EARLY COMPLICATIONS FOLLOWING PENETRATING WOUNDS OF THE SKULL

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AN ANALYSIS of 14,000 battle wounds treated in 5th Army hospitals in the year 1944 disclosed that 6.17 per cent involved the head (exclusive of maxillo-facial injuries). One third of these were classified as intracranial† while the remainder were scalp wounds. At the same time 24.4 per cent of all deaths in these institutions were attributed to brain injuries. The vast majority of these patients were hopelessly injured and died within a short time after reaching a forward hospital. Of those patients with penetrating skull wounds who survived to reach a general hospital in the Zone of Communications, another 3.7 per cent succumbed. For the most part these deaths were ascribable to complications of wound healing. These disorders occurred not infrequently and even though not fatal in the majority of cases, entailed further damage to neural tissue and prolongation of convalescence. It is to describe our experiences in dealing with the problems that arose during the early postoperative course of 426 cases of penetrating skull wounds that this paper is written.

Since morbidity and mortality in military surgery vary according to the echelon, and to the tactical situation, and since weather, topography and evacuation are factors that must always be considered, the following facts are pertinent. The patients whose cases form the basis of this report were wounded in the Tunisian, Sicilian and Italian campaigns. The majority were operated upon in evacuation hospitals, situated 5 to 30 miles behind the front lines. After 3 to 10 days they reached general hospitals, consecutively located in Oran, Bizerte, Rome and Leghorn, where they came under the care of the authors. Evacuation was by ambulance, air, rail or hospital ship. In general the trip appeared to have upset them very little, save those individuals with elevated intracranial pressures. During the period in which this study was made, the skill and experience of forward neurosurgeons greatly increased, with the result that debridements were carried out more thoroughly. Penicillin was used routinely (25,000 units intramuscularly every 3 hours) beginning in the Spring of 1944.

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† Major W. R. Pitts reported 108 (1.03 per cent) penetrating brain wounds which came to operation among 10,455 battle casualties admitted to the 38th Evacuation Hospital. Shearburn operated upon 189 (1.6 per cent) patients with similar lesions among 8,660 battle casualties at the 8th Evacuation Hospital; an additional 28 patients were desperately ill on admission and died without operation.
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SUPERFICIAL INFECTION

Superficial infection occurred in approximately 19 per cent of the cases in 1943; the incidence was approximately 16 per cent or significantly unchanged in 1945. In this category we have included infections that extended no deeper than the dura, wound dehiscence, and necrosis of even mild degree (in other words any condition less than per primum healing). For the most part they were mild, localized processes, usually associated with too much tension or too heavy silk. Removal of sutures and sometimes the application of hot wet dressings sufficed to clear them up within a few days. Rapid healing was not always the case, however, and if the dura had been left open grave complications sometimes ensued. If the wound were large, and particularly if the debridement had not been thorough, it often filled with dirty, purulent granulation tissue and required weeks to heal.

The types of incision employed and the tensions under which they were closed were factors of considerable importance. Even mild wound necrosis or local dehiscence usually led to superficial infection. Where practical the simple vertical or curvilinear incision was most satisfactory from the standpoint of healing. Quite often so much scalp was destroyed that direct closure, particularly after debridement, could not be carried out. To effect approximation under these circumstances was not easy. Methods commonly employed were the “tripod” incision or its Isle of Man modification, one or more relaxation incisions or a large flap. The latter sometimes included the scalp defect in one limb or, if small, in its center.

Tripod incisions, while affording a convenient and rapid exposure, have, in our experience, not healed well. In one series of 26 cases, necrosis of the apex of one or more flaps, wound separation or infection occurred in 18. Sometimes a multangular wound made such an incision unavoidable. When employed, great care must be exercised in handling the flaps to avoid bruising their apices. The flaps should be sufficiently long for the limited elasticity of the scalp to permit stretching over the defect without undue tension. The narrowest angled flap should be on the side of the best blood supply, while constricting sutures at the apices should be avoided.

If relaxation incisions or pedicle flaps are used, it is well to leave the pericranium intact and to cover the defect with a split thickness graft immediately. Grafting requires but a few additional minutes’ work and goes far to insure primary healing. Failure to do so led to local infection in several instances, thus endangering the primary wound.

S-shaped incisions, in which the wound was included in the central limb, proved very satisfactory. Here again it is well to point out that they should be generously long, for the scalp has but limited elasticity, and it is desirable to distribute the tension over a wide area.

DEEP INFECTION

Deep infection occurred in 72 or 16 per cent of our 426 cases. Local purulent cerebritis progressed to abscess formation in 58 cases, and resulted
in cerebral fungi in 32, and in meningitis in 25. Of these patients, 15 died. One patient succumbed from a reaction to mismatched blood. There were no deaths from other causes in this group. The mortality rate was therefore 22 per cent for those patients who developed deep infection or 3.7 per cent for the group as a whole. In the light of our experience it would appear that several of these deaths might have been prevented had infection been recognized earlier.

A summary of our observations follows: Infections occur within the cerebral wound approximately 10 times more frequently about roentgenologically retained bone fragments than in their absence. Their presence is a measure of the thoroughness of wound debridement. Together with clots and pulped brain tissue they offer a splendid medium for the growth of the bacteria inevitably carried into the wound. If the process is not too extensive and bacterial contaminants not too numerous or too virulent, healing can and often does take place spontaneously. However, in a series of 49 cases in which bone fragments were retained, 20 developed deep infection, whereas in a similar group of 45 cases in which the removal had been complete (as determined by roentgenograms) but two infections occurred.

The pathologic process is not strictly comparable to that encountered in a brain abscess of otitic origin. Here, in addition to the neural tissue necrosed by trauma and bacterial toxins, are the added factors of extravasated blood, of indriven bone and foreign bodies. We believe that these factors must be taken into consideration in treatment.

The bacterial flora of both deep and superficial infections was made up largely of skin inhabitants of relatively low virulence. In another paper one of us reported the results of bacteriological studies in 25 infected head wounds. Of 39 organisms recovered, 23 were hemolytic or non-hemolytic staphylococci. It is noteworthy, however, that of 9 strains of bacteria isolated from the wounds of 6 patients with meningitis, 6 were streptococci (3 aerobic non-hemolytic, 2 aerobic hemolytic and 1 anaerobic hemolytic) while but 3 were staphylococci (all aerobic non-hemolytic).

Diagnosis of Deep Infection. The early manifestations of deep infection are frequently mild and easily overlooked. A well-healed pulsating scalp flap combined with normal temperature, normal white blood count, and the absence of cervical rigidity may give one a false sense of security. Headaches, at first slight and later increasing in frequency and severity, have been the most constant manifestations of smouldering infection. Head pains that come on suddenly or awake the patient from sleep are particularly significant. Later on the flap may become tense, the discs choked, neurological changes progress and signs of increased intracranial pressure appear. The roentgenological demonstration of retained bone fragments, particularly if in a cluster, then becomes highly significant, for it was about these that 90 per cent of the abscesses developed. On 5 occasions a retained metallic fragment was observed in successive roentgenograms to have changed position, and in all but one instance was found to lie free within an abscess.
cavity. In the fifth case it was found in a cerebellar hematoma. There was no instance of loose metallic fragment in a ventricle in this series of patients.

The manifestations of meningeal irritation or infection are well known. When arising as the result of spread from the deep infection it was often attributable to direct extension into a ventricle. The subarachnoid spaces were, as a rule, well sealed for approximately 1 cm. about the edge of the cortical wound.

The presence of more than a few cubic centimeters of necrotic brain tissue, even though not infected, may give rise to irritation and local edema with increased intracranial pressure, much in the manner it sometimes does following any extensive resection of cerebral tissue. It is usually impossible preoperatively to differentiate it from an early infection. Prompt alleviation of symptoms may be expected to follow its removal.

Treatment. Delayed debridement or redebridement of infected brain wounds was successfully employed towards the end of the Tunisian campaign by Schwartz. We have repeatedly confirmed the efficacy of the procedure. Redebridement of wounds elsewhere in the body, including compound fractures, has likewise proved a very useful operation where early surgery had been inadequate or totally lacking. The presence of dead tissue is of considerably more danger than the breaking of newly formed "barriers of resistance," save when the last boundary before a ventricle or mesothelial-lined space is concerned.

While it might appear desirable to postpone operative intervention until abscess formation has occurred, it should be pointed out that encapsulation, if occurring at all, is sometimes quite tardy and that much mischief can be done by the infection in the interim. Further destruction of brain tissue, the development of cerebral fungus or fatal meningitis may take place before a frank abscess is formed. The following case from the Bizerte series is illustrative and represents our lack of appreciation of these facts at that time:

Case 1. A young British infantryman was struck in the right frontal region by a shell fragment. There was slight weakness of the left face and arm. The wound was debrided and closed without drainage on the same day at an evacuation hospital; 48 hours later some bloody fluid was said to have escaped through the wound.

He was admitted to the Head Center 4 days after injury, at which time he was alert, comfortable and cooperative. The wound was well healed, the flap soft and pulsating. There was no fever or tachycardia. Roentgenograms disclosed several small bone fragments beneath the skull defect in the right frontal region and a large metallic foreign body just to the left of the midline in the frontal region. The following day his neck became slightly stiff and the flap bulged. Several cc. of serosanguineous fluid containing flecks of necrotic brain tissue were aspirated from beneath the flap. Smears of this material revealed no bacteria but cultures could not be made since our laboratory had not been set up completely at the time. The next day the bone chips were removed but the bullet, which lay beyond the falx, was not touched. Death from meningitis took place 2 days later, or 9 days after wounding.

Autopsy disclosed pus about the metallic fragment but no sign of capsule formation (Fig. 1). Direct extension into the ventricle was not demonstrated in this case.

Comment. Had this wound been thoroughly debrided and the huge
metallic foreign body removed at the first operation, or by us at our first opportunity, it is altogether likely that this catastrophe would have been avoided. The history of the next patient exemplifies the favorable course that may be anticipated after adequate redebridement.

**Case 2.** An American infantryman incurred a penetrating wound of the right frontal lobe when struck in the right forehead by a shell fragment at 2200 hrs. on 26 October 1944. The wound was debrided 80 hrs. later, at which time bone fragments, a few clots and some necrotic brain tissue were removed. The dura was not closed. His immediate convalescence was apparently quite satisfactory, neurological changes having remained minimal.

When seen in the Head Center 10 days later he was alert, cooperative and intelligent. He complained of mild pains in both eyes and of precipitate urinary and fecal incontinence. The Z-shaped incision was well healed but, though pulsating, seemed a little full. Early bilateral papilledema was present and the neck was slightly stiff. Roentgenological examination of the skull disclosed a 5×4 cm. defect in the right frontal bone, with radiating linear fractures, one of which entered the cloudy right frontal sinus. A bone fragment, 13×6×5 mm., was observed 5 cm. beneath the defect and 2 cm. to the right of the midline. A 17×6×4 mm. metallic foreign body was present in the midline, approximately in the region of the midportion of the corpus callosum.

The wound was reexplored on 9 November 1944 under general anesthesia. Immediately beneath the flap several cc. of necrotic brain tissue of mushlike consistency were found and
removed. Cultures taken from this material yielded non-hemolytic Staphylococcus albus and E. Coli. Following removal of the large bone fragment in the depth of the wound there was an escape of several cc. of watery fluid containing particles of pulped brain tissue. The shaggy walls of the wound were redebrided back to viable looking tissue. A hematoma-filled tract extended along the right side of the falx and apparently led back to the metallic fragment. The clot was removed no further back than the genu of the corpus callosum, since the tract from there on was narrow and exposure difficult. The shell fragment was not removed. Penicillin (10,000 units in 5 cc. of saline) was left in the cavity. The galea and skin were closed in layers with fine silk without drainage.

Convalescence was prompt and uneventful. The incision healed *per primum*. Urinary and fecal incontinence had disappeared by the 9th day.

_Drainage_ of deeply infected brain wounds, as well as of frank abscesses, has been very unsatisfactory in our hands. If redebridement had been done satisfactorily a drain was not necessary, and if not, it did not suffice. On the other hand, extensive purulent granulation tissue beneath the scalp calls for a soft drain of some kind for a few days.

**MENINGITIS**

Meningitis occurred in 25 or 6 per cent of our cases; there were 9 deaths. Organisms cultured from the wounds (but not always from the cerebrospinal fluid) were: aerobic hemolytic streptococcus, 3; anaerobic hemolytic streptococcus, 1; pneumococcus, 2 (one type 29, the other unknown); aerobic non-hemolytic streptococcus, 3; aerobic non-hemolytic Staphylococcus albus, 5; A. aerogenes, 2; B. Coli, B. subtilis and diphtheroids, each 1. We believe that in those cases in which the infection has passed from the infected wound into the ventricle or subarachnoid space, one should, providing the patient’s condition permits, redebride the wound as early as possible, and at the same time vigorously employ chemotherapy. This applies particularly to incipient meningitis. If, on the other hand, infection has entered through a fracture of a paranasal sinus, it is better to rely solely on chemotherapy in the beginning, since the results of this method can be expected to be good, and second, the operative closure of the dural laceration would be difficult and hazardous in a very sick man whose brain was edematous. This latter procedure may then be done at a future date when the patient is in better condition.

As an example of the first problem (meningitis from an infected wound) the following case may be cited:

_Case 3._ An American soldier received a penetrating wound of the right temporal lobe from a shell fragment on 4 February 1944. Six hours later debridement and closure with drainage was performed. His initial convalescence was said to have been satisfactory. The drain was removed after 2 days. However, the wound broke down.

When he entered the Head Center 2 weeks later headaches had become a prominent symptom. The flap was bulging and tense; pus was draining from the posterior end of the incision and spinal fluid from the anterior. Four days later his neck became quite stiff. Lumbar puncture revealed the presence of 560 white cells in the spinal fluid, of which 94 per cent were polymorphonuclear leucocytes, while cultures disclosed non-hemolytic Staphylococcus albus.
Redebridement of the wound and removal of several retained bone fragments, together with intensive sulphathiazole therapy, were followed by healing and prompt subsidence of the meningitis. Cultural studies of the wound revealed the presence of non-hemolytic Staphylococcus albus and A. Aerogenes.

Rhinorrhea, if not profuse, may pass unnoticed or the patient, in view of his other woes, may not consider it worthy of complaint. The soldier whose history follows was wounded in the battle for the Gothic Line, entered
the Head Center during a period of great rush, and the existence of the fistula was not suspected until meningitis had set in.

Case 4. A 28-year-old infantryman received a penetrating wound of the right frontal lobe when struck by a shell fragment at 0415 hrs. on 7 October 1944. The fracture extended into the right frontal and ethmoidal sinuses. The wound was debrided and closed at an evacuation hospital 29 hrs. later. Convalescence was prompt, and the wound healed per primum.

When he reached the Head Center almost a month later he was ambulatory and without complaints. No neurological changes were observed. On 16 November 1944 meningitis suddenly set in. Then, belatedly, we obtained the story of rhinorrhea. It was said to have been present almost constantly until the previous day, when it had ceased. Pneumococcus, type 29, was recovered from the spinal fluid. He was alarmingly ill, but responded promptly to sulphathiazole and routine intramuscular penicillin (25,000 units every 3 hours).

On 7 December 1944 a right frontal craniotomy was performed under ether by Captain W. B. Weary. A large encapsulated subdural hematoma overlaid the frontal lobe; the lower portion of the latter had herniated through the defect in the cribiform plate into the right nostril (Fig. 2). A small aerocele was found in this fungus when excised. After removing the hematoma the dural defect over the frontal and ethmoidal sinuses was repaired with fascia lata. After operation an extradural hematoma developed, the removal of which was followed by rapid recovery (Fig. 3).

OSTEOMYELITIS

Osteomyelitis of the spreading type, which sometimes follows frontal sinus infection, was not observed in this series of cases, and but one in-
stance of a relatively mild nature has come to our attention elsewhere. A low-grade inflammatory reaction in the edges of an infected craniotomy was commonly seen, but seldom gave trouble after its removal by rongeur during the redebridement of the wound.

CHEMOTHERAPY

In order to assess the value of sulphonamide or penicillin therapy in penetrating skull wounds, comparable series of cases must be studied. We have observed no such group in which neither drug was employed. The incidence of deep infections during the period in which sulphonamide therapy alone was practised was 37, or 23 per cent of 158 cases, while following the introduction of penicillin therapy in the Spring campaigns of 1944 the rate fell to 35, or 13 per cent of 268 cases. While this is apparently an improvement, it is felt that at least two other factors must share the credit with penicillin, namely, better debridement and the more generous use of whole blood replacement therapy. The value of penicillin and/or sulphonamides in arresting the invasion of certain bacteria is widely recognized; it is equally important to bear in mind the inability of either agent to sterilize a wound containing necrotic tissue, blood clot or foreign matter. Furthermore, in all fairness to Mother Nature, it is to be recalled that well-debrided wounds in the brain or elsewhere usually heal well without the benefit of any chemotherapy.

Sulphonamides have not been used locally in brain wounds because of their irritating effects. During the past year it has been customary to instill a solution of penicillin (10,000 units in 10 to 15 cc. of normal saline) in the wound after completion of debridement. It is not possible to prove the value of this particular procedure, since these patients received penicillin intramuscularly as well. We have observed no ill effects from its local use, although on more than one occasion mild irritation of the meninges appeared to have resulted from repeated intrathecal injections.

CEREBRAL FUNGUS

Cerebral fungus occurred in 32 cases, an incidence of 7.4 per cent. In another paper (“Cerebral fungi complicating penetrating brain wounds”: to be published) we pointed out that this condition is to be looked upon as a complication of wound healing, and that treatment must be directed primarily at the cause rather than at the fungus itself. In this series fungi that appeared following wound debridement readily fell into two groups.

The first, which we termed benign, was made up of 13 instances of local cerebritis associated with superficial wound infection and an open dura. The herniae grew slowly, were seldom large, shaggy or friable, nor were they associated with high intracranial pressure nor progressive neurological

* Since the observed difference 10 is less than twice the P.E. (5.81), the probability of this occurring by chance is about 1 in 4 and the significance is therefore highly questionable.
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changes. None was accompanied by deeper infection. There were no deaths in this series. Hot wet dressings were employed but otherwise no special treatment was required, since the natural tendency was toward healing and retraction of the hernia. In but one early case was the mass excised. It was 3 to 4 cm. in diameter, was found to be undergoing fibrosis and would in all probability have subsided spontaneously. Retained bone fragments were observed in but 4 individuals and were removed from 3. When located superficially it is probably better to remove them, since they so frequently harbor infection. The following case, reported in brief, illustrates the problem of benign fungus.

Case 5. A 23-year-old infantryman suffered a severe penetrating wound of the right parietal lobe with complete left hemiplegia on 25 October 1944. Indriven bone and metallic fragments, blood clots and pulped brain tissue were removed at the time of wound debride-
ment 29 hours later. The dura was not closed.

When admitted to the Head Center 11 days afterwards the hemiplegia remained complete. The wound was gaping widely and bathed in pus; in its center was a small herniation of cerebral tissue, approximately 1 inch in diameter and ½ inch in height. It was pulsating fairly well. He was afebrile, alert, cooperative and complained of only very mild headaches. There was no papilledema. Roentgenograms disclosed no retained bone or metallic fragments. There being no evidence of markedly elevated pressure, meningeal irritation or retained bone fragments, it was assumed that the fungus was brought about by the local cerebritis associated with a superficial wound infection in the presence of an open dura.

Hot wet dressings were applied to the wound; sulphathiazole and penicillin therapy were instituted. The local infection subsided, the fungus gradually receded and within 8 weeks the wound had healed. During this time the hemiplegia began to clear up.

Nineteen patients in this group developed cerebral herniations associated with increased intracranial pressure. In each instance deep infection, hematoma or rarely a large mass of necrotic brain tissue was responsible. Once started on their way through open dura these fungi grew rapidly, were shaggy and bled easily. Evidence of increased intracranial pressure and progressive destruction of neural tissue was readily found. We termed these malignant fungi. A hernia of this type may follow the intense cerebritis of a virulent local wound infection, but we did not encounter it in this series of recently debrided war wounds. In every instance early surgical intervention was required. Accurate preoperative localization of retained bone and metallic fragments by stereoscopic roentgenograms was essential. Removal of the necrotic portion of the fungus often served to reduce pressure locally and occasionally uncovered a sinus leading down to an abscess. Six patients died while under our care and three others may have succumbed subsequently, since the military situation required their evacuation while they were still quite sick. In each fatal case the underlying abscess had been overlooked or its evacuation too long delayed.

As an example of malignant fungus improperly treated the following case is recorded:

Case 6. An infantryman incurred penetrating wounds of the left parietal lobe, right ear, right mandible and right groin from a machine pistol on 13 October 1943. Records of the initial operations were lost but it was known that meningitis had set in while on a hospital
ship between Italy and Tunisia. At that time a lumbar puncture had revealed gram-positive
diplococci in the spinal fluid. Improvement followed intensive sulphadiazine therapy.

On arrival at the Neurosurgical Center 11 days after injury he was semi-stuporous and
inarticulate. There were complete right hemiplegia and early bilateral papilledema. A tense,
shaggy cerebral fungus, 2 inches in diameter and 1 inch in height, was present in the left
parietal region. Roentgenograms disclosed many retained bone fragments in the left parietal
lobe and a few more, together with a piece of metal, in the left temporal lobe. Sulphonamide
therapy was continued. Within the next 3 days he improved somewhat and spoke a few words
but remained almost completely apraxic.

On 28 October 1943 the fungus was excised and the wound in part redebrided. Several
small bone and metallic fragments were removed. An abscess beneath the parietal defect,
which contained perhaps 5 cc. of pus, was evacuated. Improvement was but slight and within
4 days the spinal fluid pressure had risen again to approximately 400 mm. of water and
meningitis developed. Spinal fluid cultures revealed aerobic non-hemolytic streptococci and
Staphylococcus albus. The fungus reappeared, thrusting outward the original abscess capsule.
It was reexcised and the parietal and temporal lobes were unsuccessfully explored for abscess
with a ventricular needle. The following morning another exploratory tap disclosed a left
temporal lobe abscess, from which approximately 20 cc. of pus were evacuated. It was too
late, however, and he died the same day.

Autopsy revealed a poorly encapsulated abscess located principally in the temporal lobe
but extending into the frontal white matter as well. It had formed in the terminal portion of
the principal missile tract. Rupture had occurred into the lateral ventricle, the ependyma
of which was covered with shaggy exudate. One or two small bone fragments were incor-
porated within the abscess. The metallic foreign body in the temporal lobe was surrounded
by a tiny independent abscess about 1⁄4 in. beyond the larger cavity.

Comment. Within a few days after the first redebridement, mounting
intracranial pressure indicated that the seat of the trouble had not been
found. At that time abscess was the diagnosis, and one should not have
given up after unsuccessful tapping. Abscesses may be difficult to find. It
should be recalled that the missile and the bone fragments seldom follow
the same tract, and that abscess occurs much more often about bone frag-
ments. A ventriculogram should have been made in this instance.

In the following case the abscess was readily evacuated with prompt
relief.

Case 7. A 31-year-old infantryman was struck in the left frontal region by a rifle bullet
on 16 October 1943 in Italy. The wound was debrided, the missile removed, and closure
effected the following day at a field hospital. A few days later at another institution the
wound was observed to have broken down and a fungus was evident. The amount of sulphonam-
ide administered was unknown, and penicillin was not available.

On arrival at the Head Center on 25 October 1943, 8 days after the initial operation, the
wound was found to be draining pus and a tense, shaggy, non-pulsating fungus was present.
Neurological examination revealed mild right hemiparesis and early papilledema. Mental
processes were slow, but he was rational, cooperative, and complaining of little headache.
There was little fever, but the neck was slightly stiff. Roentgenograms revealed several
retained bone fragments a short distance beneath the defect in the posterior portion of the
left frontal bone.

Under novocaine anesthesia the fungus was excised flush with the dura. A mass of necrotic
tissue and bone fragments was found beneath associated with a partially encapsulated abscess.
Following evacuation of the latter and secondary debridement of the wound, the scalp was
closed loosely about a drain. Wound cultures revealed aerobic hemolytic Staphylococcus
albus, and aerobic hemolytic streptococcus. His highest recorded cerebrospinal fluid pressure
was 800 mm. of water, and a cell count of 330, of which 40 per cent were polymorphonuclear leucocytes. Convalescence was uneventful and his neurological recovery complete.

HEMATOMA

Hematoma within the cerebral wound was the rule, whereas large subdural and particularly large extradural extravasations were unusual. Among a group of 333 cases, subdural hematomas were found 7 times; extradural and subtentorial clots were even less common. In this echelon one encountered the overlooked or recurrent clot, which may have occurred at any point along the missile tract. Major J. Shorstein of the R.A.M.C. has drawn attention to the huge intracerebral clot that sometimes follows the small missile wound. The following case illustrates this problem, which is more commonly encountered by the forward than the base surgeon.

Case 8. A German prisoner was brought to the hospital 2 days after having been wounded in the battle for Cassino. He was very drowsy and could give little account of what had happened to him. Partial motor aphasia and right facial weakness were obvious. Close examination of his head revealed a tiny pin-point wound in the left temple. Roentgenography disclosed a metallic fragment, approximately 2 mm. in diameter, within the temporal lobe. Exploration of the wound disclosed a subcortical hematoma of 3 to 4 cm. diameter, the removal of which was followed by prompt recovery.

The more commonly encountered complication is that of overlooked or recurrent hematoma within the wound. If the ventricle has been traversed, either blood or infection may set up an alarming reaction. The next case offers an unusually interesting example of such a problem.

Case 9. A 24-year-old infantryman was rendered unconscious by a mortar shell fragment which entered the right frontal lobe and came to rest in the left temporal region. When subsequently examined at an evacuation hospital he was drowsy and confused but quiet. The temperature was 100.6°F., pulse 60, respirations 18 and blood pressure 130/60. Speech was slow and hesitant but he could name test objects. The right frontal wound was 1.5 cm. in diameter; 38 hrs. after injury it was debrided down to a perforation in the falx, the tract having been found not to traverse the right ventricle. Numerous bone chips, clot and a considerable amount of pulped brain tissue were removed, the dura was repaired with a pericranial graft, and the scalp closed in layers without drainage. Penicillin (10,000 units) was instilled into the wound and subsequently administered by intramuscular injection as well. Postoperative improvement was but slight and temporary. Within 2 days fever, cervical rigidity and increasing stupor were evident and he was evacuated to the Head Center.

He arrived conscious but slightly drowsy, with a rigid neck. The temperature was 104°F., pulse 98 and respirations 28. There was mild left hemiparesis. The lumbar spinal fluid was grossly bloody and under a pressure of 500 mm. of water. (No organisms were subsequently grown from this material on culture.) The craniotomy wound was well healed. Roentgenography disclosed a large metallic fragment in the left temporal lobe 3 cm. above the petrous pyramid. Two bone chips were visible just to the left of the midline between the metallic foreign body and the right frontal bone defect. By the following day he was quite stuporous, the temperature had reached 105°F., and it was observed that he perspired only on the left face and trunk.

Operation: 20 July 1944 (Capt. W. B. Weary). Under ether anesthesia, a 6 cm. opening was made in the squamosa of the left temporal bone. At one point the dura was obviously bruised on its inner surface. Several small clots and bits of pulped brain tissue marked the posterior tract of the missile from the point of ricochet. After cleaning out this path and removing the fragment, the tract was followed forward. Numerous clots of rubbery con-
sistency were evacuated and the anterior horn of the left ventricle encountered. Both in this region and in the ventricle itself was an extensive hematoma. This was removed by washing and suction, as were the bone fragments which lay nearer the falk. The foramen of Monro was clearly in view. Despite good hemostasis and repeated irrigation of the tract the brain remained under tension. Consequently the wound was closed, and the right frontal craniotomy reopened. Two hematomas were found and removed, the second being located just to the right of the falk. The brain was then quite slack. The dura and scalp were resutured in layers without drainage.

His postoperative course was rather stormy for the first 48 hrs. and the temperature was not normal for 9 days. There was mild bilateral facial weakness, but although speech was slow and hesitant, it was fairly complete. He was able to be out of bed 2 weeks after the operation. Reports several months later from the Zone of Interior indicated that he was greatly improved and was talking quite satisfactorily.

While subdural hematoma may be associated with a penetrating wound, it can also follow a glancing blow. As in blunt injuries, it may be situated beneath the point of impact or at some distance. The following case was of interest in that the extravasation of blood was in the posterior fossa.

Case 10. A 20-year-old infantryman was struck in the right ear by a sniper's bullet on 17 July 1944. The huge gutter wound, which extended through the external ear, over the mastoid process and through the muscle in the right suboccipital region, was debrided and partially closed.

When admitted to the Head Center 3 days later he complained of throbbing, right-sided headaches, counter-clockwise vertigo and diplopia. Neurological examination revealed bilateral papilledema, deafness in the right ear, weakness of both external recti and bilateral ataxia and atonia of the arms and legs, the left having been more affected than the right.

At operation (Capt. W. B. Weary) a large subdural hematoma was found covering both cerebellar hemispheres. Following its removal he recovered rapidly, although slight ataxia was still evident when he was evacuated 3 weeks later. In a letter written from the United States several months later he indicated that he was symptom free.

EPILEPSY

Convulsions occurred not infrequently between the time of wounding and debridement. They were quite unusual in the early postoperative period (1 to 2 months in our echelon). When they appeared within the first 2 to 3 weeks after operation they quite often signaled the presence of an abscess, a hematoma or a pocket of necrotic tissue in the cerebrum. In the series of 100 penetrating skull wounds referred to but 5 patients had fits postoperatively (exclusive of cases of meningitis). "All of these were associated with some degree of motor weakness, and were Jacksonian in type." Three of these patients were subsequently found to have abscesses. Convulsions of alarming severity were initiated by a small infected hematoma near the motor cortex of the patient whose story follows:

Case 11. This soldier received a penetrating shell fragment wound in the left temporoparietal region on 20 July 1944. Six hours later the wound was debrided at an evacuation hospital. The cerebral wound was approximately 2×2×3 cm. in size. Satisfactory hemostasis was said to have been obtained.

On reaching the Head Center 4 days later he was seemingly in excellent condition, save for mild left-sided headaches. The wound was well healed and no neurological changes were observed. Two days afterwards he suddenly vomited and became stuporous. An hour later
a second vomiting attack was followed by violent right-sided convulsions. These began in the right face, spread to the right hand, arm and leg; they persisted, and 1½ hrs. later became generalized. Continued cyanosis and a thready pulse were cause for concern.

The wound was reexplored under ether anesthesia and found to contain a mass of hematoma and necrotic brain tissue. Cultures from this material yielded hemolytic Staphylococcus albus. Thorough wound toilet and tight closure were followed by rapid recovery. At the time of evacuation a month later there were no neurological abnormalities and he had had no more fits.

**DURAL CLOSURE**

Dural closure has long been a moot point in the treatment of penetrating wounds. This is but natural when the majority of wounds heal satisfactorily whether or not the dura is sutured. It has been argued that it should be left open to permit spontaneous drainage if infection occurs. In our experience deeply infected brain wounds have not drained satisfactorily and redebridement has usually been necessary. On the other hand, we have on at least four occasions observed the deeper wound effectively shielded from superficial infection by a dura closed either by suture or graft. In an equal number of wounds of the spinal dura, closure by suture or graft prevented inward extension of epidural infection. Another possible advantage may accrue in deeply infected brain wounds, whereby the formation of a fungus is prevented or delayed. We believe that where practicable the dura should be closed; if simple suture is not possible then a graft of living tissue (pericranium, temporal fascia or fascia lata) is advisable. That a living graft imposes little additional burden on the wound is indicated by the following comparison. In one series of 50 cases of penetrating brain wounds in which no graft was employed, there were 7 deep and 6 superficial infections. Among an equal number of similarly wounded individuals whose dura had been patched there were 9 deep and 6 superficial infections.

**COMMENT**

The vast majority of individuals whose penetrating skull wounds entailed irreparable damage to vital parts of the brain died on the battlefield. In a series of 1000 autopsy examinations on soldiers who succumbed before reaching an aid station, Captain W. W. Tribby of the 2nd Medical Laboratory, 5th Army, found that 133 had only head wounds, while a total of 401 had incurred head wounds of sufficient severity to have caused death. For the year 1944, 24.4 per cent of all deaths in the 5th Army field and evacuation hospitals were attributed to head injuries. The great majority of those patients who lived to reach general hospitals 4 to 10 days later had brain damage that was compatible with survival. The chief hazards to be faced are the complications of wound healing, which are for the most part overlooked, or recurrent hematoma, masses of necrotic brain tissue and infection; most of these stemmed from incomplete debridement.

Those of us who have had the privilege of operating in forward medical installations during heavy fighting realize all too well the difficulties under which surgeons must work. These are well known and require no elaboration,
save perhaps on two points. The first is the need for better roentgenograms. The incidence of deep infection has been shown to vary directly with the thoroughness of wound debridement. The number of demonstrably retained bone fragments may be taken as one measure of this. We feel strongly that better work could be done if stereoscopic roentgenograms were available to the neurosurgeon, for flat plates, even when they happen to be clear, leave much to be desired. The equipment is available and the x-ray department is usually an hour ahead of the operating room during rush periods; but seldom have these views been made.

A second factor of no little importance is that of fatigue. After a few days of working under heavy pressure the neurosurgical team becomes very, very tired. When the tactical situation has permitted combining the teams of two evacuation hospitals in the more forward institution and triaging all head cases there, it appeared that more and better work was done. When operating on a 12-hour shift the teams could carry on day after day without undue fatigue. It is realized that this arrangement will not always be possible but when it is, we believe that the combination of two teams is of distinct advantage.

SUMMARY AND CONCLUSIONS

The early complications that followed 426 penetrating skull wounds of the Tunisian, Sicilian and Italian campaigns have been studied. Superficial infection, local skin necrosis or dehiscence took place in 74 cases. Tripod incisions were associated with faulty healing in the majority of instances in which they were employed. When possible, their use should be avoided. By rotating flaps or making relaxation incisions practically all scalp defects can be covered by full thickness skin. The bed from which the flap has been moved should be covered by epithelium at once. If suture is not feasible because of tension, a split thickness graft serves well.

Deep infections developed in 72 cases (16.8 per cent), in the great majority of which debridement was demonstrably incomplete. In this group there were 58 abscesses, 32 cerebral fungi and 25 cases of meningitis. There were 16 deaths (3.7 per cent for this echelon), only one of which was not due to infection. The diagnosis and treatment of these complications were discussed and illustrative cases cited. The value of redebridement and late debridement was stressed.

The ability of sulphonamides and/or penicillin to check the invasion of certain bacteria is unquestioned. On the other hand, the power of either to prevent or to arrest bacterial growth in a wound, particularly if the latter be incompletely debrided, is doubtful. Although the incidence of deep infection diminished from 23 to 13 per cent after the use of penicillin became routine (Spring of 1944), it is to be recalled that with greater experience and skill debridements were done with more thoroughness during this latter period. At the same time the more generous use of whole blood made it possible to maintain patients in better general condition. The value of thor-
ough debridement in the prevention of deep infection was shown in an earlier study by one of us (E.H.C.). In a series of 94 cases it was found by stereoscopic roentgenograms that 45 had had all indriven bone fragments removed, while in 49, some part or all of these had been left behind. Twenty-two deep infections occurred in the latter group and but 2 in the former. Penicillin was not in use at that time. From the above observations it appears that most brain wounds will heal without deep infection if adequately debrided, but if this is not done a number of infections will occur whether or not penicillin or sulphonamides are employed.

Cerebrospinal fluid fistulae are conducive to meningitis. Penetrating craniocerebral wounds that involve the paranasal sinuses usually require dural repair. Should meningitis supervene beforehand, it is advisable to treat it vigorously with both sulphonamides and penicillin. As soon as the infection has subsided and the intracranial pressure has returned to normal, the dural rent should be closed.

Hematomas occurred most frequently along the missile tract, particularly in its distal portion. Necrotic cerebral tissue, with or without infection, often accompanied the clot and was a common cause of elevated intracranial pressure. Subdural and large extradural hematomas were unusual.

Epilepsy was quite uncommon during this early period and when it appeared often signaled the presence of an abscess, a hematoma or a focus of necrotic tissue.

REFERENCES