# WAR WOUNDS OF THE NERVOUS SYSTEM*

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INFORMATION is not yet available for definite statements as to the incidence or character of injuries of the nervous system in the present war. Scant consideration has been given to injuries not caused by penetrating missiles in the medical records of previous wars for the obvious reason that such injuries were few in number compared with those produced by bullets, shrapnel and shell fragments. The traditional medical attitude that penetration is characteristic of war trauma was justified by past experience; but warfare is now waged by mechanized equipment and this is conducive to the production of injuries similar to those of transportation and industrial accidents in civil life.

An important activity of the present conflict is the aerial bombing of thickly populated areas of the belligerent countries, producing the greatest number of casualties among the civilian population. The bombing of cities will inevitably inflict serious injuries of the nonpenetrating type. The ratio of open wounds to closed injuries may show fluctuation according to the agencies and methods of military action. Many different types of injuries of the nervous system among the civilian population as well as the combatant forces will require the services of the modern army neurologic surgeon.

In the First World War, injuries to the nervous system were numerous, while the number of surgeons qualified to treat such injuries was small. During the past 20 years the field of neurologic surgery has developed rapidly, and with this development there has come a better appreciation and wider understanding among the medical profession of the problems of surgical neurology. The principles of treatment of injuries of the nervous system established during the First World War, with the added experience in the management of many thousands of injuries resulting from transportation and industrial accidents during the past two decades, can readily be applied to similar injuries produced in modern warfare.

In view of the voluminous literature on the management of closed injuries of the head and spine appearing since 1920, it seems unnecessary to make any reference to such injuries in this discussion, although injuries of this type may be numerous in modern warfare. Penetrating wounds of the brain and spinal cord are by no means rare in civil life, but since the appearance of the medical records of the First World War the literature has made little reference to such injuries. The purpose of this communication is to recall briefly the principles of treatment found to be effective in the manage-

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ment of wounds of the nervous system in the First World War, with some discussion of the advances made through the application of these principles to similar injuries in civil life.

In a review of statistics of the last war, it is shown that of the patients reaching hospitals in one of the belligerent countries, approximately 25 per cent presented neurologic problems of one kind or another. Among the 174,296 battle injuries in the American Expeditionary Forces reaching hospitals, the head alone was involved in about 6 per cent, and of these, about 11 per cent resulted fatally. The delay in surgical treatment of penetrating wounds of the head, and lack of unanimity of opinion as to the best method of treatment were important factors in the mortality of casualties involving the head alone in the early period of the war. Another important factor in the mortality of head wounds was the frequent association of severe injuries in other parts of the body. In the early part of the First World War the operative mortality of gunshot wounds of the brain was about 60 per cent. This mortality was reduced to about 28 per cent by the operative methods advocated by Dr. Harvey Cushing. There has been no modification of importance in this technic of operation for gunshot wounds of the brain received either in warfare or in civil life since it was first proposed by Doctor Cushing.

War as waged to-day by some of the involved nations produces the greatest number of casualties at or near well-equipped hospitals, thus making possible early and adequate treatment regardless of the nature of the injury. The facilities for early and complete care of head injuries should be provided as far as possible in all phases of military operations, leaving only the very minor types of injury or those in shock to be cared for at the front line posts or First Aid Stations. Prompt transportation by airplane of soldiers with gunshot wounds of the head in field operations has been successfully used in some of the countries now engaged in war. In this connection, it has been stated that open wounds of the brain do not well tolerate elevation of more than 5,000 feet. Experience has shown that patients with head injury, when not in shock, stand ordinary transportation very well, and this also applies to patients in good postoperative condition. While every effort should be made to provide early operation upon penetrating wounds of the brain, a delayed operation at a station or hospital where complete surgical treatment can be provided is much better than an early inadequate operation. Adequate treatment of head injuries at advanced posts when transportation to a completely equipped hospital is impracticable may be provided by means of motorized surgical units. The prompt transfer of patients to base hospitals or the competent treatment at advanced posts by trained neurologic surgeons should bring about a definite reduction in the mortality of head injuries.

*Open Wounds of the Brain.*—Too much emphasis, perhaps, has been given to a time limit for operations on open wounds of the brain. It is highly desirable that these wounds should be operated upon within 16 hours if possible. However, many cases may be operated upon to advantage as

late as 48 hours or more, if obvious infection is not present. It is reasonable to expect that chemotherapy, promptly instituted in penetrating wounds of the brain, will increase the number of cases that may be benefited by later operation, and that the incidence of severe intracranial infection will be reduced by chemotherapy in all cases.

The treatment of head wounds at First Aid Posts should be limited to the control of external hemorrhage, treatment of shock, shaving the scalp, irrigation of the wound with saline or Ringer's solution, followed by the application of a sterile dressing and the administration of prophylactic tetanus antitoxin and some of the sulfonamide compounds. No effect should be made to remove bone fragments or other debris unless they lie loosely in the wound. Simple laceration of the scalp may be débrided and sutured at the First Aid Station provided there is no involvement of the skull and no evidence of intracranial injury.

When the patient with a penetrating wound of the head has been placed under conditions suitable for complete investigation, careful neurologic examination should be made, and the entire head shaved. There may be multiple bullet wounds of the scalp and each should be considered a potential brain wound until otherwise disproved. Tangential or gutter wounds of the skull are especially liable to cause severe brain damage by shattering fragments from the inner table of the skull. These fragments often penetrate the brain for a considerable depth. The effect upon the skull and the location of intracranial foreign bodies, such as indriven bone or metallic fragments, should be shown by roentgenograms, and the number of these foreign bodies checked with the number removed at subsequent operation. Restless patients may be given morphine preliminary to the use of local anesthesia by novocain injection of the scalp. Local anesthesia should be employed in every case if practicable. Sometimes the treatment of shock and the intracranial operation may be carried out simultaneously.

The fundamental objective in the treatment of penetrating wounds of the brain is the prevention of infection. Disinfection of a penetrating wound is accomplished by copious irrigation of the wound with saline or Ringer's solution, excision of the edges of the scalp wound, and careful removal of bone fragments, macerated brain tissue, blood clot, and foreign bodies whenever practicable. Chemical disinfection of fresh wounds should be discontinued in view of the superior results from mechanical disinfection with large quantities of saline solution. It may be necessary to enlarge the scalp wound by incisions, in order to give better exposure of the underlying wound of the skull and brain. Slight enlargement of the bone defect may be required, but it seems unnecessary to remove the fragments *en bloc*, unless the depressed fragments lie directly over one of the large venous sinuses. After removel of the bone fragments the wound should again be thoroughly irrigated. Large quantities of solution are required for thorough cleansing of these wounds. Macerated brain tissue is removed by irrigation through a catheter attached to a bulb syringe, supplemented by gentle suction through

a bent glass tube attached to the suction tip. By the use of irrigation and suction, alternately, the macerated brain tissue, blood clot and foreign bodies may be removed. Missiles which have passed beyond the midline of the skull from the point of entrance may be removed through a trephine opening made at a point most accessible to the missile, as shown roentgenologically. It may be possible, after removing the missile in this way, to effect a through-and-through irrigation for complete cleansing of the brain wound. Removal of débris from the brain wound will usually permit inspection of its depths, provided hemorrhage has been controlled and infection has not developed. Great care must be exercised in following the track of the bullet, in order to prevent further injury to brain tissue, and, in many cases, to avoid penetration of the ventricles. The devitalized brain tissue should be removed by suction down to the limits of normal brain. All foreign bodies should be removed when accessible, providing this is compatible with the protection of important functional areas. Bleeding vessels may be drawn up into the suction tip and coagulated with the electrosurgical unit, under direct inspection, made possible by the use of the lighted spatula. The addition of the suction apparatus and coagulation unit to the surgical equipment will do much to facilitate complete operation in penetrating wounds of the brain and to lower mortality. After thorough cleansing and complete hemostasis, the brain defect is filled with Ringer's solution. The dura should be closed securely without drainage unless there is some doubt as to the completeness of disinfection. The scalp is closed in layers, using interrupted fine silk sutures. Drainage of the scalp wound is unnecessary.

When there is evidence of infection the operation must, of necessity, be a limited one. Easily accessible bone fragments may be removed, the opening in the dura enlarged and drainage provided. The scalp wound should be packed with vaselinized gauze, and not sutured. The resulting brain fungus should be protected by a rubber dam over which is placed a doughnut ring of gauze.

The prevention of infection by thorough removal of devitalized brain tissue, blood clot and foreign bodies will minimize the subsequent scar tissue formation, thus decreasing the chances of epilepsy.

The surgical management of compound fractures of the skull with dural laceration is similar in principle to that of penetrating gunshot wounds of the brain. Reliance is placed upon careful mechanical disinfection of the wound with thorough débridement of the scalp, removal of bone fragments, blood clot, and damaged brain tissue. The dura is closed without drainage. Patients with compound depressed fractures of the vault, with laceration of the brain, are often in surprisingly good condition and early operation may usually be undertaken. In civil life such fractures are often very inadequately treated, and extensive local infection of the brain is a common result.

*Injuries of the Spinal Cord.*—The results of treatment of penetrating spinal cord injuries in the First World War were very discouraging. Approximately 80 per cent of all patients with spinal cord injuries died within

the first few weeks. This was due in part to severe associated injuries, but there was also a high mortality from sepsis arising either from bed sores or urologic infection, or both. These results were not unexpected and, unfortunately, may not be greatly altered in any future conflict in which early transfer of patients to adequate hospital facilities is impracticable.

In all types of spinal injuries, proper handling of the patient is of greatest importance, in order to avoid damaging the cord or increasing the damage of an existing cord injury. Penetrating wounds of the spine may require operation for the purpose of disinfection or for the removal of the penetrating agent in partial lesions of the cord. The cord lesion may be physiologically complete from the concussional force of the penetrating missile even though the cord itself has not been hit. Many such cases recover function in a short time with little residual impairment, while in others the cord may be completely disintegrated by the concussion. Practically all that can be accomplished by operation in gunshot wounds of the spinal cord is the disinfection of the wound and removal of fragments of bone and foreign bodies which rarely cause compression.

At the U. S. A. Hospital, No. 11, Cape May, N. J., following the First World War, there was a small number of gunshot wounds of the spinal cord showing varying degrees of spinal cord impairment. In some of these cases the patients suffered intractable pain for which cordotomy was performed. The general condition of such patients was usually very bad, due to sepsis and long-continued suffering. This series was probably among the first group of cordotomies performed by Dr. Charles H. Frazier.

*Peripheral Nerve Injuries.*—The records of Base Hospitals, according to Davis and Pollock, show that 14 to 16 per cent of all wounds to the extremities in the American Expeditionary Force, caused injuries of the peripheral nerves; and it was estimated that wounds of the peripheral nerves constituted 4.5 per cent of all casualties. The larger number of these injuries were operated upon many months after the wounds were received and, although the final results of operation were not accurately ascertained in any considerable number of cases, analyses of end-results of small groups indicated that recovery of function was very incomplete. Débridement of deep wounds by inexperienced surgeons was evidently responsible in some cases for injury to the nerve which had escaped injury from the missile. Operations for nerve suture were delayed until after fibrosis had replaced normal muscle tissue, particularly in the intrinsic hand muscles. Much time was lost by relying on misleading signs of nerve regeneration, such as Tinel's sign, which, at the time, was regarded by some as possessing a degree of infallibility.

Before the primary operation for repair of deep wounds of the extremities, a neurologic examination should be made, in order to determine whether there is involvement of important nerves. The disinfection and débridement of such wounds, when nerve impairment is probable or evident, should be undertaken by those competent to expose, identify and suture a divided nerve at the time of the primary treatment of the wound. Early suture of a divided

peripheral nerve is desirable. Chemotherapy may be utilized to prevent or retard infection.

In patients with paralysis of a peripheral nerve, when the condition of the nerve was not ascertained at the time of the repair of the wound of the extremity, the type of nerve lesion should be investigated at open operation as soon as the local condition of the wound will permit. It is advisable to wait three months after healing of an infected wound before exploration and suture of the nerve, but it is important that infection be eradicated as early as possible so that later suture may not be delayed longer than absolutely necessary. If infection develops after primary suture of a nerve, it is often advisable to excise the suture line and resuture the nerve after the infection has been eradicated. Peripheral nerve lesions are often associated with injury to important blood vessels of the extremities, and this, undoubtedly, contributes to unsatisfactory end-results.

Physiotherapy and proper splinting are essential adjuncts to the successful treatment of peripheral nerve injuries. To obtain the best results, both should be started early and continued through the period of paralysis.

The attitude toward peripheral nerve lesions which have not been adequately dealt with at primary operation, should be one that encourages direct inspection of the nerve, so that an early decision may be arrived at as to the type of treatment the nerve itself requires. In other words, the attitude toward operation for the exposure of the nerve may well be radical, while the treatment of the exposed nerve lesion should incline to conservatism.

In the writer's experience at Cape May Hospital, which probably handled one of the largest groups of nerve injuries collected from the American Expeditionary Force, I was often impresed in delayed exploratory operation by finding complete division of nerves when repeated clinical examinations had appeared to justify the assumption that nerve function was recovering spontaneously. Such errors may be avoided by exploration of the paralyzed nerve when there is any doubt as to the type of nerve lesion present.

The exposure of peripheral nerves is a procedure of little difficulty to those familiar with anatomy of the extremities. Judgment may be critically tested in cases in which the nerve lesion is manifested by a neuroma in continuity. The conservative operation of neurolysis is often advisable in such circumstances. The protection of important branches of the injured nerve during the dissection, the excision of scar tissue from the nerve ends, accurate approximation of the nerve segments without tension or torsion, and careful hemostasis are essential details in a successful technic for nerve suture.

The use of autogenous transplants to bridge wide defects in peripheral nerves, has been, so far as I know, unsuccessful in every case. A novel method of repairing divided peripheral nerves has been suggested by Young and Medawar (Lancet, August, 1940). By their technic the divided nerve ends are held in approximation by a cuff of concentrated liquid plasma. The originators of the method, which, thus far, appears to be experimental,

claim that regeneration following this technic is superior in every respect to that of direct suture. The procedure, obviously, has decided limitations.

The facial nerve is sometimes paralyzed by gunshot wounds of the mastoid region. Facial paralysis resulting from such wounds usually requires anastomosis with another motor cranial nerve. The hypoglossal is preferred for this anastomosis. Traumatic lesions of other cranial nerves do not require surgical treatment.

Much was expected from the study of the large collection of peripheral nerve injuries resulting from the First World War. These nerve injuries were received in a space of a few months and were segregated in special hospitals with special staffs interested in the treatment of such injuries. The hospitals in which the patients were treated were well equipped surgically and provided with elaborate departments of physiotherapy and electrotherapy. Unfortunately, in the study of this large collection of nerve injuries no standardized criteria of recovery were formulated; and after the patients were discharged from the hospital there were no well directed efforts to determine the results of treatment. An unparalleled opportunity for definite information relative to nerve repair and nerve regeneration was, therefore, lost.

Under the most favorable conditions, regeneration of sutured peripheral nerves leaves much to be desired. The misdirection of fibers from the central stump cannot be prevented, although this may be minimized by accurate approximation of the nerve segments, without torsion. The defects of regeneration, shown by the straying of fibers from the central stump, greatly interfere with the results of suture of such important nerves as the ulnar and median.

Further research is needed on nerve transplantation, particularly in view of its almost universal failure in peripheral nerves, and the good results claimed for transplantation in facial nerve defects. It is also important to have further information on the relative effects of early and delayed suture in the final recovery of function, and after what length of time can no further benefit be expected from surgical treatment of divided nerves. The technic of nerve repair, the treatment of neuroma in continuity, the effects of neurolysis—all present problems which are by no means settled and are worthy of further study.

It is absolutely essential that standardized criteria of partial or complete recovery be formulated, if actual knowledge is to replace mere impression as to the regeneration of injured peripheral nerves. These criteria should be applied in determining the end-results of treatment of every peripheral nerve.

DISCUSSION.—DR. JOHN S. MCEWAN (Orlando, Fla.): I had a large hospital in France during the World War before the Americans went over, and I wish that we had had you specialists there at that time. We had to do surgery from the top of the head to the bottom of the feet. If Doctor Blair had been there to see the plastic work by the French, he would have been amazed. They really did some very remarkable plastic surgery on the face.

Far be it from me to discuss nerve surgery. I suppose we had many hun-

dreds of nerve suturings, but I have never seen them since operating, so the results we obtained are not known. In a large percentage of cases, these injuries were due to compound fractures, with loss of bone and nerve. After these cases came from the front and the wounds healed, bone was grafted and then followed suture of the nerves.

This reminds me of a true story of a Colonel in the army. In this case, the Colonel could not find the proximal end of the nerve in the arm, and he worked on it for hours, and still could not find it. Finally, he picked up a piece of fascia and started to suture it to the distal end of the nerve. A young doctor from Savannah said to him, "Colonel, that is not nerve; that is a piece of fascia." The Colonel replied, "When I say it is nerve, it is nerve"—and continued to suture it.

It was the dirty clothing in these gunshot wounds that gave us our worst infections. We picked out pieces of shirts and clothing that had been worn for weeks. It was not the shrapnel that caused the most serious infections, it was the contaminated clothing.

We found that the brain operations should be undertaken early, and I believe the best results we had were in those cases operated upon within the first ten days.

Speaking of chemotherapy, three weeks ago we had a lot of Negro orange pickers, who had been riding in a truck that was wrecked. Twelve of them were brought to the hospital. Among this number were three with fractures of the skull, two of them compound, with depressed fragments. They were full of dirt, sand, grass, and cockleburs, and one had brain tissue extruding through the wound. We operated upon these two compound fractures, raising the fragments, and then dusted sulfanilamide all over and in the wound, sutured them without drainage, and got a primary union in both cases.