REPAIR OF CRANIAL DEFECTS WITH TANTALUM

MAJOR ROBERT C. L. ROBERTSON, M.C., A.U.S.
Brooke General Hospital, Fort Sam Houston, Texas
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Autogenous bone transplant repair of cranial defects is not completely satisfactory. It entails an extended or separate operative procedure to secure bone, the size and contour of which leaves something to be desired. A "crows-nest" appearance may result from a multiple fragment repair and there is some question of the survival of the bone fragments as osseous tissue. An ideal substitute material has yet to be discovered. Such a substance should be readily available, easily worked, preferably workable when cold, strong enough to withstand ordinary trauma, and above all, inert in tissue.

Until 1936, when Venable, Stuck and Beach found that vitallium caused no tissue reaction, a satisfactory substitute for bone was unavailable. In the search for an inert metal, Burch (1938) obtained tantalum and, for the first time, used it in surgery. Burch and Carney's observations on the inertia of tantalum in tissues were reported in 1942. Burke (1940) reported that no reaction was produced by tantalum wire in soft tissue.

The adaptability of tantalum to neurosurgery was demonstrated by Pudenz (1942). He proved that brain substance and meninges of cats tolerated the metal extremely well and that the skull plate replacements were efficient. Fulcher (1943) reported a case in which he repaired a frontal skull defect with tantalum sheet metal. Neither Craig nor Spurling have reported their considerable experiences with tantalum in several applications in the field of neurosurgery.

Some information regarding tantalum will explain its suitability for use in surgery, and particularly in cranioplasty. It is an element; a heavy metal with a density of 16.6 (about twice that of steel). It reacts only to strong alkalies, hydrofluoric acid, and concentrated or fuming sulfuric acid at ordinary temperatures. It is virtually non-magnetic and is very high in the EMF Series. These attributes obviate the "storage-battery effect" frequently found in alloys when placed in tissues. Its chemical inertia obviates reactions to body fluids.

Tantalum is workable when cold but cannot be cast. Strength and thermal conductivity are approximately that of steel. The coefficient of expansion of tantalum is 50 per cent that of steel, 40 per cent that of copper and 30 per cent that of silver. Its workability makes it "adaptable to the situation" in contrast to stock or specially cast metal replacements. In the range of body temperature, changes in size of the metal are insignificant.

* Tantalum is produced by the Fansteel Metallurgical Corporation, North Chicago, Illinois.
† While the present article was in press the use of tantalum wire and foil in peripheral nerve surgery was reported by Lt. Col. R. G. Spurling (J. Neurosurg., 1944, 1: 133-148).
Tantalum sheet metal (.015 and .02 inches thick) has been used to repair skull defects at Brooke General Hospital, Fort Sam Houston, Texas, since September, 1942. It has been found that tantalum is easy to use, very adaptable to situations met at the operating table and it has been demonstrated that its reaction in tissue is minimal. No reaction was observed in one tantalum cranioplasty revised after six days, or to segments of tantalum foil after being in place over cortical lacerations so long as 54 days.

Two methods of cranioplasty with tantalum have been used at Brooke General Hospital. One is a two-stage operation, the other a one-stage procedure. In the former, the bed for the plate is prepared by mortising the periphery of the bone defect. A shelf is made in the outer table by chisel, or burr, 2 to 3 mm. beyond the limit of the defect. An impression of the defect, and details of the margin of bone, is obtained with ordinary dental impression compound. A wax model is made duplicating the contour of the portion of the skull to be replaced. From this positive, a die and counter die are made of either calcar, or zinc and lead to swage the metal to conform to size, shape and contour of the missing bone. At secondary operation, the plate is merely placed into the previously prepared bed and fixed in position.

The more frequent, and highly satisfactory method, is a one-stage procedure. The bed is prepared as described above. The approximate size segment of tantalum is molded by bending and shaping, or more frequently by "beating" to contour. Then the exact outline is cut with heavy scissors to conform to the outline of the mortised defect. By this method, done at primary operation, it has been possible in several of the cases to omit the precaution of fixing the plate into position.

If the outline has been cut accurately to size and shape, after the contour has been formed, one border of the plate is engaged into the shoulder of the mortise and by slight bending, and forcing the opposite border into its corresponding shoulder, the plate will fit so well when it has flattened out as a result of its inherent spring, that it will lock itself into position. This is not so difficult as it would seem in description.

Other methods exist or may occur to the surgeon. Moulage, or other type of impression, can be made of the cranial defect before operation. Contour and approximate size and shape of the replacement can thus be formed pre-operatively. This planned type of replacement is advantageous, especially in the frontal regions of the skull where bilateral exact symmetry is most important.

Fixation of the tantalum replacement may be accomplished by wire suture passing through the edge of the plate and through the adjacent bone. In several instances, we used small triangular trimmings of the tantalum sheet, utilizing the principle of glazier's points. These points are driven into the diploic space about the margin of the defect in the same manner that a glazier immobilizes a glass window pane before applying putty about its border. We believe that, with rare exceptions, all replacements should be fixed and the "glazier point" method has mechanical advantages over fixation with wire.
The two-stage operation may be preferable where a prolonged one-stage procedure is contraindicated or in those portions of the skull where the curvature is great, such as over the occipital pole, or where there are complicated contours such as the inferior fronto-temporal-parietal area. Preoperative preparation of the plate is preferable in the latter.

A series of 26 cases of tantalum cranioplasty in service men has been done. All cases have been gratifying in the ease with which the cranial repair has been made, the efficiency of the repair and the cosmetic results. Four illustrative cases are reported in some detail. Although the reports may not reflect a constant refinement in technic, practice has, naturally, resulted in many minor changes in our original methods.

CASE REPORTS


Skull Pathology. Depressed fracture, occipital region, midline.

Associated Injuries. Multiple scalp lacerations, fracture of inferior pubic ramus, moderate concussion (unconscious 24 hours).

Mode of Injury. After having skidded and fallen with a motorcycle, he was struck by a heavy combat vehicle, January 8, 1942.

Course and Residuals. Transient, homonymous hemianopia, right. Relatively uneventful recovery. Returned to duty in a few weeks. Later developed headaches and dizziness precipitated by sunlight and activity for which he was hospitalized three times. Readmitted on August 81, 1942 and transferred to Brooke General Hospital September 16, 1942.

Operation. First stage, September 28, 1942: Removal of depressed area of skull, 6 x 7 cm. diameter and of approximately 3 cm. depth, the external occipital protuberance being the vortex of the cone-shaped depression. Dura was intact. The edges of the bone defect were mortised. An impression of the defect and bone edge was made with dental impression compound. The dental service swaged a segment of tantalum, reproducing a normal contour of this portion of the skull, of exact size and shape of the bone defect. Second stage, October 31, 1942: The tantalum replacement was introduced and anchored to bone with two tantalum wire sutures.

Postoperative Course. Uneventful recovery. Returned to full field duty, December 23, 1942.

Skull Pathology. Skull defect 4.5 × 6.7 cm., left parietal.

Associated Injuries. None on admission to Brooke General Hospital.

Mode of Injury. January 24, 1943, in a forced landing crash, his airplane struck a tree and he sustained a depressed fracture of the left parietal region and lacerations about the head and face.

Course and Residuals. He was not unconscious but was aphasic. There was weakness of the right hand, paralysis of the right thumb, hypaesthesia and hypalgesia of the right hand. A debridement and repair of scalp and facial wounds was done shortly following the accident. On the following day, the depressed fragments of skull were removed. Since dura was intact, it was not opened for investigation of the cortex. Aphasia improved rapidly and the paresis and sensory changes of the hand only slightly less rapidly. He was later transferred to Brooke General Hospital.

Operation. On March 33, 1943 the three-limb scar of the previous operation was completely resected down to periosteum. The galea was separated from periosteum over the bone defect. The periosteum was incised near the margin of the defect and turned down as a flap.

A mortise was created in the border of the defect. A tantalum replacement was molded and trimmed to exactly fit the mortise. On increasing the curvature of the plate slightly, while forcing it into the mortise, it locked itself into position so that it could not be displaced. No fixation was thought indicated. The wound was closed anatomically.

Postoperative Course. He was out of bed the following day for a short walk on the hospital grounds. On the second day he went for an extended walk. Daily needle aspirations of fluid and blood from beneath the scalp flap were necessary for a time. He was returned to full field duty April 10, 1943.

Case 10. S.C.N., Brooke General Hospital.

Skull Pathology. Compound comminuted depressed fracture of supraorbital region, rim of orbit, roof of orbit, right.

Associated Injuries. Severe acid burns, left upper extremity and multiple lacerations, abrasions and contusions of body, limbs and face.

Mode of Injury. November 20, 1942, the observation coach in which patient was riding was derailed, rolled down a high embankment and pinned him under the car next to the storage batteries. The supraorbital wound was of penetrating origin. Battery acid ran over the left upper extremity.

Course and Residuals. He was in profound shock when extricated and received blood plasma at the scene of the accident. He was then transported to Brooke General Hospital by ambulance, arriving in moderate shock.
About four hours following injury, his various wounds were debrided and repaired. The orbital wound contained cinders, bits of hay and mud. The foreign material and displaced bone fragments of the frontal sinus, roof and rim of orbit were removed. The orbital fascia had a rather extensive laceration from which protruded periorbital fat. This was amputated in the debridement because it had many foreign bodies in it. The orbital fascia was then closed. The operative tract was irrigated and frosted with sulfanilamide before closure. On January 1, 1943, a small superficial tract of granulation tissue in the upper eyelid was curetted and closed with tantalum wire, healing without delay.

Operation. On April 15, 1943, a coronal incision was made and the scalp flap reflected forward to expose the orbital fascia on the right. A mortise was created about the bone defect in the right supraorbital region. A segment of tantalum metal was cut in such a manner that it would fill the defect in the supraorbital region, repair the defect in the roof of orbit and replace the missing medial two-thirds of the superior orbital rim. The posterior extension formed an angle of approximately 100 degrees with the supraorbital extension. The supraorbital portion was made convex on its anterior surface. Where it joined the posterior extension and replaced the orbital rim it was concave on its inferior aspect. The posterior extension was rather sharply concave to conform to the normal curvature of the roof of the orbit.

Since there was enophthalmos from the defect in the roof of the orbit and laceration of the orbital fascia with escape of some of the orbital fat, the posterior extension was purposely made to exert more pressure, from above, than the normal contour of roof of orbit would exert. This reduced, but did not eliminate, all enophthalmos.

When the tantalum replacement was placed into the prepared bed it locked itself into position into the roof of the orbit and the supraorbital defect so that no anchoring device was thought necessary. Anatomical closure resulted in primary healing.

Postoperative Course. This patient had congenital diplopia on extreme lateral gaze. Following his accident, there was enophthalmos and increased diplopia. The plastic operation reduced his enophthalmos and diplopia but left much to be desired. Therefore, the Ophthalmol-

![Fig. 5 (left). Case 10. Lateral skull film showing replacement of defect in frontal region, frontal sinus, rim and roof of orbit. This demonstrates how tantalum, because of its ductility, can be "adapted to the situation."](image1)

![Fig. 6 (right). Case 10. Posterior-anterior view of tantalum cranioplasty of frontal bone, frontal sinus, rim and roof of orbit. Small opacities are tantalum wire sutures used to close a sinus which was curetted a few weeks prior to cranioplasty.](image2)
Ophthalmology Department suggested a fascial transplant to correct the enophthalmos. Within 24 hours following the latter procedure a panophthalmitis developed and necessitated removal of the right eye.

Following all operative procedures, with the exception of the last one, done on the Eye Service, convalescence was uneventful.

**Case 13.** S.B., Brooke General Hospital.

*Skull Pathology.* Compound, comminuted fracture, right fronto-temporo-sphenoidal and zygoma.

*Associated Injuries.* (1) Severe laceration, scalp, right fronto-temporo-zygomatic region. (2) Severe laceration, right frontal lobe, postero-lateral. (3) Extensive wound of lateral and posterior aspects, right upper extremity. (4) Compound fracture, lateral epicondyle, right humerus.

*Mode of Injury.* At a foreign station April 12, 1943, soldier was struck on the head and right arm by a propeller revolving at about 1800 r.p.m. He recalls nothing of the accident or circumstances preceding it. The propeller tips traversed the frontal lobe, cutting a vertical path through the cranium from the midline through the squamous temporal and zygoma. He was treated for shock and the wounds debrided. Sulfonamide medication locally and systemically was instituted. Conservative local treatment was given the wounds.

*Course and Residuals.* His highest temperature was 102°F. and became normal on the fifth day. Lucid periods began on the third day and gradually increased in length. In spite of this he was somewhat confused and repeatedly removed his head dressings although he was restrained. A continuous cerebrospinal fluid leak was present from the cranial wound and on the eighth day was particularly profuse. He was transferred, by air, to Brooke General Hospital on the twelfth day, April 24, 1943.

The granulating wound in the scalp appeared to be chiefly cerebral herniation, about 2.5 cm. in width, extending from the midline to below the right zygoma on a plane just anterior to the ear. The upper two-thirds was pulsating and cerebrospinal fluid was escaping synchronously with the pulse. On conservative therapy the cerebrospinal fluid leak healed spontaneously, and the granulating surface contracted in width until operation. His mental status had gradually improved to the point that relatives believed him almost normal.

*Operation.* On June 30, 1943 the scar on the scalp and face was resected down to cranium and the upper end of the resulting scalp wound continued in the coronal plane to the opposite

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**Fig. 7 (left).** Case 13. Lateral X-ray film demonstrating path of propeller tips through right frontal region.

**Fig. 8 (right).** Case 13. Anterior-posterior skull film showing extent of loose bone fragment which was removed and replaced with tantalum.
zygoma. The scalp was reflected forward almost to the level of the supraorbital ridge. Periosteum was reflected from the loose frontal bone fragment, which was then removed. The dura was defective posteriorly where the propeller passed through it. The dura was turned forward as a flap. In the line of the initial injury the soft granulating cerebral tissue was resected en bloc. The underlying white matter was yellowish and contained innumerable cysts of various size. The right frontal cerebral lobe was amputated so far back as the pathological changes extended. This section was carried through the anterior horn of the ventricle to within 1.5 cm. of the interventricular foramen. The right half of the genu of the corpus callosum was incidentally removed. Inferiorly the section was just anterior to the sphenoid ridge. Closure of the dura required reflecting the outer layer, inverting it as a flap, to correct the dural defect. The bone removed from the right frontal region did not fill the cranial defect because the posterior edge had been destroyed in part by the propeller tips. Therefore, the edge of the defect was mortised, and a piece of tantalum was molded by beating, trimmed to size, and then placed in the defect. Small trimmings of tantalum sheet were cut into triangles simulating glazier’s points. These were driven into the diploic space about the periphery of the tantalum plate. This accomplished firm fixation of the plate. Closure of scalp was in anatomical layers.

Postoperative Course. Repeated aspirations were required to remove blood-stained cerebrospinal fluid beneath the galea for about two weeks. Several lumbar punctures were also done. His behavior, postoperatively, was characterized by recurrence of some of his post-traumatic aberrations but these gradually subsided over a period of two weeks when his family stated he appeared and behaved the same as before entering the Army.

A thorough psychiatric inventory by Major Martin L. Towler was reported negative. An electroencephalogram on July 26, 1943, was reported to show no indication of disturbance of cortical activity either localized or generalized.

**TYPES OF CASES**

Fourteen of the twenty-six cases were simple or compound depressed fractures of the skull. Routine treatment of acute cranial trauma was followed by immediate repair of the skull defect. However, some of the patients...
had initial care at other Army hospitals. In these cases, indication for operation was the presence of a cranial defect that gave rise to a feeling of insecurity in the patient or was objectionable from a cosmetic point of view. Continued localizing symptoms, post-traumatic syndrome, or corticomeningeal cicatrix with depressed fracture were considered indications for operation.

**TYPE OF OPERATION**

Single-stage operations were done in all but two cases. A two-stage procedure would have been wiser in another instance since there was a grossly contaminated wound and the condition of the patient at the time of operation was such as to make haste imperative.

**TANTALUM IN SOILED FIELDS**

In five cases there was compounding of the fracture with destruction of brain and exposure of brain to the atmosphere for periods longer than thirty hours. Yet these patients were operated upon and tantalum cranioplasty was done following debridement and sulfonamide therapy without later difficulty. We believe that in soiled or infected fields sulfonamides and penicillin make early surgery possible, whereas before these drugs were available, it entailed too great a risk. Also tantalum is well tolerated by tissues. Soiled intracranial wounds, containing various amounts of foreign bodies (hair, straw, cinders, dirt, stones, etc.) occurred in five cases. In one case an
TANTALUM CRANIOPLASTY

Osteomyelitic area of bone was removed four months before cranioplasty. Only three and a half weeks intervened between removal of a brain abscess and tantalum cranioplasty.

Compounding into the frontal sinuses occurred in three instances. In these cases the mucous membranes were removed, the communication with the nose was occluded with muscle stamp, and the bone defect was repaired without complication. Also in three cases the superior rim and roof of the orbit were defective, requiring repair. Restoration of contour and support was readily accomplished due to the ease with which tantalum sheet metal can be worked when cold. The orbital fascia in two of these cases was lacerated and required suture.

ASSOCIATED INJURIES

It should be noted that many patients in this series had associated, moderate to severe, injuries. These ranged from simple fracture to compound, comminuted fractures of the lower extremities and pelvis to severe and extensive lacerations and acid burns.

CRANIECTOMY-CRANIOPLASTY

In one case in the series an intracranial exploration was made through a small opening (previous trephine opening which was enlarged) and the bone was not replaced. Rather, a tantalum replacement was done. Another repair followed removal of a solitary granulomatous lesion of the skull.

Two patients had repair of a cranial defect in the subtemporal region which was made for approach to the gasserian ganglion in a posterior root section for trigeminal neuralgia. One patient had had a subtemporal decompression a year previously for hypertensive meningeal hydrops. Operation was done to save his vision (5 diopters of papilledema, secondary retinal changes, etc.). The residual bulging decompression was disqualifying for full military duty. Because the need for decompression no longer existed the cerebral hernia was reduced at operation and a tantalum plate was fixed in position.

POSTOPERATIVE COMPLICATIONS AND SEQUELLAE

Postoperative complications have been few and none were ascribable to the presence of tantalum. One patient who had a severe, soiled, compound skull fracture containing much foreign material, a few days after operation developed impetigo contagioso on the arms and scalp. Within forty-eight hours thereafter the anterior limb of the operative scar ruptured because of tension created by collected cerebrospinal fluid beneath the scalp flap. This was closed by flamed adhesive strips and an iodine-soaked cotton dental roll over the opening, and healed so that no fluid escaped thereafter. In spite of the impetigo, no infection was discovered beneath the flap in the cerebrospinal fluid collection in specimens aspirated before and following the establishment of open cerebrospinal fluid leak.
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OBSERVED REACTION OF TISSUE TO TANTALUM

In one instance revision of a wound was necessary five days postoperative due to slight displacement of the plate. Evidence at the second operation pointed to the formation of a thin, filmy, translucent, gelatinous membrane enveloping the tantalum which must have formed so early as forty-eight hours after the primary operation. Similar observations have been noted when tantalum foil or sheet metal have been examined after being in tissues or between membranes, particularly during secondary craniotomies and peripheral nerve operations. On all occasions, the envelope has been complete and loosely adherent to surrounding tissues. Microscopic examination of the thin envelope has shown it to be composed of "tangled masses of fibrin strands."

CONCLUSIONS

Tantalum metal has been found very useful in neurosurgery. It approaches the theoretical ideal plastic material for replacing lost portions of the cranium.

The nature of the minimal reaction of tissues to the presence of tantalum is advantageous in situations where it has been used. The thin, translucent membrane which forms an envelope about the metal isolates nervous tissues from surrounding tissue thus preventing fixation or traction of subsequently forming scar tissue.

The chief advantages of tantalum from a surgical point of view are its chemical and electrical inertia and ductility.

The work on plastics for repair of cranial defects may well advance cranioplasty and modify our views regarding metallic substances.

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