THE REPAIR OF CRANIAL DEFECTS WITH
ZIRCONIUM
AN EXPERIMENTAL STUDY*
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The extensive literature on the subject of the repair of cranial defects was reviewed by Grant and Norcross in 1939 and by Woolf and Walker in 1945. It is apparent from the literature that the ideal material for the repair of cranial defects should be: (a) non-irritating, both electrically and chemically; (b) equivalent in strength to that of the skull but easily adaptable to the shape and contour of any defect; (c) light in weight; (d) easily secured to the cranium by the use of inert materials; (e) non-absorbable; (f) non-toxic; (g) radiolucent; (h) unaffected by present therapeutic procedures of x-ray, diathermy, ultraviolet light and also by the extremes of cold and heat normally encountered by humans; (i) unaffected by infection; (j) inexpensive; (k) not epileptogenic or carcinogenic; and (1) should not affect electroencephalographic readings. Materials that have been used include animal and cadaver bone; autogenous osseous grafts; many foreign materials such as gold, platinum, aluminum, lead, silver, cellu-lloid, vitallium, ticonium, plexiglass, tantalum and stainless steel.

Tantalum fulfills many but not all of these criteria. It has been used in recent years by numerous surgeons for varied purposes. Zirconium, like tantalum, is an inert element with very similar physical and chemical properties. The basic characteristics of zirconium have been discussed in a preceding paper. It can be rolled into a sheet of any thickness and as thin as 0.001 inch. The plates can be made of different degrees of malleability and then further appreciably hardened by the surgeon by “work hardening” with a hammer or heating in a flame for 5 to 10 minutes followed by rapid cooling. The purpose of this experimental study is to evaluate the usefulness of zirconium for the repair of cranial defects in dogs. The surgical methods employed were similar to those used by Pudenz in his work on cats using inlaid tantalum plates, except that in this study larger cranial defects of dogs were repaired with zirconium plates, using a modified inlay technique.

Zirconium Foil. The importance of prevention of meningocerebral cicatrices in traumatic and operative wounds has been stressed by Penfield; Chao, Humphreys, and Penfield; Pudenz and Odom and Robertson and Peacher. Tantalum foil 0.001 inch has been shown by these workers to be

* The zirconium was kindly supplied to us by Foote Mineral Company, 510 Germantown Trust Co. Bldg., Philadelphia 44, Pennsylvania.
both experimentally and clinically useful in preventing meningocerebral adhesions.\textsuperscript{6,19}

As a preliminary study, zirconium foil was inserted in dural defects of 2 dogs.

**EXPERIMENTAL METHODS**

Eleven dogs were anesthetized with intravenous nembutal (veterinary Abbott) 0.4 cc. per kg. of body weight. The head was shaved and the skin prepared with tincture of iodine. Sterile surgical precautions were observed. The scalp and underlying fascia were incised in the sagittal plane and retracted laterally. An incision was then made into the temporal fascia along its attachment to the calvarium. The fascia and temporal muscle were reflected from the skull with a periosteal elevator, and a piece of bone was removed.

Of the 11 dogs 9 had cranial defects repaired with rectangular zirconium plates. Four of the plates were made less malleable by heat after being molded to the size and shape of the defect, and 5 of the plates were not heated. The other 2 dogs were subjected to different procedures. In 1 of them, the 10th dog, a small right parietal bony defect was covered by a zirconium plate, and a left-sided dural defect was filled with zirconium foil. In the 11th dog zirconium foil was inserted in a larger dural defect. Closure was performed by approximating the muscle and fascial layers with bridging interrupted alternate sutures of zirconium wire and silk in order to compare the histological reaction. In most of the dogs the skin was closed with a continuous subcuticular silk suture. In the last 2 dogs, closure was made with wire throughout, including subcuticular wire. No skin sutures were removed postoperatively. A dry dressing was fixed with liquid adhesive.

**Defects.** In 9 of the dogs a rectangular defect extending over the vertex was made with a trephine and mastoid rongeurs. Bone wax was used to control hemorrhage where necessary. The size of the defects varied from $5.2 \times 3.5$ cm. to $3.5 \times 1.6$ cm.

A piece of zirconium 0.015 inch was cut slightly larger than the defect and bent manually, aided by a mallet, to conform to the normal curvature of the skull. No perforations were made in the plate. In the midline anteriorly and posteriorly an inlay ledge was chiseled in the outer table. Annealed zirconium wire 0.008 inch was used as stay sutures to immobilize the plates in this modified inlay technique. Usually it was necessary to use only 4 sutures placed as shown in Fig. 1a and b. In 5 of the 9 dogs used for cranioplasty a regular piece of unheated zirconium 0.015 inch thick was used. In the other 4 dogs the plates, after being molded to the defect, were heated in a Bunsen burner to a red glow for 5 minutes and cooled rapidly in sterile saline. In this manner the zirconium was appreciably hardened and made less malleable. The surface of the plate was dull and slightly rough and remained so in the tissues of the dog.

No further molding was done after the heating. Eight dogs were killed by intracardiac injection of 10.0 cc. of chloroform on the 12th, 17th, 32nd, 40th, 53rd, 132nd, 141st and 149th days. One dog died on the 17th day for reasons not related to the cranioplasty.

In the 10th dog a right trephine hole was covered by an unheated 0.015 inch zirconium plate 1.8 cm. in diameter, and fixed by 2 zirconium sutures. On the left side a button of bone was removed with the Hudson drill and the underlying dura excised. A piece of zirconium foil, $1.3 \times 1.0$ cm. and 0.001 inch thick, was inserted over the dural defect and under the edges of the bone without trauma to the brain. The button was replaced without fixation. This dog died due to an overdosage of intravenous nembutal while being x-rayed on the 171st day.

In the 11th dog a left parietal oval defect, $2.2$ by 1.6 cm., was made and the presenting dura completely excised. A piece of foil, 0.001 inch thick and slightly larger than the dural defect, was inserted under the dura so as to lie on the untraumatized brain. No attempt was made to cover the bony defect and the temporal muscle was sutured to the midline. This dog was killed on the 13th day by injecting 10 per cent formalin into the common carotids.

In all dogs care was taken to leave tissue relationships undisturbed. The scalp and galea were removed by sharp dissection and the temporal muscles and pericranium incised at an appreciable distance from the plate. The bone and dura were then cut at the periphery and