THE ONE-STAGE METHOD OF CRANIOPLASTY
WITH A FOLLOW-UP STUDY

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Acrylic derivatives were employed early by odontologists for making various types of dental appliances, as well as by orthopedists.5,16 Zander, in 1940, was the first to perform a cranioplasty with methylmethacrylate (Lucite), and around the same time Kleinschmidt,11 in experiments on rabbits, demonstrated its nonirritative character. Other pioneers are Gurdjian et al.,5 Kerr,10 Kahn,9 Krüger,12 Small and Graham,15 Schorstein,14 and Woolf and Walker.20 In recent years, further investigations have been reported which favor the use of plastics.4,14,18,19 The method, however, has one drawback: it is based on the principle of impression and therefore necessitates a two-stage procedure.

THE ONE-STAGE METHOD

In 1948 the British authors Oliver and Blaine13 reported 3 cases in which they had shaped the plastic and allowed it to harden in situ. They had an observation time of 1 year and the results were successful. In 1951 Woringer et al.22 presented 15 cases and described the method in greater detail. Woringer has since been its chief advocate and, while visiting the Mayo Clinic, prompted Dodge and Craig to adopt it. The latter authors presented, in 1953, a preliminary report of their experience on the basis of animal experiments and 7 successful cases.5 Since 1952 the method seems to have been used consistently by Spence,17 though he has not described the number and character of his cases. Following a visit by Woringer to Stockholm, the procedure has been standard at our departments since January, 1953, and up to January, 1957, 51 cranioplasties had been performed. Of these cases, 46 have now been followed up and form the basis of the present investigation.

Principle. The chemical basis of acrylic plastics1 is that the molecules of methyl esters of methacrylic acid (monomer) possess the ability of additive polymerization, i.e., of uniting in long chains on dissociation of the double bond C=\(\text{C}\).

If the monomer (liquid) is mixed with its polymer (powder), a plastic paste results that can be shaped as required. For the earlier acrylic plates this mixture was placed in a mold and a countermold was applied. The two

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were then compressed by heavy clamps and placed in a water bath at approximately 70°C for 1 hour. Not until then had the polymerization terminated, leaving the prosthesis ready for use. The solution to the problem, making a one-stage procedure possible, was reached by adding certain substances, producing a redox complex, which eliminated the need for heating and compression and brought about autopolymerization that terminated within 8–10 minutes. With this rapid method, heat evolves with a temperature of between 70 and 80°C.

**Bacteriologic Studies and Animal Experiments.** Woringer has shown that the liquid (monomer) not only is sterile but also has a bacteriostatic action, tending to inhibit cultures of staphylococci, coliform bacteria and streptococci. The powder (polymer) can be used direct from the manufacturer’s package, for it is satisfactorily sterilized by addition of the liquid. Important, therefore, is to mix the substances adequately, so that the mixture will be sterile.\(^3,12,13,21,22\)

Blaine, in a series of animal experiments, found only a minimal fibrous tissue reaction to the implant. A similar result was obtained by Hoffmann\(^7\) as well as by Dodge and Craig in experiments on dogs. Woringer compared the tissue reactions from tantalum and from acrylic implants and found them to be equally slight.

**OPERATIVE TECHNIQUE**

Following exposure of the cranial defect all tissue is removed from edges of the bone, so as to permit accurate fitting of the prosthesis. The dura mater, if injured, is sutured; minor dural defects are repaired with muscle grafts and major ones with polyethylene film. In order to protect the dura mater and adjacent tissue from the heat produced at polymerization, a covering of cotton strips moistened in saline is applied. This also ensures that the prosthesis will not rest directly on the dura mater, thus leaving a space for expansion of the brain. The powder is poured direct from its container into a sterile dish in an amount commensurate with the size of the defect. The liquid is then stirred in, care being taken to ensure that all powder is incorporated in the mixture; this is important both for sterility of the plastic and for homogeneity of the finished prosthesis.

The resulting paste is initially somewhat viscose, but this phenomenon disappears after a minute or so, leaving a highly cohesive and homogeneous sheet, moldable to any shape. It can be thinned out by stretching, and conversely it can be thickened by folding. This facilitates shaping of the plastic in the defect and exact duplication of the anatomy. When the paste begins to harden, cold salt solution is poured over it, and after a further minute or so the prosthesis is removed, now retaining its shape yet still having a consistency enabling it to be trimmed with shears. Once having hardened, the prosthesis is firm, difficult to break, and has a slight degree of elasticity which prevents distortion from bending. The final trimming can now be done with a rongeur, and a few holes are drilled for fixation with stainless steel wire.

Adaptation of the prosthesis to the defect has consistently been done according to the inlay principle; only in a few cases has a layer of adequate thickness overlapped the margins of the bone by about 5–10 mm., somewhat like a lid. Some
authors drill numerous holes in the plate on the theory that it increases the stability, promotes ingrowth of connective tissue and hence better fixation, and ensures better drainage of any fluid collecting between prosthesis and dura mater. We used this procedure in only a few cases in the early part of our series.

In all cases the surgical field was powdered with dimezathine penicillin (ICI) before closure of the wound.

The procedure outlined above obviates thermal action, since the essential process of polymerization takes place outside the surgical field. A question upon which there has been some discussion concerns the degree to which the monomer in free form is irritating to the tissues and for what length of time a free monomer may be expected. In the Oliver-Blaine cranioplasties, part of the polymerization was allowed to proceed in situ after Oliver had shown that its deleterious effect on the tissues was negligible in cranioplasty. Diener\(^8\) arrived at a similar result.

The irritation from the monomer apparently is caused largely by its low pH. Woringer’s modification of the Oliver-Blaine method lies in the fact that he protects the exposed part by covering it with a sheet of amniotic tissue which acts as a barrier against the low pH. A similar procedure is suggested by Dental Fillings Limited, London, for their product Simplex-Pentocryl, which we employed in all of our cranioplasties. Krüger\(^9\) suggested polyethylene sheets as being impermeable to the monomer. We have not employed this procedure, since the plastic does not come into close proximity with the brain during the 8–10 minutes taken by the polymerization process, with concurrent heat production, and also because the amount of free monomer after the conclusion of that process is inappreciable.\(^1\)

**ANALYSIS OF CASES**

During the period from January 1953 to January 1957, 51 cranioplasties were performed by the above method. Twenty-six defects were closed at the first operation; the remaining 25 underwent secondary repair.

**Primary Cranioplasties.** The defects in this type of cranioplasty were associated with the following conditions: compound depressed fractures in 11 cases, 8 of which were frontal, 2 occipital and 1 parietal; impression fracture in 1 case; meningioma in 6; osteoma in 2; post-traumatic epilepsy with corticodural scar in 1; epilepsy following operation for cerebral tumor in 1; and intraosseal hemangioma, dermoid cyst, mucous and salivary gland tumor, and a metastatic hypernephroma of the skull each in 1 case.

In 7 of the 8 cases of compound depressed fractures, localized to the frontal region, the frontal sinus was damaged. Further, the frontal sinus had to be opened for eradication of the mucous and salivary gland tumor, and also at 2 of the operations for meningiomas because the tumors had infiltrated the bone. In each of these 10 cases the sinusal mucosa was curetted and the sinus was then plugged with muscle. In 3 cases, concomitant damage to the supraorbital ridge was repaired by reconstructing the latter with acrylic plastic.
Secondary Cranioplasties. Of the 25 cranial defects in which repair was secondary, 17 were of traumatic origin and 5 resulted from excision of the bone flap because of osteitis. Two were caused by operations for meningiomas infiltrating the bone; 1 arose from removal of a postoperative hematoma secondary to hypophysyal enucleation. The size of the defects ranged from 3 by 4 cm. to 9 by 12 cm. and averaged 5 by 5 cm. The interval between the initial defect and cranioplasty averaged 2.5 years. In the flap excisions necessitated by osteitis, cranioplasty was performed after 4–6 months.

Twelve of the defects of traumatic origin were localized to the frontal region, and at cranioplasty an open communication was found, in 2 cases, between the defect and the frontal sinus and ethmoid cells, and in 1 case between the defect and the frontal sinus alone. The supraorbital ridge was reconstructed in 1 case.

RESULTS

Immediate Results. Two of the 51 patients died during initial hospitalization. One of them was a 16-year-old youth with an enormous compound depressed fracture in the frontal region and lacerated injuries bigger than tennis balls in both frontal lobes, posteriorly involving the basal ganglia too. The other was a 57-year-old man with a defect of the frontal bone measuring 4 by 5 cm. who succumbed to concomitant thoracic contusion with multiple fractures of the ribs, pneumothorax and pulmonary hemorrhages.

Analysis of the postoperative course in the remaining 49 cases shows that only a single patient had a rise of temperature exceeding 38.5°C.

All cranioplasties healed uneventfully. In 3 cases the skin flap had to be punctured for a moderate subgaleal hematoma.

Spinal fluid collected beneath the flap in 6 patients. Of these, all of whom had more or less extensive dural injuries at the time of cranioplasty, the phenomenon subsided after 1 week in 2, after a month in 1, and not until a year had elapsed in 2. These last 2 patients, who had been operated on for parasagittal meningiomas infiltrating the bone, had pronounced dural defects which, as at the original operation, had to be covered with polyethylene film. In the sixth patient, a persisting fistula had to be surgically closed 8 months after the operation.

Two patients underwent further operation for rhinorrhea 3 weeks and 4 months respectively after the cranioplasty. In the first of them there was leakage from the ethmoid cells. The surgical approach was via a bone flap; the acrylic plate was found to have produced no tissue reaction. In the other case the frontal sinus had to be replugged, and here too the acrylic plate had caused no untoward effect on the tissues; however, it was necessary to remove and replace it, since it had been shaped into the frontal sinus.

Late Results. At the follow-up in January and February, 1957, there had been 1 further death. The patient in question was a 60-year-old woman who had been operated on for a metastatic hypernephroma of the skull and who succumbed to further metastases 5 months after the cranioplasty. Two pa-
tients were untraceable. Of the remaining 46 cases followed, the cranial defect had been repaired at the first operation in 22 and at a second operation in 24.

During the 4-year period in which the method has been applied, our indications have tended towards the greater use of acrylic plastic for immediate repair.

Eleven of the primary cranioplasties were concerned with compound depressed fractures. Two of these patients died, the respective causes of death being extensive cerebral injuries and chest injuries. Five of the remaining 9 patients had concurrent fracture of the frontal sinus. In 3 operations for tumors, in which the bone defects were subjected to primary repair, there was contamination from the sinus. A similar condition was present in 3 of the 24 secondary cranioplasties.

In the entire series only 1 complication occurred that could have been referable to the acrylic plastic and which necessitated removal of the prosthesis.

The cosmetic results were excellent in 43 of the other 45 cases. In 1 patient the surface of the acrylic plate was slightly irregular and in another it should have been a little more curved.

A female telephone operator with a prosthesis 4 by 5 cm. parietally over the right ear was distressed by pain as soon as she put on the headphones. Follow-up examination revealed a suture granuloma that was very tender to pressure.

Four patients complained of moderate pain localized to the prosthesis. Three of them had undergone secondary cranioplasty and one of the pre-operative symptoms had been headache localized to the defect. The fourth patient had been operated on for a large frontal compound fracture involving the frontal sinus and roof of the orbit.

**DISCUSSION**

The use of bone in craniplastic operations is naturally the most physiologic method. Yet the surgeon of today, confronted with a steadily increasing number of severe head injuries caused by domestic, industrial and street accidents, has to contend more and more with problems in which the methods hitherto employed for repairing cranial defects are inadequate.

In comminuted fractures, repositioning of numerous small fragments in the defect may present major technical difficulties. Fixation of the fragments is often instable, so that the reconstructed area later becomes depressed. The danger of resorption of individual fragments cannot be disregarded, and there is a considerable risk of infection, notably in the region of the paranasal sinuses.

If autogenous grafts have to be used, there are the difficulties of shaping them exactly to fit the defect; indeed, repair of large defects with bone grafts may be impracticable. In traumatic cases, operations of major extent may be inadvisable, since two procedures are required; in order to keep the operat-
CRANIoplasty with acrylic plastic

ing time to a minimum two surgical teams are necessary. The method with homologous frozen cranial grafts, obtained from a bone bank, may perhaps eliminate the last-named reservation, but the danger of resorption and infection will still remain.

Of the relevant alloplastic materials, tantalum, Vitallium, stainless steel and acrylic derivatives seem to be equal with respect to their nonirritating properties. The metals, however, are technically far more difficult to handle besides being radiopaque. With the introduction of the rapidly polymerizing acrylic derivatives that enable a cranioplasty to be completed in one stage, the question as to the most appropriate substitute for bone has assumed quite a different aspect. We possess today a method which, for simplicity and reliability, is superior to all others. It is surprising, therefore, to find it has come so little into use, judging from the few papers published hitherto.

All of the present series of 51 cranioplasties healed uneventfully. Of the 46 that were followed up, there was only 1 case of supervenient infection that necessitated removal of the plate. It is debatable, however, whether this complication may be attributed solely to the acrylic plastic, for the inflammatory process may equally well have originated from a polyethylene film.

The cosmetic results were excellent in all except 2 cases. In these 2 patients the acrylic plate was difficult to shape (restoration of the supraorbital ridge); the results, however, must be regarded as satisfactory.

Orthopedists (Judet, in Lisbon, 1953) have pointed out that acrylic protheses do not tolerate the loads to which they are subjected; they become deformed. In cranioplasty we are concerned with entirely different static factors. In the present investigation nothing has emerged to suggest that acrylic plastic is insufficiently strong. On the other hand, a case was reported recently in which an acrylic plate fractured as a result of a direct trauma. It was situated directly over the convexity and had broken when the wearer’s head struck the roof of an automobile in a collision. The thickness of the plate was not stated, but the photograph published suggests that it was thin. One of our patients suffered a heavy direct trauma which the plate withstood. The above report nevertheless provides food for thought, and it would be interesting to try adding glass fibers to the plastic with a view to increasing its strength.

All authors who have worked with cranioplasty agree that it is contraindicated by the presence of an open communication between the frontal sinus and the defect. Similarly, it is cautioned against in cases of compound depressed fractures. We have subjected defects of this type to primary repair with acrylic plastic, and our experience has been so satisfactory that the procedure is now routine. Moreover, we now use acrylic plastic initially in all cases of relatively extensive loss of bone that may arise at operation.

SUMMARY

1. The principles and operative method for the use of rapidly polymerizing acrylic derivatives (Simplex-Pentoaryl) are described.
2. During the 4-year period from 1953 to 1956, 51 cranial defects in as many patients were repaired by this method. Of 46 cases followed up, the defects had been subjected to primary repair in 22, including 9 cases of compound depressed fractures. The frontal sinus was involved in 5 of these cases and in 6 nontraumatic cases, in 3 of which secondary repair was done.

3. In all cases healing was uneventful. There was only one complication (infection) necessitating subsequent removal of the plate, and it is debatable whether it had been caused by the acrylic plastic as a foreign body.

4. The method is technically very simple, reliable and, on critical appraisal, appears to be superior to other types of repair.

5. We now use it routinely in cases of compound depressed fractures, even when the frontal sinus is involved, and also in primary repair of defects caused by loss of bone associated with operation.

REFERENCES

2. Dienner. Cited by Krüger,12