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PRS GLOBAL OPEN

ORIGINAL ARTICLE

Pediatric/Craniofacial

Modification of the Melbourne Method for Total Calvarial Vault Remodeling

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Background: Sagittal synostosis is the most common form of single suture synostosis. It often results in characteristic calvarial deformities, including a long, narrow head, frontal bossing, a bullet-shaped occiput, and an anteriorly placed vertex. Several methods for correcting the phenotypic deformities have been described, each with their own advantages and challenges. In this study, we describe a modification of the Melbourne method of total calvarial remodeling for correcting scaphocephaly.

Methods: We conducted a retrospective review of all consecutive patients who underwent total calvarial remodeling using a modified version of the Melbourne technique from 2011 to 2015. We evaluated clinical photographs, computed tomographic imaging, and cephalic indices both pre- and postoperatively to determine morphologic changes after operation.

Results: A total of 9 patients underwent the modified Melbourne technique for calvarial vault remodeling during the study period. Intraoperative blood loss was 260 mL (range, 80–400 mL), and mean intraoperative transfusion was 232 mL (range, 0–360 mL). The average length of stay in the hospital was 3.9 days. The mean cephalic indices increased from 0.66 to 0.74 postoperatively ($P < 0.01$).

Conclusions: A modified Melbourne method for calvarial vault reconstruction addresses the phenotypic aspects of severe scaphocephaly associated with isolated sagittal synostosis and maintains a homeotopic relationship across the calvaria. It is associated with shorter operative times, lower blood loss, and lower transfusion requirements. *(Plast Reconstr Surg Glob Open 2018;6:e1848; doi: 10.1097/GOX.0000000000001848; Published online 9 July 2018.)*

INTRODUCTION

Sagittal synostosis is the most common form of nonsyndromic craniosynostosis with an incidence of approximately 1/2,500–5,000 births.[1,2] Over 95% of cases are thought to be noninherited, but some data suggest a potential role for mutations of the Twist 1 gene in familial cases.[3] Characteristic features of children with isolated sagittal synostosis include elongated skull, frontal bossing, anteriorly displaced vertex, biparietal narrowing, and bullet-shaped occiput with an acute basioccipital angle to the horizontal plane.

Operative treatment for sagittal craniosynostosis is indicated to reduce the risk of subsequent elevated intracranial pressure, cognitive deficits, and/or aesthetic deformity.[2] Increased intracranial pressure is rare in patients with isolated sagittal synostosis,[4,5] but neurocognitive development may be compromised even in its absence.[1,6–8] The scaphocephalic head shape becomes apparent in infancy, and the cranial deformities will not improve with growth if left uncorrected.[9] Operative techniques to improve the cranial shape and intracranial volume include endoscopic suturectomy, extended craniectomy, spring-assisted cranioplasty, and total calvarial vault remodeling.[10–13] Others have demonstrated effective correction of frontal bossing with posterior-middle vault expansion and

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Received for publication November 16, 2017; accepted May 9, 2018.

Presented at the American Cleft-Palate Craniofacial Association 73rd Annual Meeting, April 2016, Atlanta, Ga.

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Army, Department of the Navy, Department of Defense, nor the U.S. Government.

DOI: 10.1097/GOX.0000000000001848

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

subsequent spontaneous anterior remodeling.[14] Regardless of technique, each method has its inherent benefits but fails to address all phenotypic aspects of the deformity. The Melbourne method was developed to attempt to address the entire spectrum of deformities associated with isolated sagittal synostosis, especially for patients with late-presentation and severe scaphocephaly.[15,16]

The Melbourne method principally aims to release the synostotic suture and remodel dysmorphic calvarial regions.[15,17] An immediate intraoperative correction of head shape is achieved by decreasing the anterior-posterior dimension and increasing the biparietal distance, while also addressing the frontal bossing, acute nasofrontal angle, and anteriorly displaced vertex. By anticipating and allowing for brain expansion, the technique does not carry the same risk for raised intracranial pressure as the previously described pi or modified pi methods.[18,19]

In this report, we present our experience with total calvarial vault remodeling using a modification of the Melbourne method for patients with late-presenting isolated sagittal synostosis. Our modification limits the number of osteotomies and heterotopic bone movement to reduce blood loss and transfusion requirements. This surgical technique addresses each of the phenotypic characteristics of the synostotic calvaria while simplifying bone movements and decreasing the operative time.

METHODS

In this retrospective review, we included all consecutive patients with nonsyndromic, isolated sagittal synostosis who underwent calvarial vault remodeling with our modification of the Melbourne method from 2011 to 2015. At our institution, children presenting with craniosynostosis requiring intervention will typically be treated endoscopically if they are younger than 5 months old.[20] Older children who require an operation will usually undergo an open procedure according to the specifics of their condition. We identified pertinent preoperative, intraoperative, and postoperative data from our electronic medical records. Pre- and postoperative comparisons were made using *t* tests for continuous variables with SPSS v. 23 (IBM Corp, Armonk, NY). The Institutional Review Board at Boston Children's Hospital approved this study.

OPERATIVE TECHNIQUE

Under general anesthesia, the patient is placed in the supine position on a Mayfield headrest. A 50:50 mixture of 0.5% lidocaine with 1:100,000 epinephrine and 0.25% bupivacaine with 1:100,000 epinephrine is diluted with 40–70 cc of normal saline to infiltrate the entire scalp anterior and posterior to the coronal incision. The scalp flaps are dissected in a subperiosteal plane anteriorly down to the supraorbital rims and posteriorly beyond the occipital protuberance. A 3–4 cm strip craniectomy is made in the coronal plane at the site of the maximal biparietal width. Resection of this bone allows for reduction of the anteroposterior skull length. The coronal strip of bone is split into halves and is subsequently used for remodeling the posterior cranial vault. After splitting the occiput in the midline, 1 segment of the coronal strip is used to transversely expand this region. The second segment is rotated 90 degrees and secured inferior to the new occipital construct, thereby increasing the occipito-vertical distance for future brain growth. The supraorbital bar is left intact, and the frontal segment is barrel staved to increase the intertemporal width. The parietal bones are also barrel staved to broaden the parietal region (Fig. 1). Figure 2 demonstrates the parietal osteotomies completed in the coronal plane and remodeled cranium with reduced cranial length and increased occipital height. An alternate option for barrel stave osteotomies involves sagittal cuts of the parietal bones. Depending on outer cortical thickness, these parietal segments are then either partially scored or burred to allow them to cantilever anteriorly without fracturing. Either parietal osteotomy pattern can be used, and the decision is made intraoperatively based on the geometry of the neo-occipital segment. Once the occipital segments have been divided and the bone graft has been interposed, the new construct is placed into position and the parietal morphology is reexamined in light of the new occipital width. At this juncture, the specific coronal or sagittal osteotomy pattern for the parietal bones can be chosen (Fig. 3). Fixation is performed with 2-0 PDS suture and absorbable plates. Endocortical particulate bone graft harvested from the coronal strip and occipital plates is used to fill the bony defects, with the addition of fibrin sealant. We use a bulb-suction drain placed in the subperiosteal plane under the posterior flap with vaseline gauze dressing along the incision line and a headwrap.

RESULTS

Patient characteristics and operative details are outlined in Table 1. A total of 9 patients underwent the modified Melbourne technique for calvarial vault remodeling during the study period. Quantitative follow-up information was available for 8 patients. Mean operative time was 181.1 minutes (range, 147–215 minutes). Estimated intraoperative blood loss was determined in the standard fashion by consensus estimates between both surgical and anesthesia providers. The mean estimated blood loss for our study cohort was 260 mL (range, 80–400 mL; 23 mL/kg, range, 18–38 mL/kg), and the mean intraoperative transfusion was 232 mL (range, 0–360 mL). All patients received less than 60 mL/kg transfusion intraoperatively. The average length of stay in the hospital was 3.9 days. There were no major intraoperative or postoperative complications.

All patients achieved improvement in head shape based on subjective assessment of clinical photographs by the surgical team (Fig. 4). Improvement was confirmed in 8 patients with sufficient data by comparison of preoperative and postoperative cephalic indices (CI, the ratio of maximum skull width × 100, divided by length) measured by anthropometric examination and/or computed tomography. In these patients, the CI improved from a mean of 67.3 (range, 61–72) preoperatively to 74.1 (range, 68–83) postoperatively. The average follow-up period was 23 months (range, 1–54 months) with a percentage CI change during that time period of +10.3% ($P < 0.01$; Fig. 5).

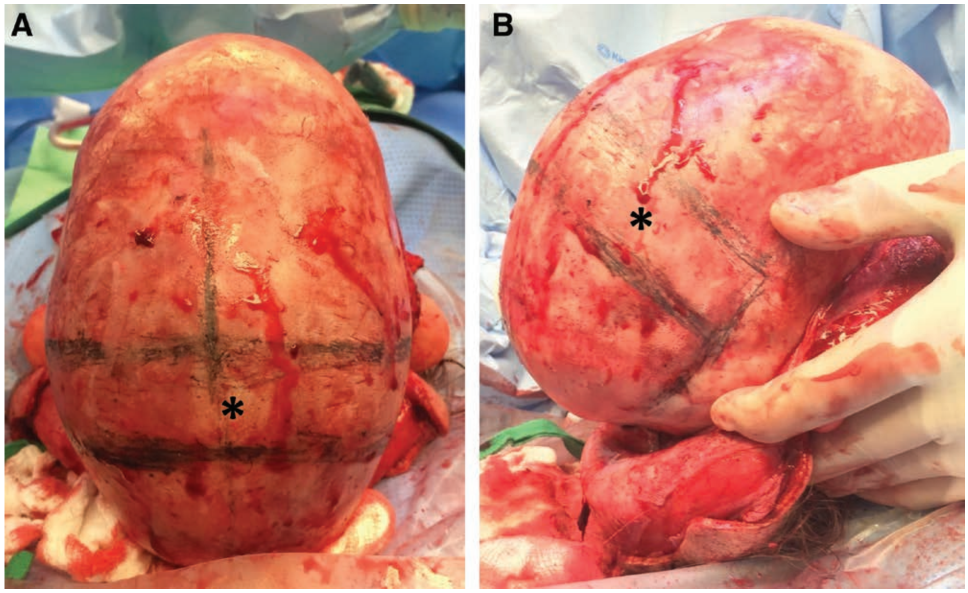

Fig. 1. Bird's eye (A) and lateral (B) views after scalp flap dissection and before osteotomies. Asterisk marks the coronal strip of cranium to be removed.

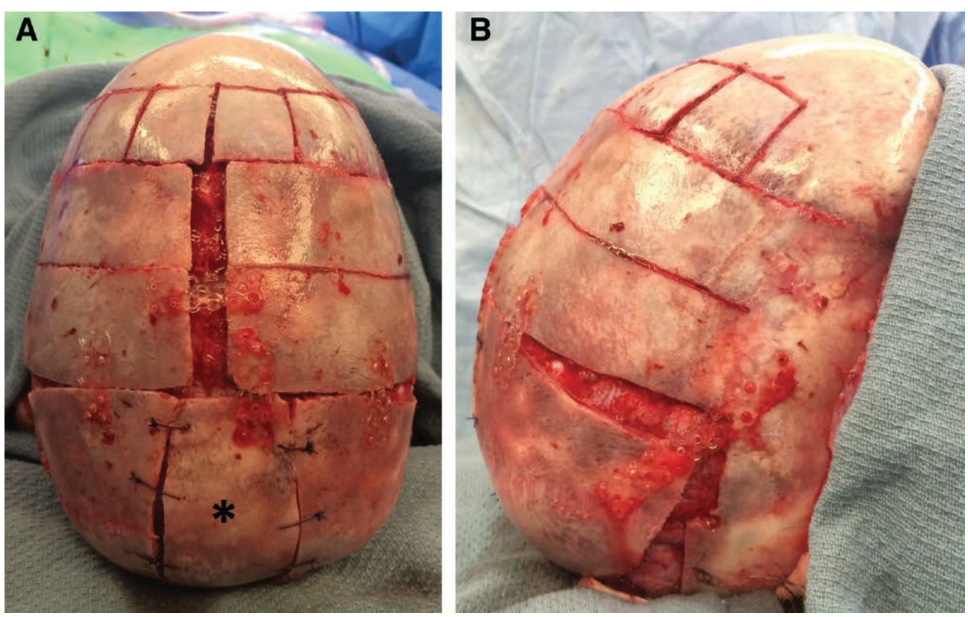

Fig. 2. Bird's eye (A) and lateral (B) views after osteotomies and remodeling. Asterisk marks the new position of the cranial strip, split and relocated to both widen and raise the occipital region.

DISCUSSION

This series of consecutive patients undergoing surgical treatment for isolated sagittal synostosis demonstrates a modification of the Melbourne method for total calvarial vault remodeling that addresses the phenotypic characteristics of the deformity. In our series, all patients experienced both subjective and objective improvement in head shape and cranial index over the course of our clinical follow-up. Through modification and simplification of previously published methods of vault remodeling, this technique attempts to minimize intraoperative blood loss, operative time, and length of hospital stay, while providing comparable clinical benefits.

The ideal technique for correction of severe scaphocephaly addresses all phenotypic aspects of the deformity. The Melbourne method of calvarial vault remodeling improved upon earlier technical approaches by addressing all the cranial dimensions. Its authors report excellent outcomes, with improved CI, decreased head circumference, and increased intracranial volume.[17] Occipital elevation, barrel staving frontal and occipital regions, and switching parietal bone flaps to expand biparietal distance achieves normalization of head shape, does not sacrifice intracranial volume, and anticipates fourth dimensional volume changes.[15,17] However, the operation is largely reliant on heterotopic bony relationships, especially in the

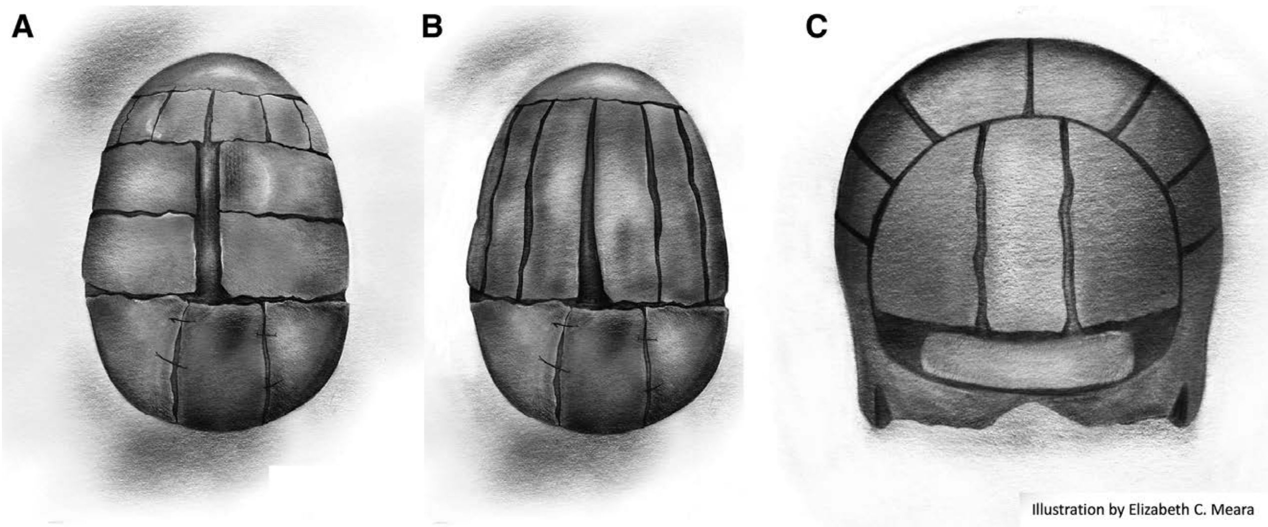

Fig. 3. Options for parietal segment barrel staving in the coronal (A) or sagittal (B) dimension. A, Calvarial reconstruction with barrel staving of parietal plates in the coronal plane. B, Calvarial reconstruction with barrel staving of the parietal segments in the sagittal plane and cantilevered anteriorly. C, Posterior view of calvarial reconstruction with barrel staving of the parietal segments in the sagittal plane.

Table 1. Patient Characteristics and Operative Details

Patient Characteristic	Mean (Range)
Age at operation (mo)	17
Preoperative Cephalic Index	67.3 (61–72)
Postoperative Cephalic Index	74.1 (68–83)
Absolute increase	6.80
Percent change	10.2% (4.2–17.8%)
Operative time (min)	181.1 (147–215)
Estimated blood loss (mL)	260 (80–400)
Length of hospital stay (d)	3.9

movement and repositioning of the parietal plates. The interchange of parietal bone grafts to increase biparietal width and the anterior relocation of the occipital graft to decrease head length inevitably lead to longer operative times, larger volume intraoperative blood loss, and subsequent transfusion requirements.

The modification described in our case series maintains the original goals of the Melbourne method, while leveraging homeotopic relationships between most of the bone grafts. By utilizing a coronal strip of bone at the maximal biparietal width to raise and expand the deformed occiput, the current modification restricts larger bony movements to the occipital region alone. Parietal plate barrel staving in either the coronal or sagittal plane allows us to achieve comparable width expansion to the original Melbourne method without the need to interchange large parietal bone grafts. Accordingly, our current modifications permit shorter operative times and lower transfusion requirements compared with the original descriptions of the Melbourne method. The average operative time for our modification at 181 minutes compares favorably with the original reports from the Melbourne method of 285 minutes.[15]

The mitigation of intraoperative blood loss holds particular importance for patients undergoing operations for craniosynostosis, as some studies estimate blood loss to be 40% of total blood volume in total vault reconstruction.[21,22] High volume blood loss and allogenic blood transfusions are both independently associated with adverse events including severe hypotension, metabolic acidosis, air embolism, cardiac arrest, death, postoperative ventilation, coagulopathies, transfusion-related immunologic reactions, and infections.[23–31] Furthermore, intraoperative transfusion greater than 60 mL/kg of packed erythrocytes in craniosynostosis cases has been demonstrated to be an independent predictor for postoperative cardiorespiratory and hematological events requiring intensive care unit admission.[29] Additional ongoing blood loss may persist from bone edges for 2–3 days postoperatively. Decreasing the number of cut bone edges and large graft movement allows our modification of the Melbourne method to address concerns about sequelae from large volume transfusion requirements by minimizing blood loss in the perioperative period. The intraoperative transfusion requirement in our study was 232 mL (23 mL/kg; range, 18–38 mL/kg), and no transfusion-related morbidity was noted in this series. By comparison, the average blood transfusion requirement for patients in the original Melbourne method was 460 mL.[15]

Objective assessment of vault remodeling techniques has commonly focused on serial measurements of the CI to quantify the severity of sagittal synostosis and its subsequent correction. Despite other more advanced modalities to evaluate head shape, CI remains the most easily measured and universally reported value as a surgical outcome.[32] Children with scaphocephaly have an average CI of 60–67%, whereas the nonsynostotic patient population has CIs that range from 76% to 78%.[33,34] In our cohort, the mean CI increased from 67.3% to 74.1%, with an overall mean increase of 10.3%. These changes are concordant with other published reports of CI changes following vault remodeling.[11] The original Melbourne method provides a mean CI increase of 11.1% postoperatively. Recently,

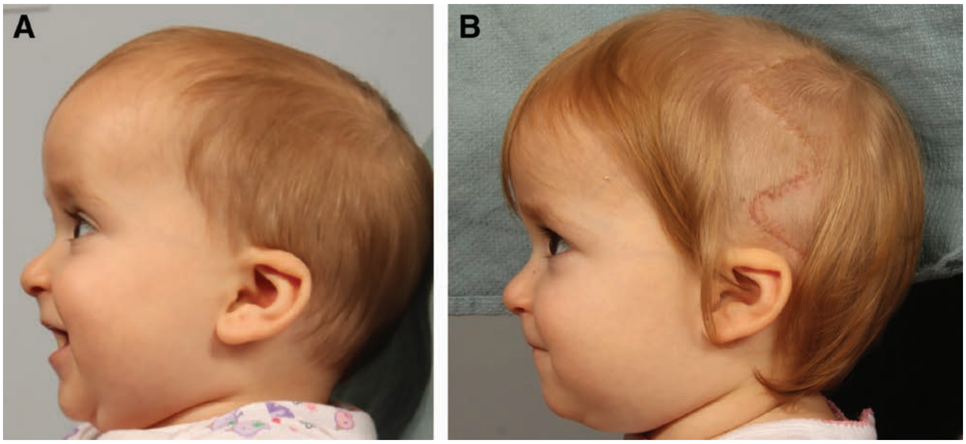

Fig. 4. Representative pre- (A) and postoperative (B) clinical photographs of a patient with isolated sagittal synostosis following calvarial reconstruction with the modified Melbourne technique. Note the more posteriorly positioned vertex and shorter A-P dimension.

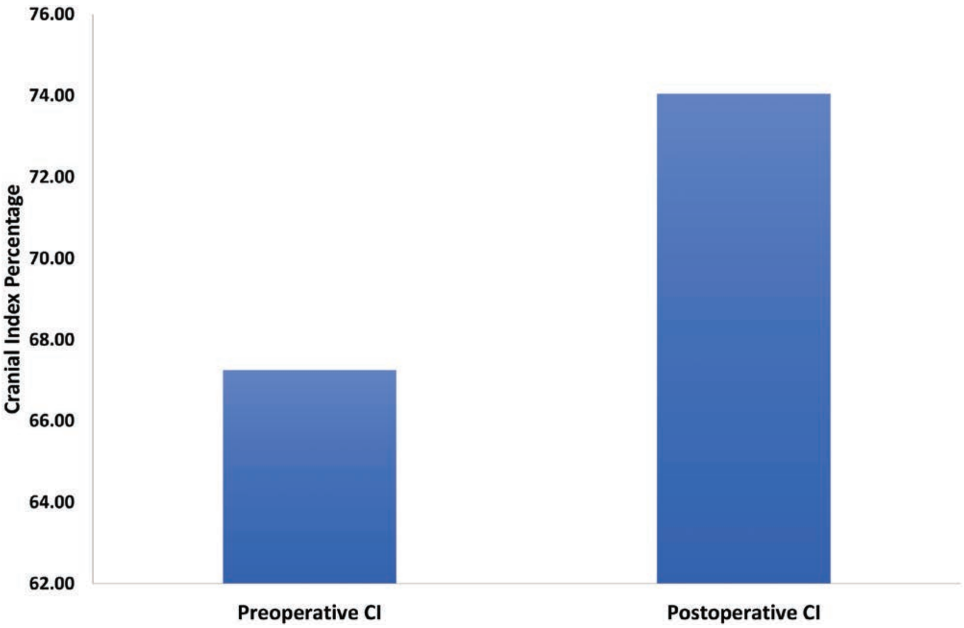

Fig. 5. Cephalic Index measured preoperatively and postoperatively (range, 1–54 months), found to be statistically significant between groups (*$P < 0.01$) using a paired t test.

some authors have begun to challenge the validity of CI measures in patients with sagittal synostosis, suggesting the anterocaudal displacement of the euryon in this patient population affects CI measurements.[35,36] Although imperfect, we used CI as an outcome measure in our series for its ease of calculation and its ability to provide meaningful comparison to published reports following different methods of vault remodeling.

Our patient series is small, with relatively short follow-up, but the results are promising. Although these early data suggest CI improvement, some studies suggest that vault remodeling may not provide long-term improvement in head shape.[37,38] Furthermore, our study population is slightly older than some other reported series, with an average age of 17 months. An older age at operation may affect our long-term results compared with those of a younger population with perhaps a greater capacity for bony remodeling. Although CI is the most accessible outcome measure following vault remodeling, its use in our study may not accurately reflect postoperative morphologic changes. Others have evaluated 3-dimensional computed tomography data in evaluating outcomes after treatment for craniosynostosis,[39,40] and future long-term assessment with CT volumetric analysis combined with neurocognitive evaluation may provide more detailed and representative information on the 3- and 4-dimensional effects of this novel technique.

CONCLUSIONS

A modification of the Melbourne method for total calvarial vault reconstruction attempts to address each of the phenotypic aspects of severe scaphocephaly associated with isolated sagittal synostosis and maintains a homeotopic relationship across the calvaria. By focusing on a simpler geometric design and minimizing large bone movements, this procedure is associated with shorter operative times, lower blood loss, and lower transfusion requirements. Long-term follow-up will elucidate the stability of morphologic changes in head shape associated with this operation.

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ACKNOWLEDGMENTS

The authors thank Elizabeth C. Meara for her original illustrations of their modified methods of calvarial vault remodeling.

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