TANTALUM CRANIOPLASTY FOR WAR WOUNDS OF THE SKULL*

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THE REPAIR of skull defects resulting from war wounds of the head has become a major task of the rehabilitation neurosurgeon. During the past year, head injuries comprised 5.9 per cent of our total casualties and approximately one-fifth of these were open head wounds. The caré of such injuries is divided by the very nature of the lesion among several echelons of medical support. In the first place, it has been estimated that 50–60 per cent of the men never seen alive again after entering a decisive engagement have fatal wounds of the head, although they may exhibit other potentially fatal injuries as well. The mortality among those that survive varies between 15 per cent[1] to 14 per cent[2] to 22 per cent.[3] The preservation of life and the prevention of infection by débridement and primary closure are the functions of the evacuation hospital or the special surgical unit; the treatment of infection and the guidance of the late stages of convalescence are the responsibilities of the base or numbered overseas general hospitals.

As we have pointed out recently,[4] when the patient with a healed head injury returns to the Zone of the Interior, he presents one of two problems and frequently both. The first comprises an evaluation of the existing neurologic defect, carried out by neurologic and psychiatric surveys, supplemented by electro-encephalography and pneumo-encephalography. Such an evaluation is a pertinent factor in determining disposition to duty or some other status. The second problem is that of repairing skull defects in otherwise fit individuals for return to duty or in patients whose skull defect represents merely a part of a disabling cerebral injury. The repair of such skull defects in Army personnel, caused by gunshot wounds and by operative relief of traumatic intracranial hematomas and as a sequel of cerebral tumor or infection has been carried out in 79 patients at the Walter Reed General Hospital, for the most part during the past 11 months. Half of these patients have thus far been returned to some type of duty. An incomplete estimate of the magnitude of this problem may be derived from the statement that the Walter Reed General Hospital is but one of 19 neurosurgical centers in the Zone of the Interior.

Before the repair of a skull defect is accomplished in any one patient, an evaluation, not only of the existing neurologic defect, but also of the potential epileptogenic activity of the concomitant cerebral scar is attempted. With the time interval between initial injury and our observation of these cases steadily lengthening, it has become apparent that the posttraumatic

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† This report was prepared while Lt. Col. Spurling was on overseas duty.

convulsive state will be an important disabling sequel of penetrating injuries of the brain, as it has been in the past. Studies to be published shortly[5] show that in a series of 76 penetrating injuries of the brain observed over a time period of approximately one year or less, 15 have developed convulsions within four months of the injury and that a further 15, a total of 40

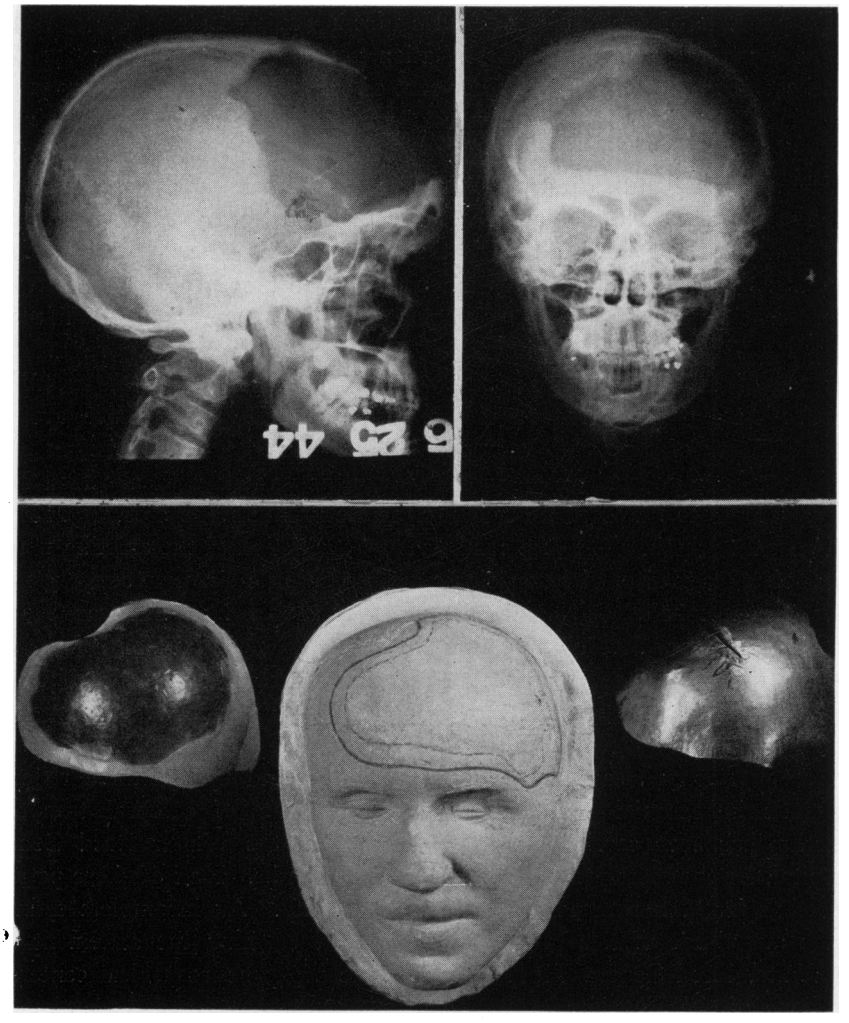


FIG. 1.—Extensive bifrontal defect following a mine explosion. The dental stone impression of the defect, the wax restoration and the completed tantalum plate are illustrated.

per cent, now exhibit electrical cortical activity highly suggestive of an epileptogenic focus. It may be noted in passing that these patients have shown a highly favorable if early response to the conservative regimens of treatment developed during recent years.

INDICATIONS FOR CRANIOPLASTY

The indications for the repair of a skull defect have been established by

the observations made upon many patients by numerous surgeons and have been stated succinctly in the classical paper upon this subject by Grant and Norcross.[6] Such indications include:

(1) Headache and other symptoms of the syndrome of the trephined, including vertigo, local tenderness, fear of injury and a subjective feeling of insecurity, easy fatigability, mental depression and intolerance to vibration.

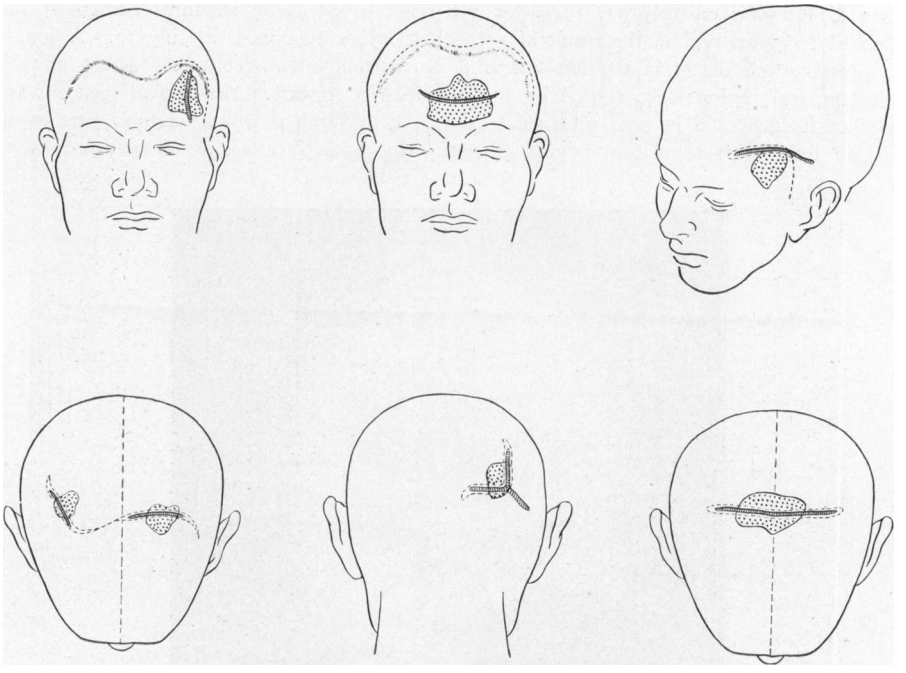


FIG. 2.—Various scalp scars following débridement of the initial injury. The proposed scalp incisions for cranioplasty are indicated with broken lines.

(2) Undue pulsation of the underlying brain.
(3) Exposure to trauma of the underlying brain.
(4) Cases with deforming and repulsive defects, and
(5) The assumed relief of an associated convulsive state.

To these more or less cogent reasons, may be added certain military regulations governing the handling and disposition of such patients when they are treated under service conditions. Under AR 40-105, par. 23 e, an applicant for a commission in the Army of the United States may be rejected for "depressed fracture or loss of bony substance of the skull." Under MR 1-9, an individual fails to meet minimum requirements for induction into the Army if under par. 40 a, he possesses "deformities of the skull in the nature of depressions, exostoses, *etc.*, of a degree which would prevent the individual from wearing military headgear." The profile supplement to MR 1-9 places patients with skull defects of this character in a permanent restricted duty status, and in order to gain a more advanced duty status, cranioplasty is indicated.

Thus, in the practice of military neurosurgery, it is imperative to repair all skull defects over three centimeters in diameter if a return to duty status is desired. That this is advisable in the rugged existence of Army service is validated in part at least by three isolated instances that have come under our personal observation.

Case 1.—P. S. S., Reg. No. 210122, age 23, was operated upon in the Walter Reed General Hospital on July 31, 1942, for the relief of an acute subdural hematoma in the left temporal region, the result of a baseball injury sustained on July 17. A four-centimeter skull defect in the left temporal region and a two-centimeter defect in the left temporal region were caused by the operative procedure. His convalescence was without incident and he was returned to duty. On March 6, 1944, he took part in a grudge fight with regulation boxing gloves. He received a series of blows on the

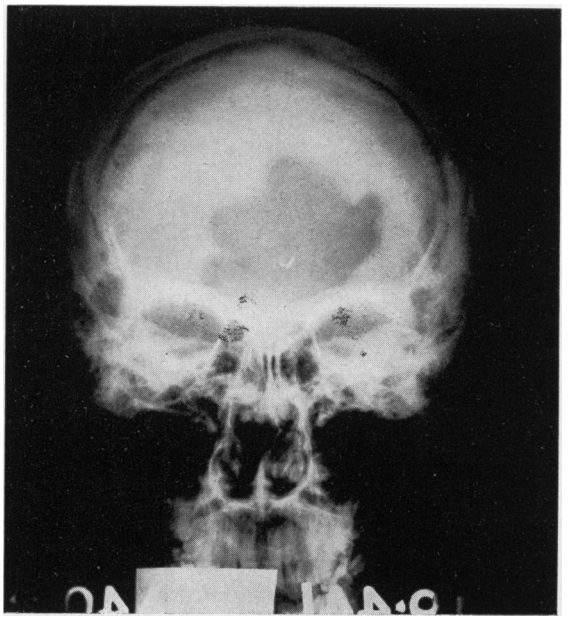


FIG. 3.—Case 1: Bifrontal skull defect caused by fragment of aerial torpedo.

head and 48 hours later, bilateral subdural hematomas were drained at this hospital through the preëxisting skull defects.

Case 2.—M. F. S., Reg. No. 195005, Walter Reed General Hospital, age 27, was struck in the left frontal region by a bayonet on January 9, 1942. The resulting compound comminuted skull fracture and cerebral laceration were débrided after resection of a 3–4 centimeter bony defect. After return to duty, he developed severe head pain, localized at the point of injury, from the pressure of a steel helmet. His symptoms were relieved by tantalum cranioplasty on July 17, 1943, with subsequent return to active duty.

Case 3.—Ashford General Hospital. W. W., age 24, a fighter pilot, assayed a return to duty with a small 3.5 centimeter defect in the right occipital region. Rapid acceleration of his aircraft caused localized pain, and more significantly, blurring of vision. Both disturbances were relieved by cranioplasty.

It seems apparent to us, after two years of experience in these problems, that the important and realistic indication for the repair of a skull defect in military personnel is the simple existence of such a defect over three centimeters in diameter. In personnel who will not return to duty because of a coexisting cerebral injury, the form of cranioplasty to be described is carried out, in the hope of alleviating in every possible way the effect of the initial injury.

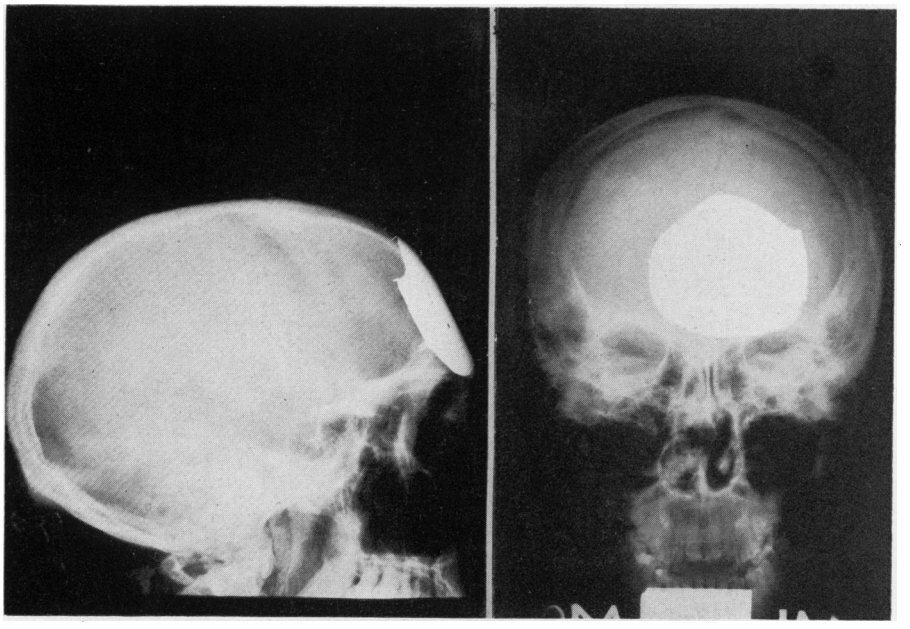


FIG. 4.—Case 1: Roentgenograms of tantalum plate inlayed in bifrontal defect and early postoperative cosmetic result. The broad scar of the original injury may be removed at a later date.

Materials Used for Cranioplasty.—Cranioplasty, being an operation essentially in the domain of plastic surgery, has been favored by the application of much surgical ingenuity in the use of many substitute materials. Its history has been described by Grant and Norcross and reviewed recently by Reeves.[7] Both papers have noted the use of such substances as animal bone, celluloid, aluminum, gold, the fabled silver plate, platinum, autogenic and heterogenic bone, cartilage, sliding grafts of cranial bone, decalcified bone, buttons of bone and chips of bone. A modern innovation in the use of bone chips and whole blood has been recorded by Converse, Clarke and Guidi.[8] There appears to be little doubt that until the appearance of certain alloplastic substances, autogenous bone derived from the adjacent cranium, the ilium, the ribs or other osseous structures, was the material of choice for cranioplasty. However, the plastic repair of extensive defects was not always feasible with the use of autogenous bone and the method suffered from the necessity of a second and frequently major operative procedure designed to secure the graft.

The use of alloplastic substances for the repair of skull defects received impetus by the reports of Geib,[9] Beck,[10] and Peyton and Hall,[11] describing the clinical advantages of the tissue-inert alloy, vitallium. Its wide application in cranioplasty has been deferred by the fact that vitallium plates must be cast and are not amenable to any degree of secondary adjustment. The use of vitallium implies a two-stage operative procedure and this and other defects in the technic have been answered only partially by Beck's employment of vitallium strips cast in various and perhaps standard sizes. The clinical use of zirconium, whose experimental reactions in tissue have been described by Campbell, *et al.*,[12] has been deferred by the onset of the war.

The use of certain synthetic resins has shown distinct, but as yet unproven, promise in cranioplasty. Certain resins appear quite inert in tissue,[13] and among these is methamethylacrylate (plexiglass). Gurdjian

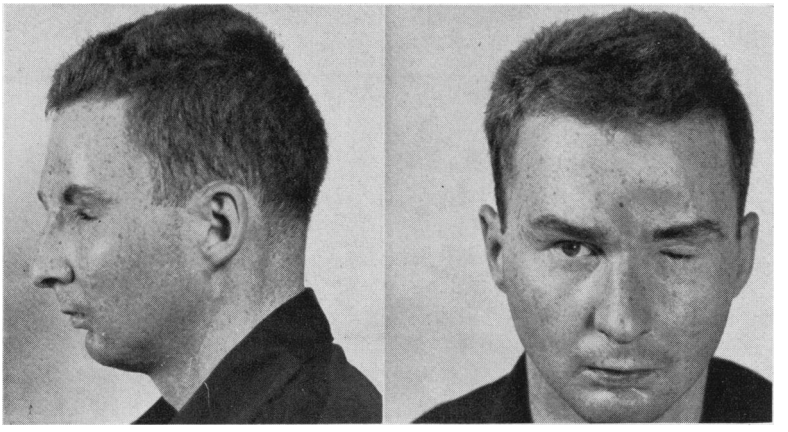


FIG. 5.—Case 2: Left frontal, supra-orbital and orbital plate skull defect from shell fragment injury.

has reported a single, but significant, instance of its use in the repair of a skull defect following removal of a meningioma.[14] Sheldon has used it successfully in his series of studies upon head injuries, marked by observation of the living brain through an acrylic skull plate.[15] Cameron and Elkins[16] have completed some 30 cranioplasties with methamethylacrylate and their results, to be published shortly, may reveal a new chapter in cranioplasty.

The Use of Tantalum in Cranioplasty.—In September, 1942, one of us (R. G. S.) performed the first cranioplasty with tantalum in the Walter Reed General Hospital. This clinical trial followed the experimental observations of Burch and Carney,[17] Burke,[18] and Pudenz,[19] and the early clinical trial by Fulcher.[20]

These studies demonstrated the existence in tantalum of the two essential features of any material used for skull defect repair. In the first place tantalum is relatively inert in tissues and may be considered absolutely inert for all practical purposes. A thin, translucent connective tissue capsule does appear

about this element, well known to military surgeons who have explored peripheral nerve lesions protected by another form of tantalum—tantalum foil. This apparently nonprogressive connective tissue reaction was described by Pudenz,[19] and has been noted also by Pudenz and Odom,[21] and by

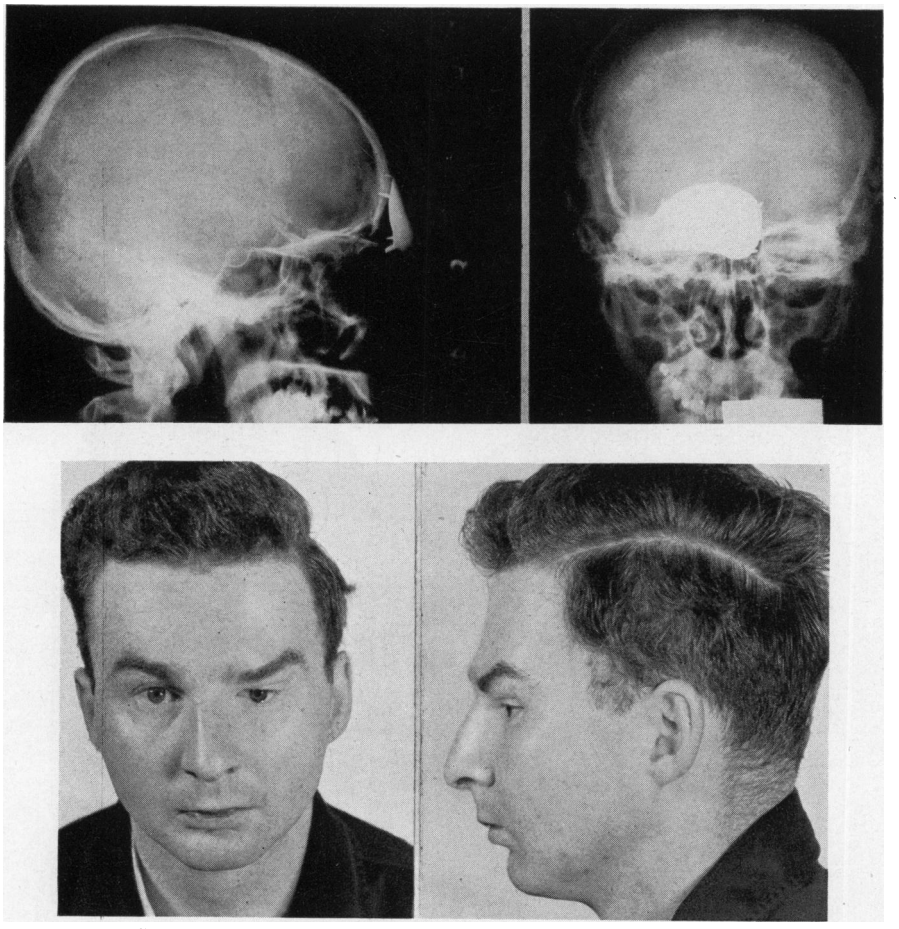


FIG. 6.—Case 2: Roentgenograms of tantalum cranioplasty and cosmetic restoration after insertion of orbital prosthesis.

Delarue, *et al.*[22] In our series of cases, there has been no clinical evidence of tissue reaction to the insertion of tantalum plates, some of them massive in size. No reactions to heat, cold or electrical fields have been a source of complaint to our patients. Pudenz has described proliferation of bone beneath the tantalum plates in his experimental animals. We have had no opportunity to study such a plate after its insertion and the reaction of tantalum to the roentgen ray precludes roentgenographic study of new bone formation.

The second, and desirable, feature of tantalum is its malleability without loss of strength. Flat sheets .015 or .020 inches in thickness and six inches square are available in the neurosurgical centers at this time and larger sheets may be obtained if necessary. The ductility of this bluish-white

element, the 72nd in the periodic table, allows it to be drawn into wire, rolled into sheets of various thicknesses, or formed into structures such as bone plates, ribbon or screws. Its strength may be considered comparable to steel. Whether formed by preoperative molding in a dye and counterdye

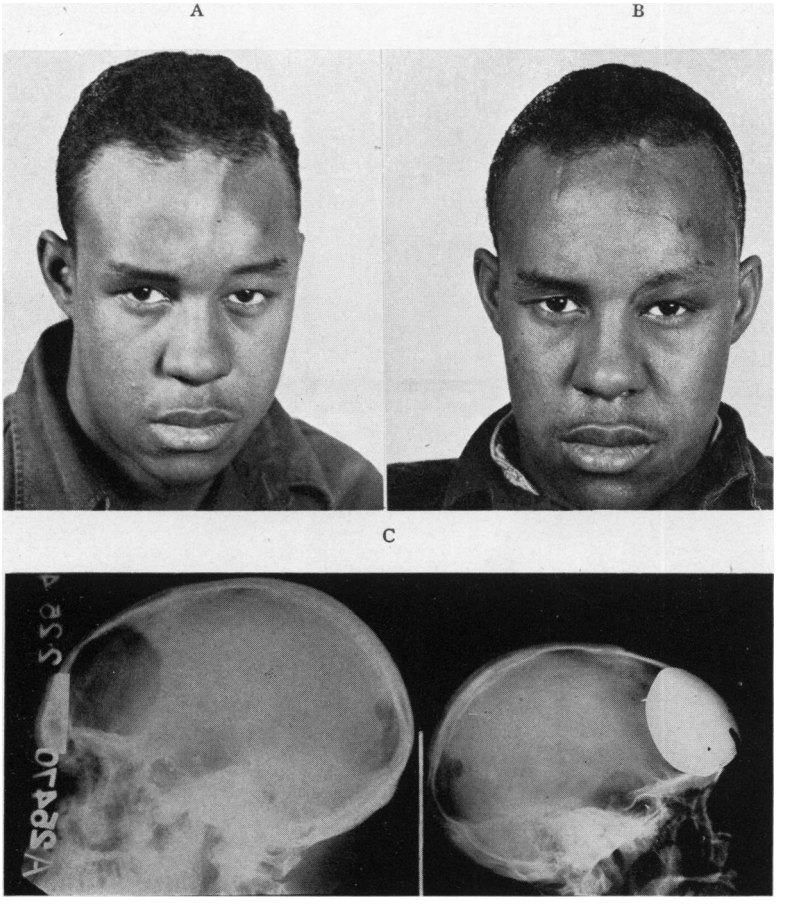


FIG. 7.—Case 3 (A) Skull defect following resection of osteomyelitic bone.
(B) Same patient following tantalum cranioplasty.
FIG. 7.—Case 3 (C) Roentgenograms of skull defect and tantalum repair.

or by rough molding at the operating table with a hammer and rounded form, this inherent malleability allows adjustment by cutting or contour changing at the time of operation and, thus, dispenses with multiple operative procedures.

The Preparation of a Tantalum Plate—Indirect or Primary Method.—One of the several technics evolved for the preparation and insertion of tantalum plates has been described by Hemberger.[23] With the exception of early exploratory efforts in this type of cranioplasty, we have adhered to this technic in the remaining cases of our series. Briefly stated, the method is as follows:

After removal of the long hair, the margins of the skull defect are palpated through the scalp and delineated with an indelible pencil. Dental compound is softened in warm water and molded into the defect and for a considerable distance upon the surrounding scalp. A model is formed by pouring dental stone or plaster into the mass of hardened dental compound and upon this cast, the mark of the indelible pencil will persist. The depressed area within the cast, representing the depth and extent of the bone defect, is filled with wax and contoured to fit the surrounding scalp outline. In complicated frontal defects, this temporary wax prosthesis may be placed in the actual skull defect, in a supra-orbital defect for instance, and compared roughly with the opposite side. In the infrequent deforming bilateral defects, the wax restoration may be studied for verisimilitude by the patient or by relatives. In the uncomplicated defects of the vault of the skull, the convexity of the wax-fill should be overemphasized to compensate for the customary thinning and scarring of the overlying scalp and for the subsequent slight inlay of the plate. A mold is next made with any of the molding sands, including the wax restoration and an ample mass of the adjacent skull contour. A dye is poured with zinc or in larger defects with hydromite. The surface of the dye, after cooling, is painted with a solution of alcohol and talc. A soft clay, such as moldine, is adapted about the circumference of the zinc dye to act as a mold for a counterdye of poured lead. The same procedure is followed when hydromite is used. The required size of .015 inch tantalum plate is roughly fashioned with at least a one centimeter greater diameter than assumed necessary to compensate for the varying convexity of the plate and for possible enlargement of the bony defect at the time of operation. The plate is swedged between dye and counterdye with a hand or hydraulic press. In the swedging of large and complicated plates, the flow of the element under pressure may be associated with kinking or furrowing. Local adjustment of such changes by hammering will allow completion of the press in successive stages. After the initial press, the edges of the plate are smoothed with carborundum and it is polished with an abrasive disk. A single hole is bored in the proposed dependent portion of the plate or in its central portion for drainage purposes and the plate is reswedged. We have had no experience with plates prepared with multiple perforations but have not used this minor variation in preparation of the plate for fear of causing undue fixation of the scalp to the underlying plate. The proposed use of stainless steel wire mesh[24] for the repair of skull defects may be mentioned at this time, since it makes use of a similar principle of multiple perforations. Before use, the plate is cleansed in laboratory cleansing fluid, washed in running water and sterilized in an autoclave. The materials and apparatus required for the formation of such plates are available in any dental laboratory and the skill and experience of Army dental officers in these matters have been of considerable aid in the treatment of the patients reported in this paper.

Operative Fixation of the Plate.—The majority of our operative pro-

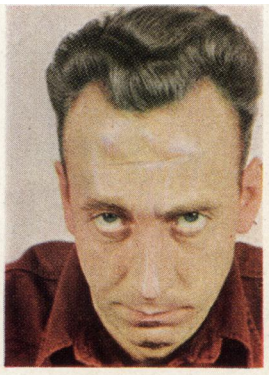
cedures have been undertaken under local anesthesia, and the required lining and chiseling of bone has been well tolerated with the aid of heavy sedation consisting of nembutal grains 1½, 90 minutes before operation and morphine grains ¼ and atropine grains 1/150, 30 minutes later. In unilateral and bilateral frontal defects, the use of a coronal scalp flap and manipulation about the frontal sinus and orbit have demanded the use of a general anesthetic, in these cases intratracheal ether. Insertion of the plate is facilitated by placing the area of skull defect on a horizontal level and full use of the cerebellar frame, and other adjuncts to such posturing, is advocated.

Among the 79 skull defects repaired, 62 were caused by direct enemy action and the definitive treatment of the acute injury was carried out by overseas neurosurgeons. In 54 of the 62 injuries, the resulting scalp scar was represented by a linear scar of varying length. Tripod or formal craniotomy scars were rarely observed; there were five of the former and three of the latter. The skull defects were uniformly oval or rounded and no defects were characteristic of formally resected areas of bone, advocated in World War I. The predominance of linear scars allowed approach to the skull defect in most cases by simple excision of the original scar, and by dissection and retraction of scalp flaps. In temporal bone defects, the usual craniotomy incision making complete or partial use of sagittally directed scars and circumscribing vertical scars is indicated since the mass of muscle and the increased vascularity following injury in this region makes direct exposure of the defect unnecessarily difficult. In frontal defects, rostral to the hair line, coronal incisions are used. Plastic revision of broad or deforming frontal scars may be done as a secondary procedure. In the rare tripod scars, exposure of one angle of the former incision may be sufficient for insertion of the plate. Cranioplastic incisions about a horizontal scar should be avoided since they will be followed by incision line necrosis. The revision of broad thin scalp scars, adherent to underlying brain tissue demand special study and may present formidable problems.[25] Typical scalp scars, defects and cranioplastic incisions are illustrated (Fig. 2).

After adequate exposure of the area of the skull defect, its edges may be readily palpated. An incision is made through the pericranium about the edge of the defect one centimeter from its margin. This pericranial tissue is resected centrally, together with any excess extradural tissue over the area of the defect. Indicated bone resection, cerebral scar resection, dural repair, or other measures, are carried out. To initiate the insertion of the tantalum plate, it is held provisionally over the defect and its margin altered if necessary with heavy cutting scissors so that it overlaps the margin of the

A.—Bifrontal skull defect from aerial torpedo fragment wound.
B.—Lateral view of bifrontal skull defect.
C.—Coronal scalp incision used for exposure of defects rostral to hair-line.
D.—Exposure of skull defect after resection of pericranium about defect.
E.—Preparation of circumferential ledge about defect prior to insertion of plate.
F.—Fixation of tantalum plate by means of tantalum wedges.
G.—Completed operative procedure.
H.—Frontal view of patient after tantalum cranioplasty.
I.—Lateral view of cranioplasty. Note restoration of frontal bone contour.

PLATE I



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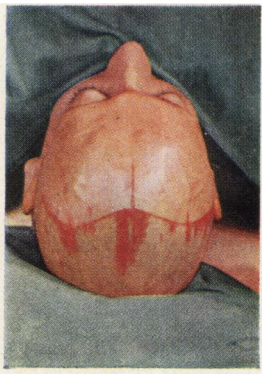

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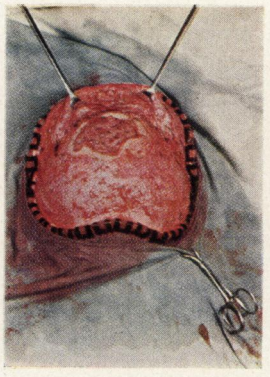

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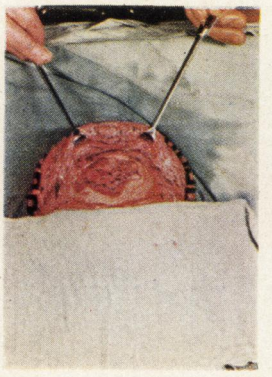

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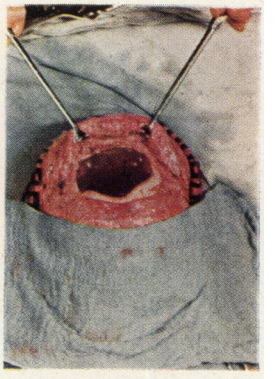

F

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H

I

defect for an approximate distance of one-half centimeter. This border is then marked by an ordinary dental scaler and cut to a depth of two millimeters with the lineator, one of the simple instruments designed by Hemberger for this procedure. This incision into bone, at right angle to the surface of the skull forms the sharp inner border of a circumferential ledge about the border of the defect, one-half centimeter wide and two millimeters deep, formed by a Stout No. 3 dental chisel. The preformed tantalum plate is then fitted into this ledge, its upper border flush with the skull, necessary adjustments being made with cutting scissors or minor contour changes with a contour pliers. With the plate held in position by digital pressure, fixation is secured by means of tantalum triangular points, much like glazier points. Seats for the tantalum wedges in the outer border of the bony ledge are made with a triangular pointed instrument, the perforator. The tantalum wedges, made of .020-inch plate, are tapped into place in the bone, and turned inward over the edge of the plate with a wedge director. Four to six tantalum points may be used in any one case. In plates assuming a vertical position, front or occiput, wedges may be driven through a drill hole in the superior margin of the plate and the weight of the plate suspended in this manner. Following insertion of the plate and closure of the scalp, a firm, evenly distributed pressure dressing is applied, preferably with one of the new adhesive dressings, such as Nuhesive. Such a dressing decreases the number of postoperative aspirations of fluid blood which may collect in spite of meticulous hemostasis. Cranioplasty in this series of cases has been undertaken as soon as primary wound healing has occurred and has not been deferred because of a history of preëxisting cerebral infection. Prior to operation, prophylactic penicillin therapy is instituted with 30,000 units of penicillin being given every three hours for the 24 hours prior to operation. At the termination of the cranioplasty, 30,000 units are injected beneath the scalp incision (10,000 units/cc.) and 15,000 units are given every three hours intramuscularly for the following three days. Two postoperative infections developed prior to the institution of this therapy, both in postinfection cases; both were controlled without open drainage and without loss of the inlayed plate. There have been no infections under the regimen outlined above. There have been no other postoperative complications of significance.

Preparation and Insertion of Tantalum Plate—Direct or Secondary Method.—The method which has been described is applicable to the majority of the skull defects observed some time, *i.e.*, two to four months, following the initial injury. An important variation, which may have a wider application in the field of civilian neurosurgery, consists of a preliminary, direct impression of the proposed tantalum plate, and its insertion at a secondary operation. The débridement of bone in acute injuries of the skull, or the removal of a skull tumor, or the sacrifice of a bone plate at craniotomy, may suggest the desirability of a secondary repair of the resultant skull defect. In suitable cases, this repair may be facilitated by ledging the circumference of the bony defect as described previously. An impression is made of the

extent of the bony defect and the exact contour of the circumferential ledge with autoclaved dental compound. Prior to closure of the primary incision, a sheet of tantalum foil, .00025 inches thick, is placed over the defect and extending well beyond the ledge. Repeated experience with this method has shown that this is an important step in this technic of repair, since at the secondary operation for the insertion of the plate, the skull defect and adjacent bone will be found uninvolved in scar tissue and not adherent to the overlying scalp. The tantalum plate, formed from the direct impression, will need no adjustment at secondary operation and the procedure may be carried out expeditiously at any time deemed advisable during convalescence. (See Case 2)

TANTALUM CRANIOPLASTY IN FRESH WAR WOUNDS

In addition to the more refined methods of cranioplasty that have been described, other methods are available for the repair of skull defects involving relatively uncomplicated skull contours. These include the preforming of plates upon a basic model of the skull, with the only individual variation being the size of the plate, the "hammering" of plates with the aid of preformed plaster molds and the preparation of plates at the operating table by "hammering." Fixation methods include the simple onlay of the plate or inlay of the plate in a ledge, springing of the plate in a ledge,[26] wiring,[23] or minor variations in the preparation of the ledge or the use of V-shaped prongs formed as part of the plate and driven into the outer table of the skull as a method of fixation. None of these methods is applicable to the repair of deforming, complicated frontal defects.

Onlay tantalum plates, secured with wire sutures, or inlay plates secured with tantalum wedges, with the plates hammered out at the operating table, may have a place in the cranioplasty of fresh war wounds, and the principles involved may be used in fresh civilian wounds of the skull. Immediate cranioplasty of this type is only possible because of the lowered incidence of infection secondary to penicillin therapy and should be reserved for those cases without dural penetration. This procedure must still be considered to be in a stage of clinical trial, representing one of the efforts to hasten the convalescence of military casualties. The following case report illustrates a pioneering effort in this direction:

Case 4.—Reg. No. 219533, Walter Reed General Hospital. R. W. D., age 21, was injured in France at 1030 hours, July 26, 1944, by the tree-burst of an 88-millimeter shell. He sustained a penetrating wound of the vertex of the skull, the shell fragment traversing his helmet and causing a compound, comminuted fracture of the left parietal bone adjacent to the sagittal sinus and also involving the right parietal bone. He was unconscious for ten minutes and upon regaining consciousness, noted motor and sensory paralysis of both lower extremities. The right lower extremity improved steadily during the next 90 minutes. Sulfonamide therapy, local and general, was continued during evacuation to England. On July 29, 48 hours after injury, débridement of scalp and bone was performed, with removal of a small extradural hematoma. The dura was intact and was not opened. The outer table of the skull about the circumference

of the bony defect was removed, forming a ledge upon which a "hammered" plate was laid and fixation secured by tantalum points. Penicillin was given locally and parenterally, and wound healing was normal.

At the present writing, the patient shows a mild spastic monoplegia, with diminution in cortical sensibility in the left lower extremity. The electro-encephalogram is normal and the cranioplasty is technically above criticism.

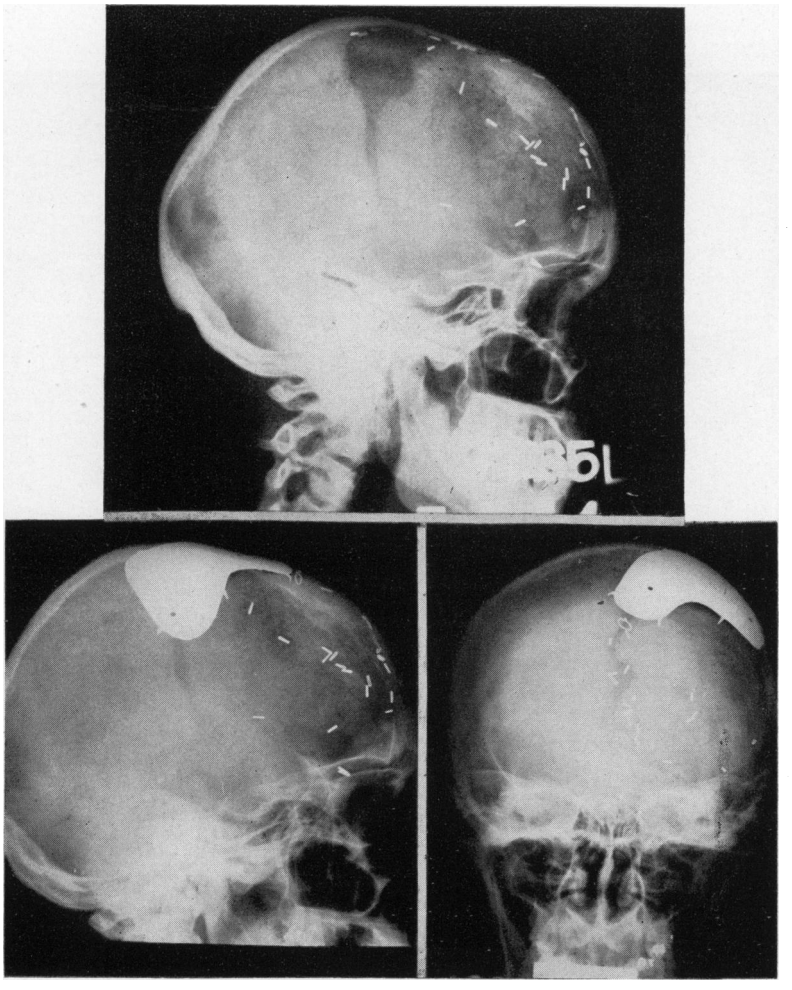

FIG. 8.—Case 4: Roentgenograms of skull defect following craniotomy for tumor and subsequent tantalum cranioplasty and wire fixation of remaining bone plate.

ANALYSIS OF 79 CASES OF TANTALUM CRANIOPLASTY

In a previous report,[23] several massive tantalum cranioplasties have been reported in an effort to illustrate the utility and simplicity of the operative technic and the facility with which the element may be adjusted to any type of repair. Similar unusual cases have been reported elsewhere,[7, 26] We wish to emphasize the fact, however, that the majority of skull defects

resulting from war wounds are relatively uncomplicated problems. This fact, added to the essential inertness and malleability of the element and the technical ease of its insertion, makes tantalum cranioplasty a procedure available not only to trained neurosurgeons but to military surgeons as a whole. Pertinent analyses of the cases we are reporting may be summarized as follows:

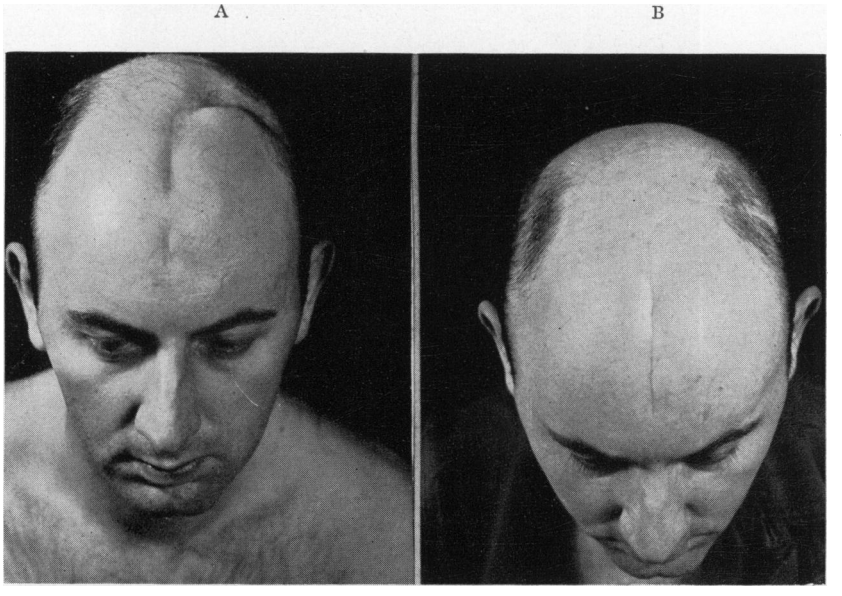

FIG. 9.—Case 4 (A) Irregular skull defect following craniotomy for tumor. (B) Cosmetic result following tantalum cranioplasty.

LOCATION OF DEFECT

Right frontal	12	Left frontal	18	Bifrontal	7
Right temporal	5	Left temporal	6	Biparietal	3
Right parietal	8	Left parietal	10	Bioccipital	3
Right occipital	3	Left occipital	4		—
	—		—		13
	28		38		

The predominance of left-sided injuries is probably not of statistical significance but in this particular series of cases has exerted some influence on the character of the posttraumatic neural defect.

CAUSE OF INJURY

Shell fragment	48	Osteomyelitis	2
Vehicle accident	6	Mine explosion	1
Blow	4	Aerial torpedo	1
Rifle bullet	4	Bayonet	1
Machine pistol bullet	3	Propeller blade	1
Machine gun bullet	3	Dynamite explosion	1
Craniotomy	3	Horse kick	1

The majority of skull defects are caused by shell fragments. This fact would suggest a failure to survive the impact of the higher velocity missiles of

rifle and machine gun. This point can only be judged with the aid of active theater military pathologists.

ASSOCIATED WITH PERMANENT NEUROLOGIC DEFECT

Hemiplegia	9
Unilateral loss of vision	8
Hemiplegia and aphasia	6
Aphasia	5
Bilateral loss of vision	5
Mental retardation	2
Hemiplegia and loss of vision	1
Monoplegia	1
Homonomous hemanopsia	1
	38

The character of the residual neurologic defect, observed at an average time of four months after injury, has been described in rough terms that serve to indicate merely the usual forms of permanent injury, the potential percentage of severe sequelae and their influence upon disposition to duty.

INDICATIONS FOR CRANIOPLASTY AND THE RELIEF OF SYMPTOMS

A statement concerning the indications for cranioplasty with particular reference to the influence of the factor of return to duty has already been made. We have not analysed in detail local or subjective symptoms presented by our patients. We have been impressed, however, by several points that deserve comment.

The majority of our patients have noted localized tenderness upon palpation of the area of the defect, and have complained of localized pain that has had a tendency toward spontaneous resolution. These subjective complaints have been benefited by cranioplasty. Vertigo and generalized headache are less common complaints and appear unaffected by cranioplasty. They represent, in all probability, the sequelae of the cerebral injury. In the same category rests the complaint of tingling paresthesias in upper or lower extremities and chest wall occasioned by a rapid and pronounced flexion of the cervical spine and unaffected by cranioplasty.

The number of repulsive or deforming defects is measured by those involving the supra-orbital and frontal regions of the skull rostral to the hair line. When associated with unilateral or bilateral loss of the orbital contents, they represent cosmetic disorders that demand improvement. The combination of tantalum cranioplasty and the insertion of appropriate orbital prostheses has given gratifying results.

A study of this series of cases has presented at least a partial answer to the problem whether or not any form of cranioplasty may influence an underlying convulsive state. Observations of the effect of cranioplasty upon changes in electrical activity of the brain have been made in 26 cases studied before and after cranioplasty over a varying time period from 4 to 12 months.[5] Identical records may be obtained before and immediately after tantalum cranioplasty, and it is obvious that the tantalum itself has no

influence upon the technic of this examination. In these 26 cases, 12 showed no subsequent change in the character of cortical electrical activity, in ten there was evidence of improvement in an abnormal electro-encephalogram and in four the abnormal activity became even more manifest, with the development of epileptogenic foci. Cranioplasty was not performed upon patients whose convulsive state had not been controlled by conservative measures and thus far, there has been no opportunity to judge the direct effect of cranioplasty upon an uncontrolled convulsive state. The excision of the concomitant cerebral scar will always invalidate such a trial. Studies upon additional cases have not altered these impressions.

DISPOSITION TO DUTY OR OTHER STATUS

Discharged or retired for physical reasons:	
Neurologic defect	28
E.E.G. epileptogenic focus	6
Convulsions	5
Other contributing factors	4
	43
Discharged from hospital to duty	36

POSTOPERATIVE COMPLICATIONS

Infection	2
Plate slipping (early case)	1
Extradural pneumatocele (frontal sinus)	1
	4

The Value of Complementary Pneumo-encephalography.—We have not been impressed by the value of pneumo-encephalography in the estimation of the degree of concomitant cerebral injury when compared to the aid derived from a carefully reviewed history, from the neurologic examination and, in particular, from repeated electro-encephalographic studies. Only 18 air studies have been conducted in these patients, the majority in those exhibiting convulsions or an epileptogenic focus. They have added nothing but confirmative evidence to less distressing methods of examination and appear to hold a minor place in the survey of a relatively fresh injury. With the use of multiple projections, the insertion of a tantalum plate, unless it be of massive size, need not detract from the future application of this method, in those cases in which resection of a cerebral cicatrix may be indicated.

ILLUSTRATIVE CASES

Case 5.—*Midfrontal defect, aerial torpedo wound on November 27, 1943. Tantalum cranioplasty, indirect, primary method on June 29, 1944. Adequate cosmetic result.*

J. K., Reg. No. 215697, Walter Reed General Hospital, age 32, was injured on a troop transport by fragments from an aerial torpedo. There was no loss of consciousness nor evidence of neurologic defect. He was lowered over the side of his ship and floated about for several hours before being rescued by a friendly mine-sweeper. Débridement and primary closure of a midfrontal, compound, comminuted fracture of the skull with cortical laceration was carried out 48 hours after injury by a British installation. Wound healing was normal. There was no history of convulsions. He was received at this hospital on June 17, 1944. He had no complaints and the neurologic examination was

normal. There was an irregular skull defect in the midfrontal region, rostral to the hair line, and involving the medial and superior margins of both supra-orbital ridges, more so on the left. Roentgenograms more clearly define the extent of the defect. The preoperative electro-encephalogram showed bursts of fast activity, 14-22 per second, in both frontal leads. Spinal air injection disclosed a normal ventricular system and subarachnoid space. Tantalum cranioplasty through a coronal scalp incision with reflection of the rostral flap disclosed the skull defect. A well-contoured, preformed tantalum plate was inlayed in the usual bony ledge and fixation was secured with tantalum wedges. An adequate roentgenographic and cosmetic result was obtained (Figs. 3, 4 and 5).

This particular defect and the method of repair may be considered as fairly typical of the majority of cases in this series.

Case 6.—*Left frontal skull defect, caused by shell fragment injury on January 6, 1944, associated with loss of left orbital contents and intra-orbital cerebral fungus. Meningitis. Resection of fungus, dural graft and control of subarachnoid infection. Tantalum cranioplasty, direct, secondary method, on June 1, 1944, and transfer to Ophthalmological Center.*

L. P. D., Reg. No. 213526, age 22, was struck by shell fragments in the left frontal region and in the left orbit on January 6, 1944. He was semicomatose for the first 24 hours and during this time the left orbital contents were exenterated and a compound, comminuted fracture of the left frontal bone, frontal sinus and orbital plate was débrided and closed. His convalescence was smooth and after return to the Zone of the Interior, he was sent to an ophthalmologic center for an orbital prosthesis. On May 7, he developed fever, cervical rigidity and rapidly became stuporous. Lumbar puncture demonstrated a sterile pleocytosis of 835 cells, half of which were polymorphonuclear in type. The acute meningeal infection was controlled readily with daily injections of 10,000 units of penicillin in the lumbar subarachnoid space. Review of the overseas record suggested the possibility of an intra-orbital cerebral fungus. On June 1, 1944, a coronal scalp flap was reflected rostrally exposing the bony defect. A yellow, scarred mass of necrotic cerebral tissue filled the orbit. This mass of tissue was resected until the margins of a triangular dural defect were visualized. An appropriate-sized area of pericranium was placed over the defect and held in place by a thin disk of fibrin foam, impregnated with penicillin. The customary ledging of the edge of the bony defect was made, the mold for the proposed tantalum restoration taken, and the defect and the adjacent ledge were covered with tantalum foil, .00025 inches thick. The coronal flap was then closed with galeal and scalp interrupted sutures of fine nylon.

Twenty-five days later, the former coronal suture line was reopened and the protecting tantalum foil removed. The operative field was quite clear of scar tissue and not adherent to the scalp. Tantalum cranioplasty was promptly accomplished. This patient has been returned to an ophthalmologic center for plastic revision of the eyebrow and upper lid and for the orbital prosthesis to complete his rehabilitation (Figs. 6 and 7).

Case 7.—*Frontal sinusitis, left, on August 26, 1943. Extradural abscess, osteomyelitis, left frontal bone. Left frontal brain abscess. Resection of brain abscess in December, 1943, after previous resection of left frontal bone. Recovery with tantalum cranioplasty on March 2, 1944.*

C. B., Reg. No. 200710, Walter Reed General Hospital, age 23, while training, developed an acute left frontal sinusitis on August 26, 1943. Drainage of this infection was followed by osteomyelitis of the left frontal bone and an extradural abscess. Resection of the involved bone was carried out on September 21, 1943. His convalescence was protracted, and following the development of stupor and electro-encephalographic localization of a focus in the left frontal lobe, an intracerebral abscess was at first aspirated and later enucleated in December, 1943. All procedures were protected by

penicillin administered by appropriate routes. On March 2, tantalum cranioplasty restored the normal skull contour of the left frontal region (Fig. 8).

Case 8.—*Craniotomy for left parasagittal tumor on December 3, 1943. Postoperative infection controlled by penicillin, with partial loss of craniotomy flap. Convulsive state, with marked anxiety concerning pulsating defect. Tantalum cranioplasty on June 29, 1944, with relief of subjective disturbances and mental rehabilitation for reëntry into civilian status.*

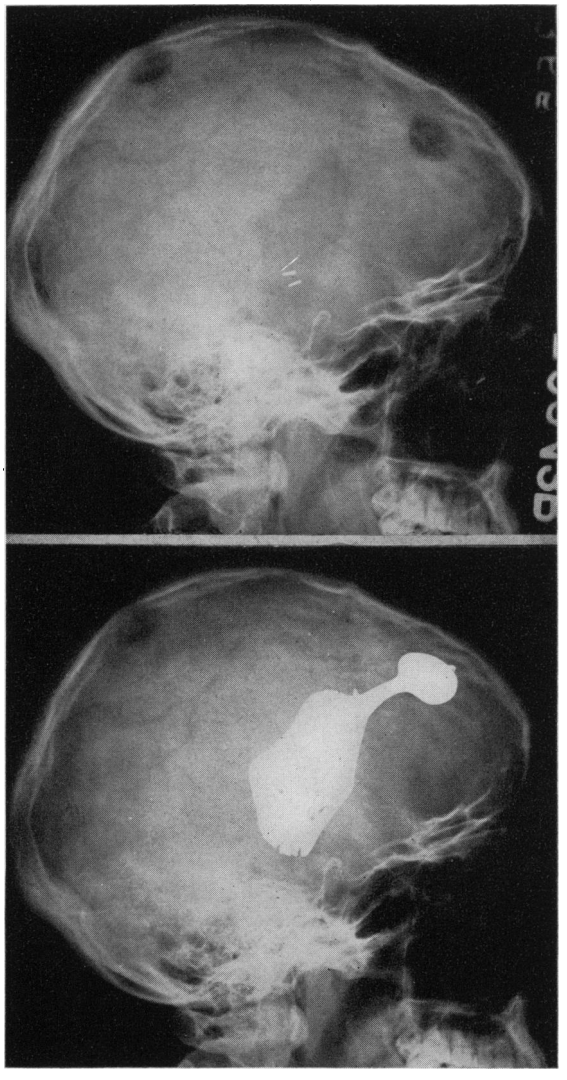

FIG. 10.—Roentgenograms of multiple skull defects following operation for subdural hematoma and following subsequent tantalum cranioplasty.

H. M. F., Reg. No. 214687, Walter Reed General Hospital, age 31, developed headache, vomiting, impairment of vision, indifference and slow cerebration while overseas, with rapid progress of symptoms and neurologic signs suggesting a left frontal lobe tumor.

A technically difficult resection of a left frontal lobe parasagittal meningioma was accomplished on December 3, 1943, necessitating further bone resection for exposure of the tumor. His convalescence was interrupted by a wound infection, readily controlled by penicillin. An intermittent convulsive state was aided with conservative measures following his evacuation to the Zone of the Interior. There was an extensive frontal alopecia and the patient developed an anxiety state, centered upon the obvious deformity and the fear of injury to the pulsating defect. On June 29, 1944, tantalum cranioplasty corrected the deformity and stimulated favorably his rehabilitation to civilian status. Restoration of much larger postcraniotomy defects have been reported[7, 26] (Figs. 9 and 10).

Case 9.—*Blow in right temporal region on February 14, 1943. Gradual onset of increasing intracranial pressure with evacuation of a chronic subdural hematoma on March 30, 1943, through a subtemporal decompression opening following two exploratory trephines. Tantalum cranioplasty on September 7, 1943.*

D. A. A., Reg. No. 198922, Walter Reed General Hospital, age 24, was struck with a beer bottle in the right temporal region on February 14, 1943. He sustained a closed head injury and was unconscious for two days. His recovery was protracted and never complete. He continued to complain of headache and developed diplopia, left-sided motor weakness and papilledema. On March 30, 1943, a chronic subdural hematoma was evacuated in another hospital. Following a smooth convalescence, he developed pain in the pulsating skull defect. Spinal air injection studies and electro-encephalography were normal. On September 7, 1943, a gooseneck tantalum plate was inserted effectively protecting the irregular decompression opening and a tender rather large, frontal trephine opening (Fig. 11).

A minor technical point is to be noted in the accompanying illustration. The thin squamous portion of the temporal bone does not allow wiring readily nor does it permit ledge formation. In this area, primary fixation of a tantalum plate may be obtained by alternating small, V-shaped wedges of the plate itself, implanted above and below the bone edge. The remainder of the plate is then fixed by any of the methods described.

CONCLUSION

Tantalum cranioplasty has been carried out in 79 skull defects occurring in Army personnel as a result of war wounds and casual injuries. Tantalum possesses two qualities essential for a cranioplastic material, inertness in tissue and strength associated with malleability. Defects involving complicated contours such as those of the supra-orbital ridge are best repaired by the use of preformed plates. The technic of inlay of the plate into a circumferential ledge and fixation by means of tantalum wedges is a simple procedure, widely applicable throughout all Army surgical installations.

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DISCUSSION.—DR. W. J. MIXTER, Boston, Mass.: I have seen a good deal of this work and, as I see it, the use of the tantalum plate is a great advantage to the men in the armed forces. There is no question but what there will be many of these plates used in this war, and we must consider what are the limitations of the procedure and what are its advantages over bone graft, and what is going to be the ultimate result to the patient. In the first place, these plates, particularly if preformed, and particularly if handled in a service which is set up for it, are easy of application. The first one you use in your civilian hospital, never having done this before, will take a long time and you will sweat over it, but after you achieve the technic you will find that you have something so much better and so much easier to handle than grafts that there is no comparison.