“DELAYED RECOVERY” IN PERIPHERAL NERVE LESIONS CAUSED BY HIGH VELOCITY PROJECTILE WOUNDING*


U. S. Naval Hospital, Oakland, California

(Received for publication December 26, 1944)

In dealing with a large number of peripheral nerve injuries due to war wounds, we have been impressed with the number of patients who recover function spontaneously, and with the satisfactory degree of recovery that many of them eventually attain. Even in the cases that have been explored with the expectation of finding the nerve trunk completely severed, a surprisingly large percentage have shown no disruption of continuity of the nerve. These observations seem to apply less to the incisional type of wound due to bayonets, knives and the like, but to be more characteristic of the wounds due to high velocity projectiles. In order to confirm our impressions, we have analyzed the histories of 154 men with lesions involving one or more of the three major nerves to the hand, whose wounds were due to projectiles. In 80 cases the wounding agent was a bullet, and in 75 instances the agent was a metallic fragment from a shell, grenade, or mine, which has been called “shrapnel.” One man sustained separate bullet wounds affecting major nerves in each arm, so that the series comprises 155 case reports.

DESCRIPTION OF THE CASES

The patients were all sailors or marines whose wounds were sustained in the Pacific theater of war. They reached our hospital on an average of three months from the time of wounding. In this interval they had received excellent care aboard ship or in the various land-based Hospital Units of the Navy, and in general their condition on reaching the mainland was excellent. The number of serious complications was remarkably low. Approximately one-third of these patients were transferred to other hospitals before our studies were completed, and a few additional have been received too recently to permit us to establish a definite prognosis as to spontaneous recovery.

In 40 cases the principal nerve injury implicated the radial nerve; in 20, the median; and in 43, the ulnar. There were 27 instances in which all three major nerves were simultaneously involved; 17 cases represented a combination of median and ulnar; 6, the radial and median; and 2, the radial and ulnar.

In 5 cases the level of wounding was in the neck; 29 were wounded in the axilla; 69 in the upper arm; 12 in the region of the elbow; 36 in the forearm; and 4 were wounded at the wrist.

IMMEDIATE EFFECTS OF WOUNDING

In the immediate history of wounding in these cases, there are four features that occurred with sufficient frequency to acquire significance. These are: (1) a lack of sensation of penetration, and sometimes an absence of any

* The opinions expressed in this article are the private views of the authors and are not to be construed as official or reflecting the views of the Navy Department.
sensation of "impact": (2) the impression that the extremity has been “blown off”; (3) the occurrence of involuntary contractions in the hand and arm; and (4) a primary phase in which there is both motor and sensory paralysis of the wounded extremity.

The majority of men feel the impact of the projectile as a heavy blow with some blunt object. They rarely experience any sense of penetration, and if they have been showered with dirt and pebbles, as in the explosion of a shell,
In 24 per cent of the cases, the wounded man had the impression that his extremity had been "blown off." In some, this impression was so vivid that the man doubted the evidence of his own senses when he saw the limb, or felt it with his normal hand. The patient might be afraid to stand up for fear that the arm, which he saw but could not feel, would fall from his sleeve. This impression of loss of the part was reinforced in a number of instances by some posture of the wounded arm which removed it from sight or placed it beyond his reach. Occasionally, such a distorted posture seemed to be due to a reflex contraction of the muscles. The arm might be drawn back in the hammer-lock position, or stiffly protruded in some fixed posture.

In 32 per cent of the series there was a history of this type of immediate contracture, or else of convulsive movements of the wounded extremity, persisting for several seconds after being hit. One marine found that he could not get up from his prone posture until he had loosened, with his normal hand, the tight grasp of the fingers of his wounded arm on the grass and weeds in which he lay; another man found that the fingers of his wounded extremity were so tightly clasped on the hand grip of his machine gun that he continued to fire the gun involuntarily until the jarring of the recoil bounced his hand off the gun; and a corpsman was certain that his hand had been shot off until he caught sight of it, behind his forearm, sharply flexed at the wrist, jerking in a prolonged series of convulsive movements. Usually, such convulsive movements or muscular contractures were of a few seconds' duration only, and were followed by a flaccid type of paralysis of more lasting nature.

Almost immediately after impact, the hand, and sometimes the arm as a whole, was rendered numb and useless. The extent of this total paralysis usually included the whole extremity to the level of the wound, although it sometimes ascended above the wound, or might be limited to the hand, with partial involvement of the arm to the wound level. Of the men in this series 74 per cent experienced this primary phase of total paralysis as far as the hand was concerned. The duration of the total paralysis varied widely in different cases. A few of the men stated that they were able to move one or more fingers weakly within an hour of the wounding, although the majority of the histories would indicate that the return of any function to the hand required much longer periods of time. In the cases of axillary and neck wounds, and those of the "ischemic" type of paralysis, the hand tended to remain functionless for weeks or months.

SUBSEQUENT EFFECTS OF WOUNDING

As we have related, the immediate effects of wounding varied widely in duration in individual cases, but after the period of total paralysis had passed, a gradual restoration of function appeared in the hand. Usually, some weak movement of one or more fingers appeared before the anesthesia began to fade, while in other patients, particularly in those most severely injured, sensory perception might be partially restored before the slightest
flimmer of movement of the fingers was observable. In the men with less serious nerve involvement, a fair degree of motor power returned to parts of the hand within a few hours of wounding, and there were left only the residual evidences of total paralysis of a single nerve. However, the prompt and complete restoration of function to any part of the hand was the exception rather than the rule. The histories elicited from these patients would suggest that the impact of a high velocity projectile, while it might affect one nerve more than others, tended to paralyze nerves at a distance from the actual pathway of the projectile. Since we did not have these men under direct observation during the first months of disability, we have been unable to estimate accurately the duration of the total paralysis occurring in undivided nerves. However, 21 patients still had a complete paralysis of one or more nerves when we first examined them at an average of 2.5 months from the time of wounding, and have since (an average of 7 months from wounding) established, or are attaining, a satisfactory return of function. The case histories, as a whole, indicate that the energies released by the passage through the tissues of a high velocity projectile are capable of paralyzing, or at least seriously depressing, for weeks or months, the function of nerves beyond the path of the projectile.

RESULTS OF WOUNDING

It is much too early to estimate the end-results for this series of cases. Three men have been invalided from service with irreparable nerve lesions; 12 have returned to full duty; and 12 have been discharged to limited duty. A return to duty does not always imply a normal restoration of function, and it will be necessary to secure follow-up examinations of these men before their end-results can be finally classified. However, a return to duty does imply that the recovery is definite and progressive, so that the prognosis for a reasonably complete restoration of function appears to be good.

Although the end-results cannot be given at this time, it is possible to secure some information as to progress by the following classification. With the three patients mentioned above as having irreparable nerve lesions, we can group 20 that have been lost from observation, or have come under our care too recently for a prognosis to be established. Exclusive of these 23 patients, there remain 132 who have had sufficient study to permit us to comment on their tendency to recover function spontaneously. Of this group 53 have been subjected to operation, so that we have first-hand information as to the status of the nerves. In only 20 cases was the nerve found to have been completely severed. In 7 additional cases, the operation demonstrated partial lesions, and in 4 of these the surgeon elected to resect the damaged portion and do an end-to-end anastomosis. In 26 cases there was no demonstrable interruption of continuity of the nerves in question. Of the 53 operations, 33 were done at our hospital, and 20 were done elsewhere. It is of considerable interest to note that of the 20 patients operated upon elsewhere, complete severance of the nerve was demonstrated in only 6 (30 per cent).
The remaining 79 patients show signs that seem to indicate that the nerve has not been completely severed. Since there are no reliable signs to distinguish complete severance from “delayed recovery,” we may find later that our present interpretations are erroneous, and exploration will show that the nerve has been completely divided. But, for the time being at least, their chances for continued improvement seem to be as good, or better, than we could confer by surgical interference.

Thus, of the 132 patients on whom our studies are reasonably complete, there are 3 discharged with irreparable damage to nerves, 20 proven by operation to have had the nerve completely severed, and 4 with partial lesions requiring resection of the nerve. The figures from this series would seem to indicate that in wounds due to high velocity projectiles, four out of five of the most seriously damaged nerves escape complete disruption of continuity. If the less seriously damaged nerves, in which the delay in recovery was not so prolonged, were taken into consideration, the ratio would be still higher.

**DISCUSSION**

High velocity projectiles are known to produce extensive damage to living tissue. The destructive effect that they produce is said to vary as the first power of the mass, and as the cube of the velocity. In other words, given a bullet of a certain mass, passing through a man’s arm: to increase its mass three times would be expected to increase its destructive effects three times; to increase its velocity three times, would raise its destructive power twenty-seven times. Apparently the tremendous energies released within the tissues
by the passage of the projectile show a characteristic oscillation of positive and negative pressures, which are transmitted widely through the fluid medium of the tissues, producing injury to structures at considerable distances from the actual path of the projectile. There are doubtless many additional factors that may increase tissue damage, such as the heat of the metallic fragment, "tumble" of the bullet, the lacerating effect of sharp pieces of shrapnel, the angle of incidence, and the density of the tissues traversed. Yet it seems probable that the high velocity of the projectile is the prime factor in causing "delayed recovery" in nerves not actually severed.

Denny-Brown and his colleagues\(^3\) have reported interesting observations that may have some bearing on our clinical findings. They have shown in experimental animals that various types of local injury to a nerve, such as compression, tapping, freezing or stretching, may be followed by a complete loss of nerve function for weeks or months. If the local lesion is of sufficient severity, the axons of the affected nerve degenerate peripheral to the injury. The axons show no ability to regenerate across the injured segment until all the local damage has been repaired. When the repair process is complete, the axons begin to grow down the distal nerve trunk, progressing at a rapid rate. Because there has been no distortion of the intra-neural pattern by the injury, each fiber eventually establishes connection with its original end-organ. Under these circumstances, as might be anticipated, the recovery of function in these experimental animals approximates the normal. In fact, after some of these experimental "lesions in continuity" the recovery is so complete that it may be difficult even by microscopic examination of the nerve, to tell where the local injury had occurred.

The reaction of nerves to percussion, as demonstrated by Denny-Brown, is strikingly similar to that shown in many of our clinical cases. In each instance, there is a phase of complete paralysis during which it can be demonstrated that the axons peripheral to the level of injury have degenerated. Then, after a variable period of time, depending upon the severity of the lesion, function begins to come back. The eventual recovery of function tends to approximate the normal, presumably because, in each instance, there has been no distortion of the intra-neural pattern.

We have stated that in this series four out of five nerves, seriously damaged by high velocity projectiles, escape anatomic interruption of continuity. In spite of this escape from complete disruption, these nerves sustain profound intrinsic and physiologic changes. In the preliminary portion of the paper dealing with the objective phenomena of wounding, it is implied that transient paralyses may be of a functional nature. It is possible that peripheral nerves subjected to sudden trauma may be capable of creating a state of physiologic block exhibiting phenomena similar to that known as "spinal shock." But we would not expect this form of blockade to persist for long periods. We are of the opinion that all nerves that remain functionless for periods of time measured in months will show pathologic changes. In some of
these the pathology may be in the nature of multiple microscopic injuries scattered throughout the nerve trunk for considerable distance. In others, perhaps the large majority, there will be gross pathologic changes present. It is possible that some of these nerves with gross lesions in continuity will never recover function spontaneously. In such instances, early resection, followed by an immediate end-to-end anastomosis, is highly desirable.

The difficulty lies in selecting the cases that cannot recover spontaneously, from the larger number that had best be left alone. The surgeon who follows a policy of early exploration realizes this difficulty. He is aware of his responsibility toward his patient in securing the best possible result in the shortest possible time. Yet, in a specific case, he finds himself on the horns of a dilemma. He has no reliable criteria for determining the chances that this particular lesion will or will not preclude an eventual recovery of function. And if he elects to resect the nerve, he has no way of determining the chances of a successful regeneration of the nerve following an end-to-end anastomosis.

The available data concerning the end-results from nerve anastomosis are incomplete and confusing. One can find reports that list the percentage of "failures" all the way from less than 10 per cent to more than 80 per cent. It is our impression that the number of failures will probably lie between 25 and 40 per cent of the total number of nerves sutured, and that the end-results in the remainder leave much to be desired. Some of the factors that militate against full functional recovery are known, such as, inadequate resection of the neuromatous ends, too much tension on the suture line, long delay in carrying out the secondary suture, rotation of the nerve trunk so as to disturb the intra-neural pattern, and damage to the intrinsic blood supply to the nerve. Yet in spite of every effort to overcome these obstacles to success, the surgeon must accept a certain hazard, as far as end-result is concerned, in every case in which he resects a lesion in continuity.

The choice which the surgeon must make at the operating table is between two courses of action, with the outcome predictable in neither one. His first important problem is to decide what the chances may be for a spontaneous recovery. We do not believe that this decision can, with safety, be based solely on the presence or absence of a fusiform neuroma. Denny-Brown's percussion experiments demonstrated that a nerve so injured tends to form a "pseudo-neuroma" at the site, which may persist for as long as twelve weeks. This pseudo-neuroma might be indistinguishable from a true neuroma except by microscopic examination. Yet it does not appear to represent any permanent obstacle to regeneration. In fact, the degree of recovery in his experimental animals tended to approximate the normal, even in cases in which the pseudo-neuroma persisted for weeks and the peripheral portions of the affected nerve remained completely unresponsive to faradic stimulation for long periods of time.

Some surgeons believe that valuable information as to the recoverability
"DELAYED RECOVERY" OF PERIPHERAL NERVES

of a nerve can be obtained by perfusing normal saline through the damaged segment. If the resistance to the passage of the fluid through the segment is great, the prospects for spontaneous recovery are assumed to be poor. It has been claimed that if the resistance to the fluid is represented by two or more atmospheres of pressure, the nerve should be resected. This rule of thumb may have some practical value, but to us it has seemed arbitrary and of limited usefulness.

Other surgeons place a considerable reliance upon the response of the nerve to faradic stimulation. If this type of stimulation fails to elicit any motor response in a mixed nerve, it is good evidence that the motor fibers have degenerated peripheral to the lesion. Yet this evidence, taken by itself, is no reliable basis for assuming that the nerve cannot regain function spontaneously. The time factor must be taken into consideration, as well as the level of the nerve injury, i.e., the distance between the site of the lesion and the nearest muscles that that particular nerve supplies. Even when months have elapsed since the wounding, the absence of response to faradic stimulation may not rule out spontaneous recovery. In this series of cases there were three instances of spontaneous recovery in which the nerves failed to respond to a maximal stimulation with a Hinsey-Geohegan stimulator more than five months after wounding. One of these patients had an ulnar paralysis, secondary to a shrapnel wound in the upper third of his forearm. In the fifth month after wounding an exploration failed to demonstrate the exact level of the maximum injury to the nerve. If there had been a single area of gross pathology we doubtless would have resected it, since at operation there was no response of the flexor carpi ulnaris or any of the hand muscles to faradic stimulation. At the end of eleven months the clinical evidence of ulnar paralysis was still complete, and a re-exploration of the nerve was undertaken. Stimulation at this time elicited a contraction of the flexor carpi ulnaris. At the present time, some 15 months from the injury, this patient seems well on the road to a satisfactory recovery of function. This case, and others of a similar nature, lead us to suspect that the microscopic lesions within the nerve trunk may prove to be just as effective obstacles to regeneration as the more obvious gross lesions. However, the point that needs emphasis is the fact that neither the microscopic lesion nor the gross pathology necessarily precludes subsequent regeneration.

CLINICAL APPLICATION

The fact that nerve injuries due to high velocity projectiles show a high percentage of spontaneous recoveries is of some clinical importance. Few surgeons would disagree with the view we expressed less than two years ago, to this effect. "An attempt should be made to do an end-to-end anastomosis on every divided nerve, within the first three weeks of wounding, excepting only those cases of severe, fulminating infection." We had in mind at that time the many advantages of early suture. A successful anastomosis, done
early, not only represents an important reduction in the disability period but, in addition, may result in a more complete restoration of function than could be secured by a later operation. Young has shown that the proliferation of the Schwann cells, so important in the successful re-establishment of nerve continuity, shows an increased growth curve after a nerve trunk has been divided experimentally. The increased activity begins in the first three or four days and reaches its maximum about three weeks later, after which it falls quite rapidly to the original base-line. There are doubtless other factors in the nerve, and in the muscles it supplies, that favor early anastomosis as against the same operation done months later. In all cases in which there is a complete interruption of continuity, there can be no argument against early operation.

In the hands of experts a careful exposure of the lesion should do little harm; complete interruptions of continuity could be repaired immediately; and important observations could be made as to the exact nature of the local lesion. On the basis of such observations it may be possible, eventually, to establish a reliable correlation between certain types of gross pathologic change in the nerve trunk and the prognosis for spontaneous recovery. However, until such a correlation is established, a rigid enforcement of a policy making it incumbent upon all surgeons to explore all nerve injuries within the first few weeks of wounding might do more harm than good.

Our own observations have led away from a rigid policy for early exploration. Our records contain instances in which resections have been done in the absence of convincing evidence that this procedure was indicated. We are increasingly aware that we lack the ability to distinguish, at the operating table and in the early weeks after wounding, the lesions in continuity that are capable of spontaneous recovery, from those that are not. There are, however, a number of conditions that, if present, would influence us to explore the lesion at as early a time after wounding as possible. If the nerve is visualized readily at the time of the original debridement and is seen to be divided, an attempt at suture should be done immediately. If the nerve ends cannot be approximated, they should be fixed to the surrounding tissues by a metallic suture, as close to one another as possible. If the patient suffers from intractable and persistent pain, it may be necessary to explore the wound at an early date. If the projectile passes through such regions as the wrist, the elbow or the musculo-spiral groove, where the nerves are relatively fixed, and hence less likely to escape injury, it would seem advisable to explore early, provided, of course, that the paralysis was complete. Exploration of these sites would be especially indicated when the injury was complicated by fracture of the adjacent bone. But if the wound occurs in areas where the nerve is not fixed, if the theoretical path of the projectile between the wounds of entrance and exit do not correspond exactly to the nerve location, and particularly when the wounding agent is a high velocity projectile, it is certainly justifiable, and perhaps indicated, to delay exploration until a period of study and a careful evaluation of the case has been completed.
CONCLUSION

Unless there is more evidence than a simple loss of nerve function, to suggest that a nerve has been severed, a period of observation of two or three months seems indicated in the treatment of nerve lesions caused by high velocity projectile wounding.

REFERENCES