SURFACE POTENTIALS AND PERIPHERAL NERVE INJURY: A CLINICAL TEST*

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In a recent preliminary note[2] concerning electrical correlates of peripheral nerve injury, it was pointed out that the condition of peripheral nerves is reflected in the changing surface potential differences. The following discussion will briefly describe certain experiments which led to this observation and to the clinical application of the method in cases where there is any question of peripheral nerve function, injury, or regeneration.

Material and methods

All potentials were recorded by means of the Burr, Lane, Nims microvoltmeter, according to the technique described[1] by them in 1936. Reversible, nonpolarizable Ag-AgCl electrodes were used. The recorded data are in millivolts of potential difference between a fixed "indifferent" or reference electrode and a moving electrode. In all animal experiments the fixed electrode was located high up on the thigh and the moving electrode was placed on surface areas of the lower leg which were supplied by the sciatic nerve. In all cases of ulnar injury in man, the reference electrode was placed on the ear lobe and the moving electrode on the surface of the most distal phalanx of the fifth finger. *Polarities represented in the graphs are those of the moving electrode.*

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A preliminary survey of the efficacy of the test in war injuries (for which funds were provided under a contract recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and the Yale University School of Medicine) was made at the Oak Knoll Naval Hospital, Oakland, California. The authors are indebted to Commander W. C. Livingston and his staff, as well as to the personnel and patients of the hospital for their kind cooperation.

The cases discussed here were examined at the U. S. Naval Hospital at St. Albans, N. Y. Our most sincere gratitude is extended to Admiral H. W. Smith (MC) USN, who made it possible for the work to be carried out; to Capt. J. C. White (MC) USNR, Commander T. Hoen (MC) USNR, Lt. T. Bennett (MC) USNR, and other members of the staff of the hospital, and to all those, personnel and patients, whose cooperation and assistance enabled us to complete the tests.

Preliminary readings were made before injury or block of the nerve, and were followed by injections of 2 per cent procaine or procaine-suprarenin (1:20,000, and in a few cases 1:50,000) into the nerve being studied. In early animal experiments the sciatic nerve was crushed or severed in some cases instead of being blocked. A series of potential readings followed the block or injury of the nerves.

Results

The experiments in which the rabbit sciatic nerve was crushed or severed, and potentials measured on the limb surface, acutely, showed that anatomic interruption of the nerve in this fashion brought about a marked positive shift in potential.

Figure 1 demonstrates these findings in one case. (In Figs. 1, 2, and 3, the six spots measured were all on the posterolateral surface of the leg—the area of sciatic innervation.) Immediately following nerve section, potentials recorded from the surface area supplied by the sciatic nerve, shifted from 7 to 19 millivolts positive. (It must be mentioned that variations in response as well as diminished quantity of reaction are observed to a much greater degree in the rabbit than in man, in part, at least, because of depression of the nervous system by anesthesia. In many cases it was also quite difficult, in attempting to block the rabbit sciatic, to localize the procaine injection accurately.)

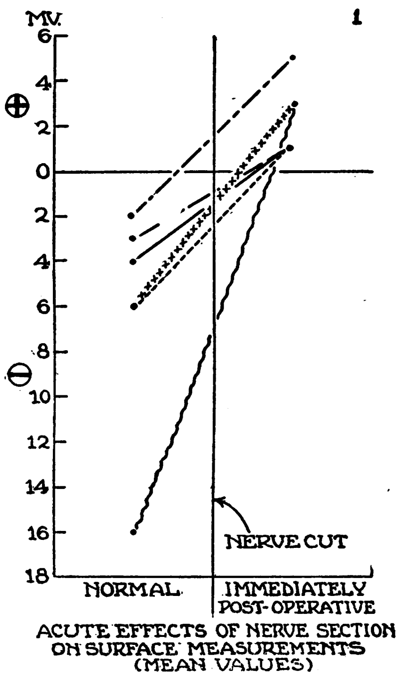


Fig. 1. Surface potentials measured at six points along the posterolateral surface of the rabbit leg in the area supplied by the sciatic nerve. Measurements were made before and immediately following section of the nerve.

This first set of experiments suggested that a close nerve-tissue relationship (as reflected by the potentials) existed, which could, if disturbed, significantly alter the tissue potential level. However, two initial questions remained, namely:

1. How could the changes during the recovery period of the

nerve be observed in a shorter time than that which had to elapse while regeneration occurred?

2. Would physiological interruption of nervous activity produce a similar disturbance of the standing potential?

These problems were approached by leaving the nerve structurally intact, but studying changes associated with temporary block by administration of procaine. It was observed immediately, as shown in Fig. 2, that physiological (or pharmacological, to be more precise) block of the nerve produced positive surface potential shifts

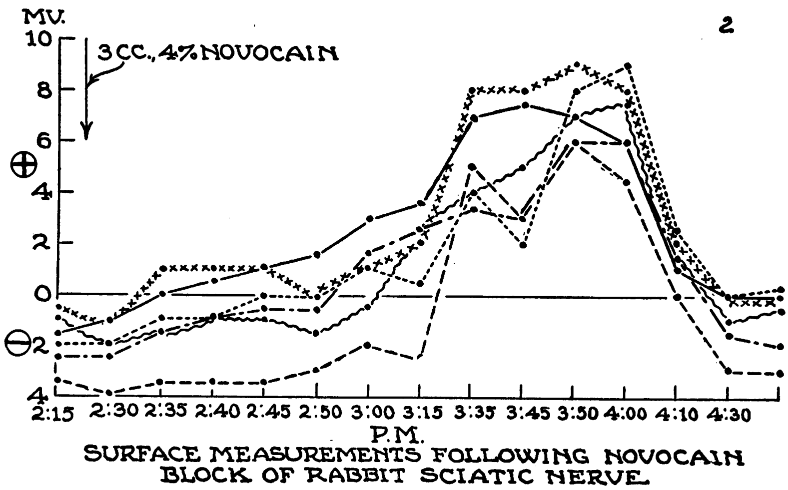


Fig. 2. Measurements of surface potentials on the rabbit leg before and after procaine injection, at the same six points measured in Fig. 1.

bearing the expected similarity to those following trauma. It is worthy of note that in all experiments potential measurements on the normal leg (undisturbed sciatic nerve) served as controls. In order to determine whether or not the potential shifts following procaine block were actually due to the procaine as such, and not merely to the injection of fluid, several animals were injected with physiological saline solution (in the same place and with the same amount). No potential change occurred in 90 minutes following this injection, but if procaine was infiltrated into the nerve at this time, the "normal" potential shift appeared.

Figure 3 represents another type of control. The six points measured here were in the surface area supplied by a sciatic nerve which had been crushed several weeks before and at the time of this experiment did not respond to stimulation. It is clear that procaine injection produced no significant shift.

With this basic material at hand, it was decided to attempt a study of the reaction in man, and the ulnar nerve was chosen because of its convenient area of innervation and the fact that its superficial location at the elbow made it readily available for injection. With the exception of the case shown in Fig. 4, the indifferent electrode was always placed on the ear lobe, and the moving electrode on the palmar surface of the distal phalanx of the fifth finger. In the case graphed in Fig. 4, the indifferent electrode was located on the upper arm, and the readings made with the moving electrode, on three points—two on the hypothenar eminence and the third on the fifth finger. The final decision to read only the tip of the fifth finger was made in order to avoid any involvement with nerve overlap—a factor of some consequence in the hand as elsewhere.

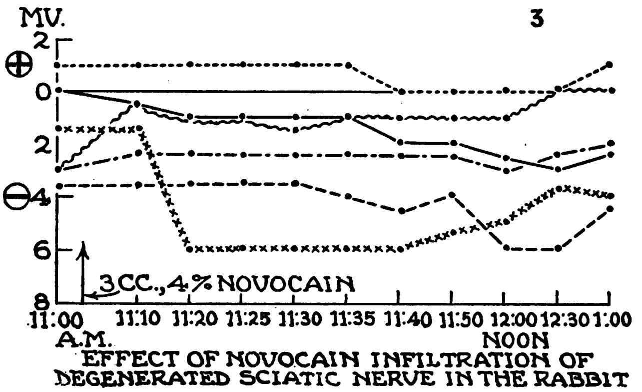
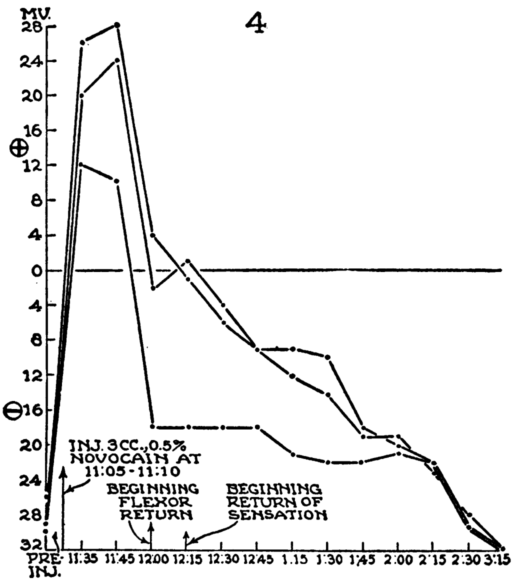


Fig. 3. Measurements similar to those in Fig. 2, but recorded in a case in which the sciatic nerve was degenerated.

The curves shown in Fig. 4 are fairly typical of the presence of a normal ulnar nerve. As is usual, pre-injection readings are markedly negative, and in this case, within 25 minutes after infiltration of the nerve with procaine, the potential differences had shifted some 55 millivolts positive. Twenty-five minutes later, with the return of flexor function, the potentials had dropped very considerably and continued to drop through the return of sensation, and after the lapse of three hours had returned to their normal relationship. The record also demonstrates another point of great interest. It is not until the potential has returned half or more of the way back to its original pre-injection level that any gross signs of sensory or motor return are visible. It will be seen that this is a constant finding. If the curves on the uninjured sides in some of the other cases are compared with the curve in Fig. 4, it becomes clear that



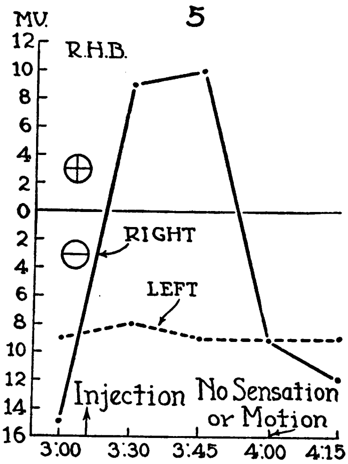


Fig. 4. Surface potentials following left ulnar nerve block in man. Nerve injected with 3 cc. of 0.5 per cent procaine-suprarenin (1: 50,000).

Fig. 5. Surface potentials before and after ulnar nerve block in a case of complete *left* ulnar paralysis. Both ulnar nerves injected with 5 cc., 2 per cent procaine-suprarenin 1: 20,000.

the pre-injection potential levels are similar, as well as is the type of shift following block. Variation in the quantitative extent of the shift may be due, in part, to differences in completeness of the block, but are probably associated with other basic factors as well.

Three types of cases are presented in order to demonstrate deviations from the normal, together with the effects of sympathectomy:

1. Those with injury of the ulnar nerve (Figs. 5, 6, 7, 8, 9).
2. Those with normal ulnar nerves, but who had undergone sympathectomy—unilateral or bilateral (Figs. 10, 11).
3. A case in which ulnar injury and repair, and sympathectomy, are combined (Fig. 9).

Figures 5 through 8 demonstrate the results obtained in complete ulnar paralysis and in three stages of regeneration following repair. In Fig. 5, following ulnar block, the normal (right) side shifted

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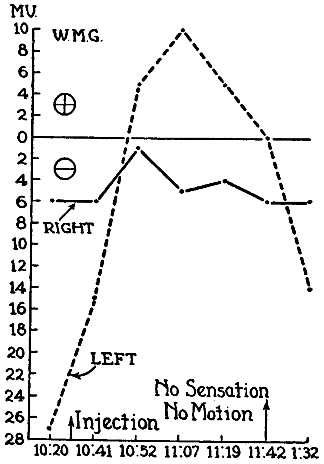

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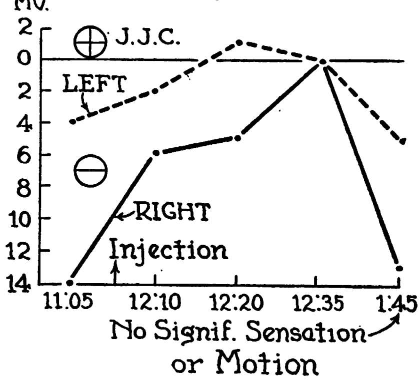

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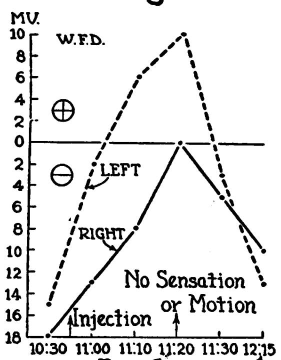

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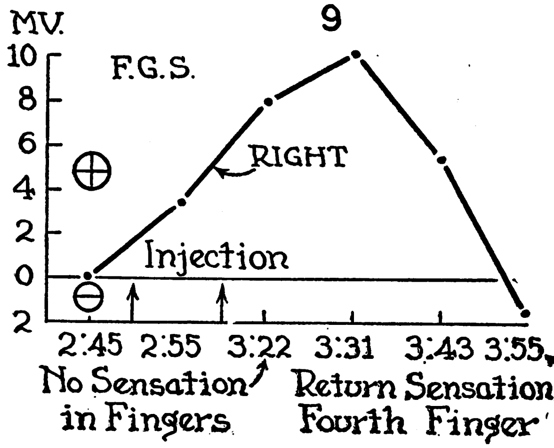

Fig. 6. Surface potentials before and after ulnar nerve block in a case of *right* ulnar injury. Injured May 17, 1945. Injected with 6 cc., 2 per cent procaine-suprarenin 1: 20,000.

Fig. 7. Surface potentials before and after ulnar block in a case of *left* ulnar injury. Wounded July 28, 1944. Operated (neurolysis) Feb. 1945 and Nov. 1945. Injected with 4 cc., 1 per cent procaine-suprarenin 1: 50,000.

Fig. 8. Surface potentials before and after ulnar nerve block in case of *right* ulnar injury. Wounded August 1944. Nerve sutured May 1945. Has regained sensation and some motion. Injected with 6 cc., 2 per cent procaine-suprarenin 1: 20,000.

Fig. 9. Surface potentials before and after ulnar nerve block in a case of right ulnar injury. Right arm sympathectomized to relieve causalgia. Right ulnar repair Sept. 26, 1945. This test done Dec. 12, 1945. Shows remarkable rate of regeneration. Nerve infiltrated at wrist with 18 cc., 2 per cent procaine-suprarenin 1: 20,000.

25 millivolts positive, and then dropped back. The paralyzed (left) side shows no significant potential change. This lack of reaction of injured nerve to block is typical and has been obtained in several other cases.

In Figs. 6 and 7, the operated sides (right and left, respectively) demonstrate the shift following bilateral injection of the ulnar nerves in very early stages of regeneration, i.e., a slight shift can be seen relative to the marked shift on the normal side. Figure 8 is the result in a case where marked regeneration is apparent. In this case

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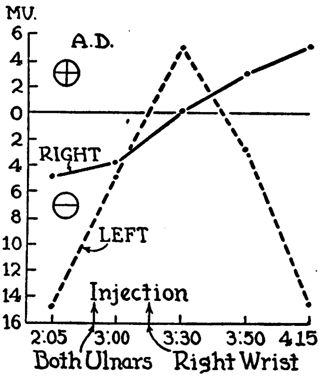

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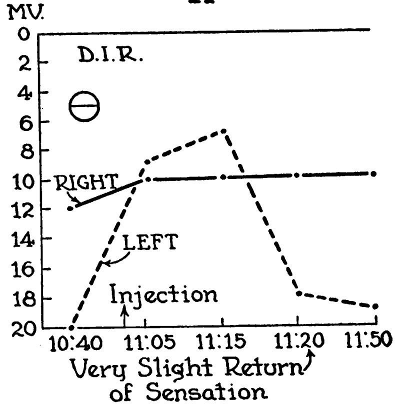

Fig. 10. Unilateral sympathectomy on *right.* Both sides injected with 5 cc., 2 per cent procaine (*without* suprarenin). First injection on right not good, so second injection made, and potential still shifting positive when readings stopped. Both ulnars uninjured.

Fig. 11. Surface potentials before and after ulnar nerve block in a case of bilateral sympathectomy for relief of Raynaud's disease. *Left* side only injected with 5 cc., 2 per cent procaine-suprarenin 1: 20,000. *Absence of sympathetic does not affect potential shift.* Note stability of uninjected side (right). Ulnars both uninjured.

all sensation and slight motion had returned on the injured (right) side. As a result, the potential on this side shifted considerably following bilateral block—18 millivolts as compared with 25 on the normal side.

The results plotted in Fig. 9 are those of a very dramatic and unusual case of ulnar injury with severe causalgia. A sympathectomy was performed to relieve the latter, and following it on September 26, 1945, the ulnar nerve was sutured high up in the arm. At the time of the present test, some 75 days following the repair, gross tests seemed to indicate that the nerve had regenerated about 40 centimeters—a rate of over half a centimeter a day! Some sensation was present in the ulnar side of the ring finger. The results of this test, as shown in the graph, show definite regeneration as evidenced by a potential shift of 10 millivolts following block. Furthermore, the fact that both the initial and the final potential differences were less negative than normal suggests that regeneration was still not complete, as the gross tests indicated.

Figures 10 and 11 show the findings following sympathectomy. In the case graphed in Fig. 11, a bilateral preganglionic sympathectomy had been performed for the relief of Raynaud's disease. Only the left side was blocked and a normal shift resulted. The readings on the right, uninjected side, demonstrate the stability of the measurements over the period of time in which the other side was shifting. In Fig. 10 the potential on the sympathectomized (right) side was still shifting positive when the readings were stopped. The delay in this reaction was due to a poor first injection of procaine which necessitated a second injection at a later time.

Discussion and conclusion

The phenomena here presented show a clear-cut correlation between the integrity of the peripheral somatic nervous system and potential differences measured on the surface of the arm or leg. Interference, pharmacological or traumatic, with the normal function of the ulnar or sciatic nerves is reflected in an altered standing potential between an indifferent electrode and a moving electrode in contact with the area supplied by the nerve in question. The mechanism by which this correlation is brought about is important. Complicity of the vascular bed might exist, but the lack of any significant change in the total pattern following sympathectomy makes this unlikely. However, the sympathectomies were all preganglionic and hence further work must be done in order to clarify the matter. However, it has been found that rapidly shutting off the blood flow in the forearm and hand by means of a blood pressure cuff on the arm, as well as the sudden return of flow on releasing the cuff, does not significantly alter the potential difference. In other words, altering the normal functioning of the vascular bed does not affect the standing potential. Furthermore, since the microvoltmeter is relatively unaffected by changes in resistance in the system being measured, "skin resistance" and sweating, as reported by Richter and his associates,[3] are not involved in the potential changes. In the light of these findings it would seem unlikely that the sympathetic nervous system controls a mediating factor. Nevertheless, the data show that in unilateral sympathectomy there is a difference in the standing potentials on the operated and unoperated sides. This is yet to be explained. These measurements, then, form the nucleus of a simple, quantitative test of peripheral nerve function, independent of sweating (potentials can be recorded in the radial area of the dorsum of the hand without any difficulty) or vascular reactions.

Summary.

1. It has been demonstrated in experimental animals, as well as in man, that surface potential differences reflect peripheral nerve activity.

2. These potentials are not affected by preganglionic sympathectomy and appear to be independent of vascular and sweating responses.

3. The findings indicate that there exists a definite relationship between nerve and tissue, which forms the basis for the preservation of a level of potential; and that this relationship allows the use of these potentials in a quantitative test of nerve function which can be performed in a short time, with simple apparatus. These facts make the test practical enough for routine clinical applicability.

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