Multiple-revolution spiral osteotomy for cranial reconstruction

Technical note

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Various combinations of cranial remodeling techniques are used in an attempt to provide optimal cosmetic results and to reduce possible sequelae associated with craniosynostosis. One element of deformity that is difficult to correct directly is an overly flattened area such as that found in the parietal area in sagittal synostosis, unilaterally in lambdoid synostosis, or even in severe positional molding. The authors present a novel application for recontouring cranial bone, namely the multiple-revolution spiral osteotomy. The advantages of this technique include the avoidance of large areas of craniectomy and immediate correction of the cranial deformity. The surgical procedure, illustrative cases, early results, and apparent benefits of this technique are discussed.

Key Words • spiral osteotomy • craniosynostosis • cranial defect • modeling technique

Premature fusion of cranial sutures or craniosynostosis may produce a variety of cranial deformities. Patients with these defects, as well as those with positional molding deformities, are frequently referred for pediatric neurosurgical and plastic and reconstructive surgical evaluation. A variety of surgical techniques and procedures have been previously described and are currently used for remodeling cranial and facial bone. These different methods are occasionally modified or combined in an attempt to provide optimal results. We describe a previously unreported technique for remodeling cranial bone known as multiple-revolution spiral osteotomy. This technique was used in two cases of scaphocephaly secondary to premature sagittal suture synostosis and one case of posterior plagiocephaly.

Illustrative Cases

Case 1

This 14-month-old boy was referred for neurosurgical evaluation after a diagnosis of premature sagittal synostosis was made. At presentation his head was scaphocephalic, with minimal frontal bossing and a marked reduction in biparietal diameter. In addition, a prominent projection of the occipital convexity was noted, although there was no evidence of a saddle deformity. His head circumference was in the 98th percentile, but the child was mildly developmentally delayed. The clinical diagnosis was confirmed on CT scanning, which also revealed a marked reduction in normal cerebral convolutional patterns over both parietal convexities. Ophthalmological evaluation revealed the absence of papilledema. After discussing with us the clinical findings and diagnosis the family elected to proceed with surgical management.

Case 2

This 8-month-old boy was referred for evaluation of cranial dysmorphia. Clinical and radiographic evaluation confirmed the diagnosis of premature metopic and sagittal suture synostosis. Clinical examination revealed a palpable midline sagittal ridge extending from the hairline to the lambda; the metopic portion of the ridge was not a cosmetic issue. The child’s head was scaphocephalic with a very narrow biparietal diameter, and there was a moderate prominence of the occipital region. The patient had reached age-appropriate developmental milestones. Surgical intervention was undertaken.

Case 3

This 21-month-old girl was referred for evaluation of left posterior plagiocephaly. The child had been recently adopted from a Russian orphanage, where she had received no treatment for this problem. Clinically the child had a slight forehead and facial asymmetry, with the left side of the face more prominent than the right; the left ear

Abbreviation used in this paper: CT = computerized tomography.
was located 1 cm anterior compared with the right ear. Results of radiographic evaluation confirmed the diagnosis of internal ridging of the left lambdoid suture consistent with functional closure of the suture. The findings were discussed with the family and they agreed to surgical intervention.

**Operative Procedure**

**Cases 1 and 2**

In Cases 1 and 2 the surgical procedure was performed with the patient lying prone on a well-padded chest support and horseshoe headrest. Cranial access was provided through a sinusoidal vertex scalp incision. Biparietal bone flaps were cut, preserving a 2.5-cm-wide bone strut in the midsagittal plane. The spiral design was then drawn on each bone flap. A high-speed drill (Medtronic Midas Rex, Fort Worth, TX) with a C-1 attachment was used to create a superficial groove along the lines of the pattern. Full-thickness drilling was then initiated, leaving occasional small segmental bridges to help prevent inadvertent fracture. Finally, these small bone bridges were removed, creating a single continuous spiral. The center of the spiral osteotomy was positioned slightly posterior to the center of the parietal bone flaps. The osteotomy attained a somewhat oval shape as it projected anteriorly toward the coronal suture. The elevation and degree of convexity of the spiral was maintained with absorbable fixation plates and screws (Lactosorb; W. Lorenz Surgical, Jacksonville, FL.). Widening of the cranial base in the posterior temporal region and also at the occipital bone was accomplished with small barrel-stave osteotomies. Each recontoured parietal bone was then returned to its original position, with slight elevation or lateral deviation of the posterior edge of the flap (Fig. 1). The flap was then affixed to the surrounding bone with the absorbable plating system. Bone dust and/or fragments obtained from the osteotomies was used to fill the largest bone-deficient area, located at the posterior edge of each craniotomy flap. The scalp was then reaproximated over a closed-suction subgaleal drain.

**Case 3**

The operative procedure used in Case 3 was performed in a similar fashion as described earlier, with minimal modifications. The design of the spiral was customized to provide optimal contouring; only the area of reduced convexity was treated. Because of increased bone thickness the osteotomy was angled outward 45° from the line perpendicular to the bone flap, starting with the outer table.

**Discussion**

Many surgical methods have been described for correction of cranial and facial dysmorphism associated with various forms of synostosis and severe positional molding deformities. Most of these are used in patients at an early age to take advantage of progressive skull and brain growth. Surgical procedures performed early in the course of premature synostosis have traditionally featured some degree of bone removal, craniectomy, or suturectomy to allow for correction of the deformity coincident with cerebral and cranial growth. These procedures take advantage of the great potential exhibited by young infants to fill and close calvarial defects. Occasionally, significant postsurgical cranial defects persist, even in young infants. This situation is even more likely to occur when surgical correction is delayed.

Because the potential for spontaneous cranial reshaping after surgery is a function of the remaining growth potential as well as the severity of the deformity, older children and those with more severe defects have typically been the ones treated with more extensive surgical approaches. However, lack of predictability and variable outcomes have prompted increased use of these more extensive operations, even in younger patients, to provide optimal cosmetic results as well as neurological and developmental outcomes. These more extensive procedures have been well described in the literature; they commonly combine various component techniques for cranial and/or facial remodeling to tailor the operation to the specific deformity. These component techniques for craniofacial remodeling commonly include various types of osteotomy and microfracture bending, or greenstick fracturing, to achieve bone reshaping. Other described methods include bone-strip or bone-plate repositioning.
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and split calvarial bone grafting. Results are dependent on the severity and extent of the deformity, its duration, the type of procedure used for correction, and the age of the patient. In addition, coexisting conditions such as various metabolic derangements or hydrocephalus may affect outcome.

With cranial reshaping, an area of difficulty has been the correction of an excessively flattened or even concave surface. A widely used method to achieve increased (or decreased) curvature is radial osteotomy with molding. Alternatively, multiple-strip craniectomies may be performed, followed by reshaping and repositioning. Another technique, described as the "gore method," uses osteotomies that are placed in a counter-cut fan pattern to allow for bone bending. Recontouring strip craniectomies or segments in older children with more mature bone may require multiple partial-thickness channel osteotomies and reshaping. A modification of the radial osteotomy technique is the barrel-stave osteotomy, which is commonly used to increase the width of the cranial vault in areas of bone flattening or constriction. This is most frequently applicable to the skull base and at peripheral bone edges.

As a result of our concern about earlier procedures for increasing the convexity of cranial bone, particularly in the parietal region in some patients with sagittal synostosis, we evaluated other methods with the potential to optimize reshaping, including concentric-Ω and concentric-U osteotomies (Fig. 2). These procedures are relatively inflexible and do not allow for curvature to be readily adjusted at the apex. In attempting to address these deficiencies, we developed the multiple-revolution spiral osteotomy technique. Several advantages were realized in using this approach. First, the technique provides considerable flexibility with regard to the correction of excessively flattened cranial bone. Adjustments may be made in both the construction of the spiral (for example, oval compared with round) and in the location of the center of the spiral. Second, aside from the small kerf created by the drill bit, there is minimal bone loss and avoidance of large areas devoid of bone. Third, adjustments in the amount of curvature may be made separately in all directions (anterior, posterior, superior, and inferior). In the two cases of scaphocephaly the apex of the convexity was positioned more posteriorly in the parietal bone flap to correct an area of extreme constriction or narrowing. A slightly oval or elongated spiral was used to provide the needed convexity shaping in the anteroposterior direction compared with the shorter length necessary in the vertical dimension. In addition, the width of the bone segments in the central portion of the spiral had to be narrower than the outer segments to allow for easy elevation and positioning. The extent of projection of the spiral was easily adjusted, however limited by difficulties with skin edge reapproximation. An additional consideration is that as the projection of the spiral is increased, the distance between the bone segments also increases, with a potentially reduced capability for bone bridging and reossification. In our second and third patients, the osteotomy itself was angulated; this provided for reduced ridge prominence at the peripheral edge of each spiral segment. It also allowed for bone-to-bone reapproximation for a portion of the thicker outer spiral segments. The remaining small open area was completely filled with bone fragments and dust obtained from the osteotomy. Because of the older age of the patient in Case 3, we applied longer term absorbable fixation (Medtronic-MacroPore, San Diego, CA) to provide a better chance for bone bridging and reossification.

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In a subsequent review of published procedures for cranial recontouring, we found a two-revolution spiral osteotomy technique described by Salyer and Bardach. In their report, the osteotomy was combined with additional procedures for total cranial vault remodeling of scaphocephaly caused by sagittal synostosis. The center of the wide-segment osteotomy was placed in the midline at or near the cranial vertex. The spiral consisted of a two-revolution oval osteotomy with the widest portion of the oval placed laterally to provide for parietal eminences that previously were lacking. The spiral was used to shorten the anteroposterior diameter and to reduce the convexity superiority by allowing these few wide segments to collapse. No fixation device was applied to the spiral segments. The multiple-revolution spiral osteotomy that we describe differs in many respects when compared with the two-revolution osteotomy described by Salyer and Bardach. These differences include size, location, appearance, application, and the implementation of absorbable semirigid fixation.

In the three cases described here, we achieved immediate, direct correction of the cranial deformity by producing an increase in convexity in the area of deformity by using multiple-revolution spiral osteotomy and recontouring. This procedure also provided for resolution of cerebral compression by increasing intracranial volume. An increase in head circumference of 2 cm in Case 1, 2.5 cm in Case 2, and 1.5 cm in Case 3 was noted 4 weeks after the procedure. The early results of this technique are en-
Fig. 3. Case 1. Photographs showing immediate preoperative appearance of the head with the patient in the prone position (left), and vertex (center) and posterior (right) postoperative appearances at 6 months.

Fig. 4. Case 2. Photographs showing immediate preoperative appearance of the head with the patient in the prone position (left), and vertex (center) and posterior (right) postoperative appearances at 4.5 months.

Fig. 5. Case 3. Photographs showing immediate preoperative appearance of the head with the patient in the prone position (left), and vertex (center) and posterior (right) postoperative appearances at 4.5 months.
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Encouraging, as noted at follow-up clinical and radiographic examination. Follow-up evaluation in all three cases was performed between 4 and 6 months postoperatively. Clinical examination revealed excellent contouring and no palpable skull defects or ridging (Figs. 3–5).

Independent review of all pre- and postoperative images was performed by a neuroradiologist, who examined CT axial and three-dimensional reconstructions (axial images were most sensitive for assessment of fusion and/or reossification). Review of CT scans in Case 1 revealed that immediate postoperative cranial defects or gaps were 85% reossified on the left side and 75% on the right at 6 months. Review of scans in Case 2 revealed 75% reossification on the left side and 80% on the right at 4.5 months. Radiographic review in Case 3 revealed 70% reossification at 4.5 months postoperatively. Follow-up radiographic evaluation alleviated our initial concerns about potential residual step-off deformities between adjacent spiral segments (Figs. 6 and 7). Only in Case 3 was there minimal radiographic evidence of subtle residual ridging at 4.5 months postoperatively. It appears that remodeling, as well as bone bridging and reossification, readily occurs, allowing for development of a new and relatively smooth contour. We believe that the use of absorbable fixation devices is important to maintain the contour and elevation of the spiral segments as this process occurs. In the youngest of the three patients (Case 2), the bone flap was not fixed to the midline bone strut, which allowed some dynamic growth to occur in this area.

When we submitted this paper we had performed 17 multiple-revolution spiral osteotomies in 10 patients whose ages ranged from 7 to 23 months. We have performed this procedure for various cranial deformities, including scaphocephaly, posterior plagiocephaly, and brachycephaly. There have been no immediate complications, with good immediate correction of the existing cranial deformity. Follow-up data are not yet available for all 10 patients; this information will be forthcoming. We believe that multiple-revolution spiral osteotomy provides an additional and/or alternative technique for cranial remodeling. This technique, used in combination with already published procedures, may provide for improved cosmetic results, especially in patients whose presentation and, therefore, treatment have been delayed.

FIG. 6. Case 2. Axial bone window CT scans obtained through the midparietal region. Preoperative scan (left), immediate postoperative scan (center), and follow-up scan (right) obtained at 4.5 months.

FIG. 7. Follow-up three-dimensional CT scans demonstrating remodeling, reossification, and normal contour. Upper: Case 1. Right and left oblique views. Center: Case 2. Right and left oblique views. Lower: Case 3. Vertex and posterior views.
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