Late surgical treatment of unilateral coronal synostosis using methyl methacrylate

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Three techniques combining the shaping of calvarial and facial bone with onlay of methyl methacrylate are presented for use in the late treatment of unilateral coronal synostosis deformities. The procedures described are suggested as possible alternatives to extensive bone repositioning procedures. They have the advantage of being quicker and are therefore potentially safer operations. Acrylic is malleable and does not resorb; thus, permanent superior esthetic results may be achieved. The two most serious risks when using this technique are infection and limitation of growth. The risk of infection may be reduced by attaching the acrylic implant securely to surrounding bone, under sterile conditions, beneath well-vascularized skin. Growth limitation may be obviated by not placing acrylic across sutures in children with enlarging skulls.

Key Words • methyl methacrylate • cranioplasty • coronal synostosis • craniofacial reconstruction

Unilateral coronal synostosis is characterized by premature closure of one-half of the coronal suture and consequent bilateral deformity of the cranial vault, the cranial base, and the orbitonasal region. Early surgical treatment, during the first few months of infancy, is the most effective treatment in reversing the distortion. Occasionally, some patients with unilateral coronal synostosis seek medical help at a more advanced age. Because the positive correcting influence of brain growth and the regenerative capacity of the cranial bone diminishes after infancy, this class of older patients requires a different surgical approach. One technique involves mobilizing and reshaping the frontal bone, orbits, and nasoethmoid complex.

Some older patients and those who desire improvement upon the results of previous corrective surgery may be unwilling to undergo extensive osteocranioplasty procedures. They may, however, obtain excellent correction from operative approaches that produce much less morbidity. In this report, three attractive and tested alternative techniques are presented for the treatment of such patients. By combining the application of acrylic with contour reshaping of the frontal bone, the surgeon may offer a safe, quick, and reliable means of creating an esthetically pleasing appearance.

Operative Techniques

Unilateral coronal synostosis results in ipsilateral flattening of the frontal and parietal bones and bulging prominence of the contralateral frontal and parietal bones. Vertical orbital dystopia and deviation of the nasal radix are also characteristic features. Treatment of the skull deformities may follow one of three approaches: 1) methyl methacrylate (acrylic) augmentation of the frontal bone and supraorbital ridge ipsilateral to the stenosed coronal suture and burring down of the excessively prominent frontal bone contralateral to the stenosed suture (Fig. 1 left); 2) full-thickness removal of the protruding contralateral frontal bone, in combination with contralateral dural plication, and the augmentation of both frontal areas with acrylic (Fig. 1 center); or 3) bifrontal full-thickness osteotomy, contralateral dural plication, and bifrontal onlay of acrylic (Fig. 1 right).

The selection of one of these three approaches depends on three considerations: the patient's age; the condition and thickness of the bulging section of frontal bone; and the degree of deformity. The severity of the deformity is the most significant factor in the selection of the procedure. In mild cases of frontal asymmetry, shaving of the protruding frontal bone contralateral to
FIG. 1. Schematic diagrams showing three methods of repairing skull asymmetry due to unilateral coronal synostosis. Left: Acrylic augmentation is placed on the hypoplastic frontoparietal region, and the contralateral frontal bone prominence is reduced by shaving the bone. Center: The protruding frontal bone is removed and acrylic is applied bifrontally. Right: Frontal bone is removed bilaterally, the dura is remodeled, and subsequently acrylic is applied bifrontally.

the fused half of the coronal sutures and acrylic augmentation of the recessed frontal bone ipsilateral to the fused coronal sutures corrects the appearance. However, in cases with more marked deformity, where the projection of the contralateral frontal bone exceeds the total thickness of the bone, the protruding section of bone is removed and the dura is plicated until the shape is normal. Acrylic is then applied bifrontally, substituting acrylic for the resected contralateral bone and augmenting the ipsilateral bone. In rare cases of extreme asymmetry in which a large volume of the contralateral brain must be displaced posteriorly by dural plications and the frontal bone region ipsilateral to the stenosed coronal suture remains significantly depressed, bifrontal osteotomy and (on rare occasions) release of the ipsilateral dura by fascia grafting is followed by insertion of a bifrontal acrylic implant.

The second consideration, the thickness and condition of the frontal bone, affects whether and how much acrylic is required. If shaving off the outer table and diploe of the protuberant frontal bone contralateral to the stenosed coronal suture is insufficient to remove the frontal bossing and provide forehead symmetry, then the full thickness of the protuberant bone is removed and replaced by methyl methacrylate. Preoperative radiography will give a measure of bone thickness that may be safely removed. At the time of surgery, percussion of the remaining bone with the handle of a chisel will aid in judging the thickness and strength of remaining calvarial bone. Dural plication precedes the application of methyl methacrylate to create a flattening of the surface in the region where there had been excess projection. This is done to allow for the placement of a sufficiently thick and structurally sound acrylic plate. Alternatively, if the bone is lined with fissures, is very thin, or is so malformed as to make shaping impossible, acrylic is substituted for it without hesitation.

The patient's age is another important consideration in the selection of operative technique. In children under 3 years of age the use of acrylic across a vault suture line may restrict skull growth. Cranial bones grow primarily by the deposition of bone at sutureal edges; crossing a growing suture with a bridge of acrylic may cause secondary deformities.\(^\text{15,17}\) Therefore, the use of acrylic in children under the age of 3 years is not advocated except under unusual circumstances.

In children over 3 years of age, limited, judicious placement of acrylic in regions of minimal growth is performed when indicated to maintain special features of contour, such as projection of the supraorbital rim area. Although contour remodeling occurs throughout the cranial bones in children, the supraorbital ridge develops relatively early, and does not grow significantly after early childhood. Acrylic onlay to this region is not likely to adversely affect the developing cranium. Skull contour irregularities are treated in these patients like those in the "adult" skull category (that is, without allowances for further skull growth).

The above three considerations determine our approach to correcting skull asymmetry associated with unilateral coronal synostosis in the child or the adult. The technique is flexible and can be modified to suit each patient's condition.

**Case Reports**

**Case 1**

This 28-year-old woman had a history of facial deformities since childhood. This observation was con-
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Fig. 2. Case 1. Left: Preoperative appearance of the patient with forehead and periorbital asymmetry. Right: Postoperative appearance.

Confirmed by family photographs. Forehead asymmetry, deviation of her nose, and vertical orbital dystopia had become more noticeable with increasing age and were esthetically displeasing to her. She reported the psychological stresses of not having had correction of her deformity in childhood. Her medical history, including her prenatal history, was otherwise unremarkable.

Examination. Physical examination showed frontal and temporal region asymmetry with flattening of the left forehead; significant vertical dystopia, with the left orbit 4 mm higher than the right; and deviation of the nasal radix to the left (Fig. 2 left). Neurological examination was normal. Plain skull radiographs were diagnostic of left coronal synostosis.

Operation. Under local anesthesia, a bicoronal incision was made and the anterior skin flap was reflected forward to the frontal nasal suture. Nasal osteotomies and transposition of the nasal radix to the midline were carried out (Fig. 3). Wire, secured to surrounding bone edges, was looped multiple times over the left cranial defect (Fig. 4). Methyl methacrylate was applied over the defect and wire scaffolding. Prior to complete polymerization, the acrylic was shaped over the cranial defect to augment the left frontal, temporal, and orbital regions for calvarial symmetry. The excessively prominent right frontal bone was recessed by burring down the outer table of the skull bone.

Postoperative Course. The patient exhibited mild nasal asymmetry. She also had a long-standing bilateral

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laxity of the eyelid skin. A nasal revision and an upper-lid blepharoplasty were performed 3 years later. Six years postoperatively the frontal forehead area of the remains symmetrical. Absolute vertical dystopia is still present but has been satisfactorily masked by facial midline revision (Fig. 2 right). The patient's psychological response has been excellent and she is pleased with the improvement in her facial image.

**Case 2**

This 5-year-old girl was the product of an uncomplicated pregnancy and normal vaginal delivery. Physical examination at birth was described as normal, except for the presence of congenital esotropia. Her family doctor noted asymmetry of the frontal regions at the age of 6 months, but skull films did not demonstrate sutural stenosis. Her congenital esotropia was treated with inferior oblique myomectomies and recession of the recti lateralis muscles at 13 months of age. Frontal skull asymmetry continued to become more prominent, and she was referred to the University of Virginia Craniofacial Anomalies Clinic at 3 years of age.

**Examination.** Examination revealed flattening of the left frontal portion of the forehead with recession of the supraorbital ridge, a shortened left lateral orbital wall, and moderate right frontal bossing (Fig. 5 left). The nasal radix was deviated to the left. The remainder of her physical examination was normal. A computerized tomography scan of the head did not reveal any intracranial pathology.

**Operation.** Following adequate exposure of the frontal regions and orbital rims via a bicoronal incision, a right frontal craniectomy was performed. Upon removal of the bone flap, the brain and dura bulged outward. The dura was plicated to provide an optimal contour. Steel wire scaffolding anchored to the surrounding bone edges was placed over the left frontal defect and right frontal craniectomy. Methyl methacrylate onlay was applied over this wire scaffolding and allowed to polymerize. The acrylic was molded to augment the left frontal region and left orbital rim (Fig. 6). The contour of acrylic over the right frontal craniectomy was sculptured with a shaping burr to produce symmetry of the frontal areas. The deviated nasal bridge was reduced by nasal osteotomies and fixed in the midline with steel wire.

**Postoperative Course.** Symmetry of the frontal, temporal, and supraorbital regions with only mild vertical dystopia was noted at 7 months after surgical correction. This satisfactory result has continued 2\(\frac{1}{2}\) years following surgery (Fig. 5 right).

**Discussion**

While the pathogenesis of unilateral coronal synostosis is unknown, the resulting deformity is always bilateral and has often been documented.
Restriction of growth at the stenosed half of the coronal suture is associated with flattening of the ipsilateral frontal bone and lateral superior orbital ridge, and shortening of the anterior-posterior length of the anterior cranial fossa. The developing brain induces compensatory growth of the frontal and parietal bones on the contralateral side. This produces contralateral frontal bossing and a prolapse of the roof of the orbit and the supraorbital ridge. The excessive growth of the frontal bone on the contralateral side is associated with flattening or lack of development of the normal convexity of the supraorbital ridge on the side of suture stenosis. One factor that accents the appearance of vertical dystopia in the patient’s face is the slanting of the nasal radix toward the side of the involvement. This increases the angle between the interpupillary and vertical facial midline planes. Current treatment of unilateral coronal synostosis in infants has centered on osteotomy and reshaping of the contralateral frontal bone and advancement of the ipsilateral forehead and supraorbital ridge, with the hope that the brain’s subsequent development will shape the skull normally.

Patients over 1 year of age require a very different therapeutic approach because brain growth, so helpful in shaping the skull of infants, is significantly reduced after 1 year of age. During the 1st year of life the brain mass doubles; it increases to 80% of its adult size by 3 years of age and to 95% by 5 years of age. Therefore, individuals with cranial deformities beyond 5 years of age require corrective reshaping or repositioning techniques that do not rely on growth of the brain to normalize skull shape. In these older patients, skull deformities must be corrected to normal adult dimensions. Tessier recommends displacement and reshaping of both orbits, the nasoethmoid complex, and the nasal pyramid, as well as bilateral frontal craniotomy. This procedure addresses the bilateral nature of the deformity and yields esthetically pleasing results, but entails a lengthy operative procedure. Because of the risks unavoidably accompanying such a major craniofacial operation, a quicker, safer, and less traumatic procedure is desirable for those patients with less severe deformity and good eye function who desire solely esthetic improvement. With the use of acrylic materials for vault reshaping, we are able to achieve results that are reliably superior to those we have achieved with any other technique. The operative procedures using the acrylic materials are shorter in duration and less invasive than other procedures using autogenous materials, thus further reducing both cost and operative risk.

The traditional alternative for reconstruction of skull defects has been by autogenous bone grafts from the rib, iliac crest, or calvaria. Of the three donor sites the calvaria offers certain advantages. Procuring bone from the rib or iliac crest requires a second operative site. The endochondral bone from rib or hip resorbs significantly more rapidly than does the membranous bone available in the calvaria. Zins and Whitaker have shown that endochondral bone grafts resorb three and four times as fast as membranous bone grafts in rabbits and monkeys, respectively. Since resorption of endochondral bone grafts is both significant and unpredictable, this type of bone is less suitable for reconstructing such a highly visible area of the cranium as the forehead. Membranous bone from the parietal or frontal bones may be harvested through the same bicoronal incision needed to correct the unilateral coronal synostosis vault deformities. However, even membranous bone grafts have significant drawbacks as reconstructive materials. Compared to methyl methacrylate, suitable bone of appropriate thickness is much more difficult to obtain and to shape. Also, membranous bone grafts do resorb. Although they advocated membranous bone use, Zins and Whitaker found volume decreases of 19.5% and 17.2% in membranous onlay grafts in rabbits and monkeys, respectively. We have already observed major absorption of calvarial bone grafts in humans, with no clinical evidence of sepsis or other complications that might account for the loss of bone. While this resorption is far less than endochondral graft resorption, it is unpredictable and can cause significant structural and esthetic defects.

Methyl methacrylate was chosen from a selection of possible metallic, synthetic, and biogenic reconstructive materials. Implants of stainless steel, Vitallium, and tantalum, which have commonly been placed in the cranium, provide protection for the brain, but their rigidity makes them unsuitable for molding the fine contours necessary in craniofacial reconstruction. They also produce troublesome electrical field changes and may loosen or develop serous effusions years later. On the other hand, silicone and Proplast, which are easily

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**Fig. 6. Case 2. Intraoperative view of acrylic augmentation of the hypoplastic left frontal region. The thickness of the bone in the right frontal region has been reduced by shaving.**

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molded, lack the structural strength needed for covering a large area of resected bone and do not establish a firm mechanical union with host bone.

Methyl methacrylate has proved suitable for fashioning a permanent skull contour as well as for protecting the brain. Unlike other alloplastic implants, methyl methacrylate is both extremely plastic and hard; while unpolymerized it can easily be applied to the defect and molded intimately to wires anchored in the calvaria; and when polymerized it fixes itself permanently in position with the contour the surgeon has created. Absolute fixation to bone is a key to prevention of complications in the use of methyl methacrylates implants.

To secure an onlay of methyl methacrylate, wire is threaded through the outer calvarial table and twisted into multiple thickness loops which are enveloped by the acrylic paste.22 When acrylic replaces a large volume of bone, a framework of wires crossing the defect and anchored to the surrounding bone edges provides excellent support. Beveling into surrounding diploe adds to the stabilization of the bone flap. Lake, et al.10 compared the "resistance to shattering" of methyl methacrylate plates and calvarial bone discs. They concluded that acrylic is at least as strong and, in many cases, stronger than the bone. This strength also enables the surgeon to achieve details of contour with a very thin sheet of acrylic and to form an unobtrusive junction of the implant with the bone.

Complications of methyl methacrylate craniofacial implants include toxicity, necrosis of overlying skin, infection, and mobilization. The toxicity of methyl methacrylate, particularly the liquid monomer when used in large volumes, has been documented in animal studies and in orthopedic surgery.2,3,13,20 Toxicity has not been reported in craniofacial surgery, perhaps because of the relatively small total quantity of methyl methacrylate used in any individual patient. As a precaution against the possibility of toxicity, excess monomer should be vaporized before the acrylic is implanted.

Morbidty from necrosis of the overlying skin is rarely encountered in this procedure since the forehead skin is generally thick, well vascularized, and immobile. However, abnormally thin skin or skin having a poor blood supply may not withstand the implantation of a significant amount of acrylic.5 Proper anchoring and a smooth contour of the implant reduce the risk of necrosis. Also, we have used flaps of galea and temporalis fascia between the acrylic and thin forehead skin when the latter has been badly scarred.

Infection can develop if the acrylic implant is situated in direct communication with a continuing source of contamination such as the paranasal sinuses. It may also develop in crevices resulting from a poor fit between bone and acrylic or in empty pockets left between the implant and the dura. The adhesive surfaces of the bone should be as clean as possible to receive the acrylic and form a continuous bond with it. Any potential dead space between the implant and the dura should be filled with acrylic to prevent the formation of an environment suitable for infection.

Infection is a rare occurrence when methyl methacrylate is used properly in craniofacial surgery. In 1948, White24 reported a case in which infection necessitated the removal of an acrylic implant, but incidences of such major infection are conspicuously absent in the subsequent literature.14,19,21 Nevertheless, prophylactic administration of antibiotics and irrigation of the implant with bacitracin solution is standard procedure.

In summary, acrylic onlay and inlay methods of frontal and temporal bone reconstruction are offered as rapid and reliable means of achieving consistently good results in vault shape reconstruction. Used in the proper setting of good vascularity and thickness of overlying skin, sterile conditions at placement, and good immobilization by securing the acrylic to surrounding bone, this technique may give outstanding esthetic results with minimum morbidity. These results have continued to remain excellent in some patients for over 15 years of follow-up monitoring in our Craniofacial Anomalies Center.

References

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