainable depends upon how abruptly the lead can be caused to change from all to nothing. Granted precision in the location of the proximal edge of the zone of application of the blocking agent, the

abruptness rests with the blocking agent selected. All agents blocking by depolarization must be ruled out. A demarcation current is set up which depolarizes the adjoining nerve in a continuously progressing way. This fault can be obviated by using an agent which blocks without depolarization. Cocaine, the prototype of this group, was introduced by Bishop. The group has two merits. The nerve is not altered on the proximal side of the zone of application; and a steady state can be attained. Against these merits must be debited a shortcoming. The block lacks satisfactory abruptness.

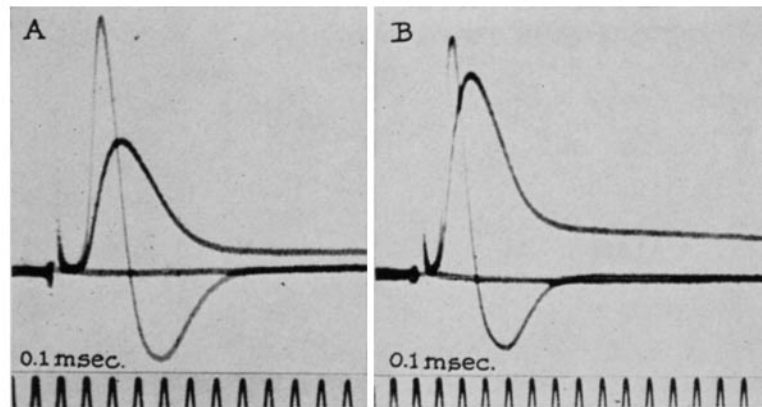


FIGURE 3. Cat saphenous nerves. Integrals obtained from nerves with a N a-p. A, gain for integral 10 times that for tangent. Shock duration 0.01 msec. Integration delay 0.04 msec. C.d., 14 mm (from series demonstrating 14 mm. within tolerance). I.s., 2.0 mm. 37.3°C. B, gain for integral 17 times that for tangent. Shock duration 0.01 msec. Integration delay 0.04 msec. C.d., 11 mm. I.s., 2.0 mm. 37.3°C.

Establishment of a Block Subsequent to a suggestion by Lorente de Nó xylocaine has been used as the blocking agent. Its blocking power is equivalent to that of cocaine; and its employment is facilitated by the greater solubility of the free alkaloid at the pH obtaining in nerve experiments. All the electrodes in the nerve chamber are movable from the outside of the box, and their position is readable on an external millimeter scale. The distal electrode carrier is equipped with a glass hook, G (Fig. 4), fixed in position with respect to the electrode, E_2 , which is a heavily chlorided silver wire. An air gap separates the hook from the wire to prevent corruption of the lead. It will be convenient to define a new leading dimension, E_1b , the distance from E_1 to the edge of the block. (Differentiation from I.s. is left for later exegesis.) In preparation for readings of E_1b , E_1 is placed alongside of E_2 , and a reading is made on the millimeter scale for the position of E_1 , when $E_1b = 0$. E_1 is then moved away again to prevent contamination. With the nerve in position a rectangle of filter paper, F, fitted snugly against E_2 , is supported across the nerve and the glass arm. Now the blocking agent is applied to the filter paper. After the agent has acted for the desired time the filter paper is removed and E_2 moved 15 mm. distally. Setting E_2 well beyond the proximal edge of the block was necessary to prevent the

impulse from reaching it. No matter how sharp the edge of the treated region the impulse dies out decrementally. This mode of extinction holds whether cocaine, phenylurethane, or xylocaine is employed; and it can probably be generalized as an attribute of blocks effected by all non-depolarizing blocking agents.

Routinely 1.0 per cent xylocaine was applied for one-half hour. These parameters allowed a wide margin of safety both in duration and in concentration. Longer times and higher concentrations did not alter the nature of the observations, and increased the possibility of spread of the agent. Experiments involving a series of observations under steady conditions demand immersion in oil for prevention of drying and maintenance of a constant temperature. As the alkaloid is soluble in oil, a margin of safety served a useful purpose. For a set of observations to be made while a nerve is in first class condition the manipulations must proceed with dispatch. Within the duration of an experiment no difficulty was encountered occasioned by solution of the xylocaine.

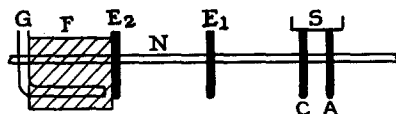


FIGURE 4. Diagram for the production of a xylocaine block at a determinable position.

PENETRATION OF A BLOCK Sample records of conduction into a block produced by xylocaine, acting at a concentration time much greater than needed for a maximal effect, are illustrated in Fig. 5. The penetration into the block seems to start with decremental conduction and to continue after about 4.0 mm. with electrotonic spread. The case for decremental conduction has recently been presented by Lorente de N6 and Condouris. As the same stimulating shock and the same amplification were used for all the observations, a graph of the heights of the records at all the positions is justified (Fig. 6). A shorter distance than is subtended by this decremting curve is not to be anticipated in any experiment, as in this instance there was evidence of some spread of the agent proximal to the zero position. The utility of defining as E_1b the distance between E_1 and the edge of the block now becomes apparent. It differs significantly from l.s., measured by the distance between the two electrodes. For E_2 to be far enough beyond the edge of the block to be out of range of effect of the impulse, considerable distance must be added to the l.s. Into some of this distance the impulse is sure to penetrate and to become recordable as part of the l.s.e. Thereby the effectiveness of placing E_1 close to a block is decreased. Evaluation of the extent of the effectiveness is reviewed in the following paragraph.

In tests of leads involving blocks, E_2 was always 15 mm. beyond the edge of the block. Thus the problem resolved itself into finding how close an approximation of the first electrode to the edge of the block, E_1b , was practical, and into evaluating the lead obtained at the optimal position. In recording a complete fiber spectrum, the defects produced by the conditions of leading

are obscured by the very temporal dispersion by which the spectrum is revealed. For better revelation of the defects dispersion was decreased by using a short conduction distance and only a portion of the alpha fibers. A quantitative comparison was not only not precisely attainable, it was difficult to attain in approximation particularly at the longer E_1b distances, where uncertainty could be introduced as to whether the fibers involved would be the same ones. Since in the procedure the position of all the electrodes except

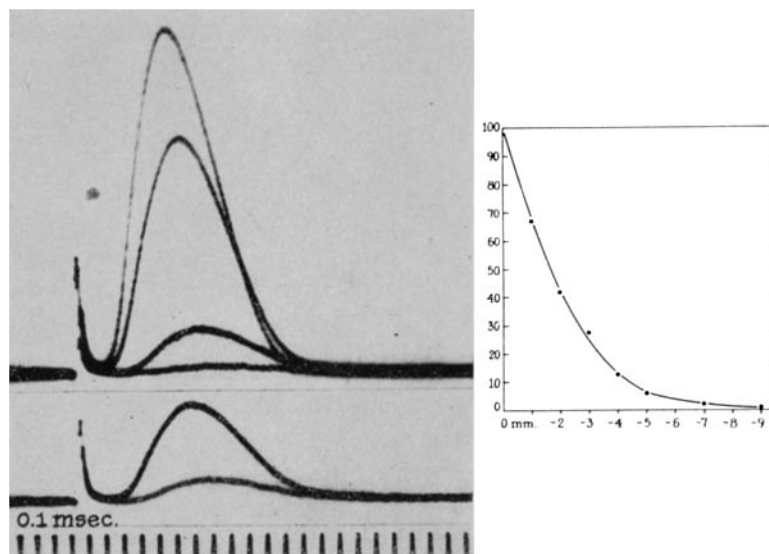


FIGURE 5. *R. pipiens*. Penetration of an impulse into a block produced by xylocaine. 2 per cent, pH 7.4, acting for 1 hour. C.d. to edge block, 12 mm. Upper, E_1 at edge of block ($E_1b = 0$) superimposed upon E_1b 's -1 , -4 , and -7 mm. (A minus sign is used to indicate that E_1 is inside the block.) Below, Records at -3 and -5 mm. Same shock and amplification for all records.

FIGURE 6. Graph of the heights of the whole series of records, of which those in Fig. 5 are samples. Ordinate, height at $E_1b = 0$ set at 100. Abscissa, distance of E_1 inside the block. No deflection was visible at -11 .

E_2 had to be moved the thresholds could not be held constant, necessitating slight adjustments in the shock strength or in the amplification for maintenance of the response at a size suitable for comparison. With the reservation noted, Fig. 7 shows a set of records in which E_1b is so dominantly the variable that the effect of lengthening it is adequately illustrated.

A glance at the figure suffices to show the extent to which the l.s.e. can distort a record when E_1b is longer than 5 mm. It is also apparent that the effect is still manifest at 5 mm. Much attention was given to distances shorter than 5 mm. In this region the major concern is that no part of the action potential be reduced in size. The exact distance allowable varies with the

experiment. In some cases 2 mm. is usable, while 5 mm. is generally quite safe. When 2 mm. is usable there is little reduction of the l.s.e. Therefore, 5 mm. was adopted as the optimal distance. One is forced to the conclusion that an optimal lead falls short of being an ideal one.

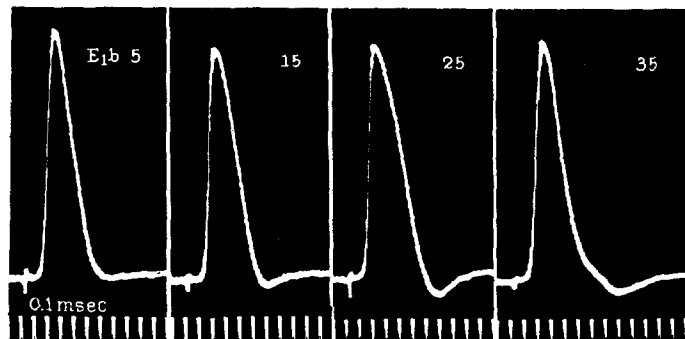


FIGURE 7. Saphenous nerve of the cat. Comparison of records taken at various distances from a block. E_{1b} marked on records in millimeters. The conduction distances were constant, 11 mm. Shocks submaximal for alpha. Slight adjustments in amplification so that the l.s.e.'s. would appear on reference spikes of approximately the same height. 37.2°C .

In the nerve from which Fig. 7 was obtained an $E_{1b} = 2$ mm. was permissible. A spectrum of the nerve obtained at $E_{1b} = 5$ mm. is shown in Fig. 8. If the auxiliary information were unknown, the fact might be missed that the depression after the alpha elevation, and hence after the delta elevation, is slightly too large.

Two alternative procedures are available for making a lead of the spectrum. Instead of employing a short E_{1b} as an optimum with its residual imperfection,

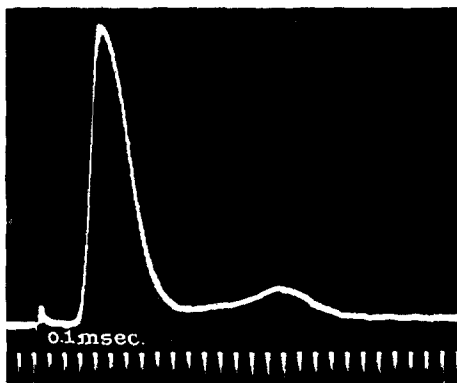


FIGURE 8. Saphenous nerve of the cat, same nerve that furnished Fig. 7. Complete action potential recorded at c.d. 31.5 mm., $E_{1b} = 5$ mm. 37.2°C .

one might accept the l.s.e.'s at a longer E_{1b} and interpret the records with recognition of them. Against the latter alternative would be its difficulty, because every velocity would manifest a different effect in accord with its wave length. Several consequences of how a lead is made are illustrated in Fig. 9. Presumably the same fibers are depicted; at least they are nearly

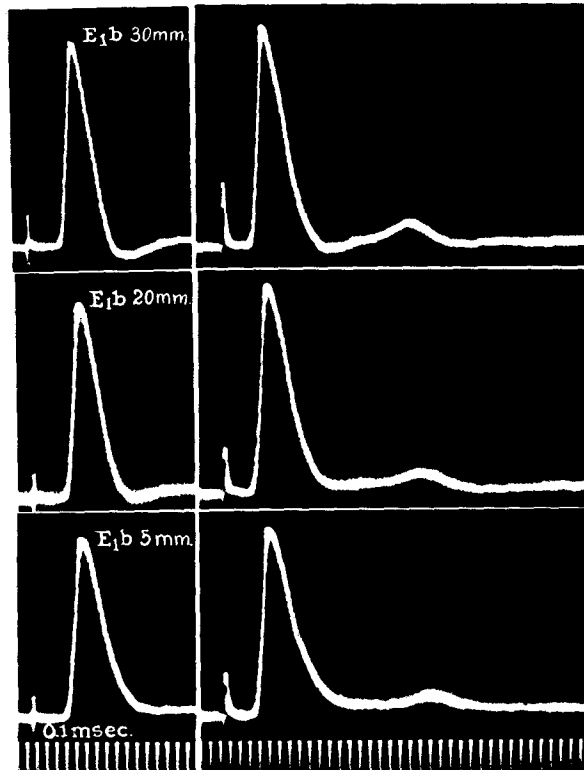


FIGURE 9. Saphenous nerve of the cat. Records taken at the same distance of conduction, 32 mm., but at the E_{1b} distances marked in the figure. The records were taken with a shock duration of 0.01 msec.; those at the left at 6 volts, 1 volt above the threshold; those on the right at 20 volts. As between the rows the heights are without significance. A lead at $E_{1b} = 2$ mm. would still have been valid. 37.3°C.

enough the same to serve for showing on a given set of fibers the differences in the reports made by leads identical except for the E_{1b} distances. Although the tracings in the left hand column manifest smaller l.s.e.'s than those in Fig. 7, where there is less dispersion, in leads of the complete spectrum the effect subsequent to alpha is rendered less visible by the later fibers. At the E_{1b} 's of 30 and 20 mm., the l.s.e. is quite visible and obviously accounts for alpha appearing too narrow at the base. At $E_{1b} = 10$ mm. (not shown) alpha has nearly the same appearance as the $E_{1b} = 5$ mm., but the depression after

delta is still discernible. At $E_1b = 30$ mm. the effect after delta is great enough to explain the one-time suspicion that delta contained a second component. That it is a single elevation follows from its appearance at $E_1b = 5$ mm. It would be almost impossible by allowance for the l.s.e.'s. involved in determining the form of the record at $E_1b = 30$ mm. to make as good an estimation of the map of the contributing fibers as can be made directly from the record at $E_1b = 5$ mm.

Examination of the technique of leading has afforded a better understanding of the configuration of a tracing and made it more possible to differentiate the features yielding information about the nerve examined from those which should be regarded as adventitious to the artificial conditions. Although a method of leading which will yield an ideal action potential has not been found, it has been possible to devise procedural improvements such as greatly to reduce the more deceptive distortions. When applied to the fiber content of a skin nerve the action potential has been found to be considerably simpler than the one originally described. There are but two major elevations, the ones that have been called alpha and delta. Thus the action potential has been brought into consonance with the maps of fiber size analyses. Gamma is entirely eliminated as it has been found to be nothing more than an appearance introduced by a l.s.e. of the alpha component. In the continuity of fiber sizes between alpha and delta, there exists only a single minimum. In some nerves there is a bulge on alpha in the beta position, apparently not artificially produced. Its appearance is an exception rather than the rule (*e.g.* Fig. 9). It has no clear representation on the fiber maps, and it has no functions associated with it. Thus a special designation for it is superfluous.

Improvement of the action potential of the saphenous nerve suggests reconsideration of the relation to the fiber sizes. Past attempts to construct the action potential on the basis that the velocity varies as the diameter of the fibers have failed to produce a match. The hypothesis of the linear relationship to the diameter is still inadequate. Reference to Fig. 9 confirms a fact long known. Shock strengths sufficient for evocation of the complete spectrum make the fastest fibers appear too early. But the departure from linearity is large enough to persist after due attention has been paid to this source of error. In the constructions the crest of the delta elevation comes considerably too early. The several maps of fiber size analyses show that the maximum of the alpha group comes at a size 2.2 to 2.4 times the size at the maximum of the delta group, whereas in the records the delta crest with some regularity comes at a time close to 3.8 times that of the alpha crest. In keeping with coming too early in the constructions delta is also too high. But that insufficient dispersion is the only reason does not follow, since when the height is reduced on bringing delta into proper position by arbitrarily supposing that velocity is as $D^{1.2}$, the height is still too great.

Construction of the action potential from the histological picture is a delicate and exacting method of testing our knowledge of nerve fibers. As long as the action potential cannot be faithfully reproduced, the failure must serve as a warning that our evaluation of the biophysical constants is inadequate. Revision of the configuration of the potential recorded from a skin nerve has resulted in a simplification of the form to be matched. An effective step toward making a match would be to find what variable in addition to fiber diameter is instrumental in determining velocity.

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