OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE
Craniofacial/Pediatric

Superior Long-term Appearance of Strip Craniectomy Compared with Cranial Vault Reconstruction in Metopic Craniosynostosis

Ryan K. Badiee, BA, BS*
Emma Popowitz*
Ian T. Mark, MD†
Andre Alcon, MD*
Joan Hwang, BA‡
Eve Rorison, RN, CPNP*
Kurtis I. Auguste, MD‡
William Y. Hoffman, MD*
Peter P. Sun, MD‡
Jason H. Pomerantz, MD*

Background: Strip craniectomy with orthotic helmet therapy (SCOT) is an increasingly supported treatment for metopic craniosynostosis, although the long-term efficacy of deformity correction remains poorly defined. We compared the long-term outcomes of SCOT versus open cranial vault reconstruction (OCVR).
Methods: Patients who underwent OCVR or SCOT for isolated metopic synostosis with at least 3 years of follow-up were identified at our institution. Anthropometric measurements were used to assess baseline severity and postoperative skull morphology. Independent laypersons and craniofacial surgeons rated the appearance of each patient's 3D photographs, compared to normal controls.
Results: Thirty-five patients were included (15 SCOT and 20 OCVR), with similar follow-up between groups (SCOT 7.9 ± 3.2 years, OCVR 9.2 ± 4.1 years). Baseline severity and postoperative anthropometric measurements were equivalent. Independent adolescent raters reported that the forehead, eye, and overall appearance of SCOT patients was better than OCVR patients ($P < 0.05$, all comparisons). Craniofacial surgeons assigned Whitaker class I to a greater proportion of SCOT patients with moderate-to-severe synostosis (72.2 ± 5.6%) compared with OCVR patients with the same severity (33.3 ± 9.2%, $P = 0.02$). Parents of children who underwent SCOT reported equivalent satisfaction with the results of surgery (100% versus 95%, $P > 0.99$), and were no more likely to report bullying (7% versus 15%, $P = 0.82$).
Conclusions: SCOT was associated with superior long-term appearance and perioperative outcomes compared with OCVR. These findings suggest that SCOT should be the treatment of choice for patients with a timely diagnosis of metopic craniosynostosis. *(Plast Reconstr Surg Glob Open 2022;10:e4097; doi: 10.1097/GOX.0000000000004097; Published online 9 February 2022.)*

INTRODUCTION

Metopic craniosynostosis is treated with surgery in infancy to prevent social and neurodevelopmental sequelae.[1] Differing surgical approaches have been developed with good safety profiles and each with advantages and disadvantages, but none has demonstrated aesthetic, social, or neurodevelopmental superiority.[2–6]

Open cranial vault reconstruction (OCVR) remains the historical gold standard treatment.[7] However, following the acceptance of strip craniectomy with orthotic helmet therapy (SCOT) to treat selected patients with sagittal synostosis,[8–10] similar approaches to metopic synostosis have been developed. Prior studies in metopic synostosis have reported that SCOT is associated with shorter operative time, decreased blood loss, and less frequent admission to the intensive care unit compared with OCVR.[11–15] Two recent small-cohort studies found equivalence between SCOT and OCVR in several anthropometric measurements, up to 5 years after surgery.[16,17] However, there is no consensus that isolated craniofacial measurements are surrogates for comprehensive appearance, and no studies

*From the *Division of Plastic and Reconstructive Surgery, Department of Surgery, UCSF Craniofacial Center, University of California San Francisco, San Francisco, Calif.; †Department of Radiology, University of California San Francisco, San Francisco, Calif.; and ‡Department of Neurosurgery, University of California San Francisco, UCSF Craniofacial Center, San Francisco, Calif.*

Received for publication November 5, 2021; accepted November 29, 2021.

Drs. Sun and Pomerantz share joint senior authorship.

Presented at the Plastic Surgery The Meeting, 2021, Atlanta, GA.

Products and devices used are Canfield Vectra H2 camera (Canfield, Fairfield, N.J.) and Canfield Vectra Analysis Module (Canfield).

DOI: 10.1097/GOX.0000000000004097

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

Related Digital Media are available in the full-text version of the article on www.PRSGlobalOpen.com.

have examined the impact of surgical approach on quality of life. Thus, there remains a need for comparative studies describing the postoperative outcomes and effectiveness of each procedure. In this retrospective study, we hypothesized that the long-term morphologic outcomes, quality of life metrics, and subjective appearance ratings for patients who underwent OCVR or SCOT for metopic craniosynostosis would be equivalent after adjusting for severity of baseline deformity.

Takeaways

Question: In patients with metopic craniosynostosis, how do SCOT and OCVR compare in long-term skull morphology, patient satisfaction, and appearance?

Findings: In this retrospective cohort study, patients who underwent SCOT and OCVR had equivalent postoperative satisfaction and anthropometric measurements of their 3D photographs at the latest follow-up. Adolescents and craniofacial surgeons rated the appearance of SCOT patients as "normal" and Whitaker class I, respectively, significantly more frequently than OCVR patients.

Meaning: In metopic craniosynostosis, strip craniectomy was associated with superior long-term appearance, and equivalent skull morphology and patient satisfaction, compared with OCVR.

METHODS

Study Design and Population

After institutional review board approval (#20-30677), chart review identified patients with a diagnosis of metopic craniosynostosis at UCSF Benioff Children's Hospitals San Francisco and Oakland between 2000 and 2020. Criteria for inclusion were (1) diagnosis of nonsyndromic, single-suture metopic synostosis; (2) preoperative computed tomography (CT) or laser scan imaging; and (3) surgery at least 3 years before the study period. Eligible patients were recalled for 3D photography and satisfaction surveys.

Surgical Approach

All SCOT surgeries involved the senior neurosurgeon (P.P.S.). A 2.5-cm incision was made behind the hairline. A 1.5- to 2-cm craniectomy was performed, aided by a lighted retractor, from the coronal sutures to the width of the frontonasal suture medial to the orbits. The inner table of the craniectomy bone edges were thinned to an eggshell thickness over 4–6 mm. All patients required one to two helmets, fitted by one dedicated orthotist.

OCVR involved similar technique among four craniofacial surgeons. A bicoronal incision was made and bifrontal craniotomies were turned with the assistance of a neurosurgeon. An orbital bandeau was fashioned and widened with a bone graft. Barrel stave osteotomies were carried out in the parietal and temporal regions. The forehead and superior orbits were then reconstructed using the craniotomy bone flaps and orbital bandeau, then fixated with resorbable plates and suture or wire. Across the four surgeons, there were no differences in patient age at surgery, estimated blood loss, operative time, preoperative or postoperative morphologic measurements, clinical outcomes, or aesthetic metrics ($P > 0.05$, all comparisons).

Data Collection and Outcome Measures

Demographic data and clinical outcomes were abstracted from the medical record. Race and ethnicity were self-reported by patients' parents.

To assess baseline severity, measurements were made from preoperative CT or laser scans (**see figure 1, Supplemental Digital Content 1**, which displays imaging methodology. A, Interzygomaticofrontal distance [IZFD] is the linear distance between the zygomaticofrontal sutures bilaterally (blue). B, Interfrontal angle (IFA), as described by Kellogg et al. Axial sections parallel to the sella-nasion plane were created. The anteriormost point was marked, and a plumb line was dropped to the level of the supraorbital notches. The angle between the anteriormost point of the forehead and the bilateral supraorbital notches forms the interfrontal angle (green). C, 3D photographs were oriented in Frankfort horizontal and rotated 7 degrees anteriorly to approximate sella-nasion plane. The anteriormost point of the forehead (glabella) was marked. Points approximating the zygomaticofrontal suture bilaterally were marked and projected superiorly to the level of the glabella. The green-colored points were ultimately used for measurement. D, The points described in (C) were connected to measure glabellar angle (green). Frontal width represents the linear distance between frontotemporale points (blue). Intercanthal width represents the linear distance between the medial canthi bilaterally (red), **http://links.lww.com/PRSGO/B914**).

An independent neuroradiologist measured the IFA[18] and IZFD[19] of each CT scan. Subjects were measured twice with an intraclass correlation coefficient of 0.94, indicating excellent intrarater reliability. The metopic angle, described by Gociman et al,[13] was measured from preoperative laser scans. For patients with only preoperative laser scans, linear regression was used to predict IFA from metopic angle values, using data from patients who had both measurements ($R^2 = 0.98$). (**See graph, Supplemental Digital Content 2**, which displays prediction of interfrontal angle from metopic angle. The interfrontal angle and metopic angle were plotted for patients who had both measurements taken from preoperative scans. A linear regression line [$R^2 = 0.98$] was used to predict the interfrontal angle among patients who only had metopic angle values. Navy points denote measured values; red points denote IFA values predicted using linear regression, **http://links.lww.com/PRSGO/B915**).

Baseline severity was stratified based on thresholds described by Anolik et al[20]: an IFA less than 114.3 degrees was categorized as moderate-to-severe, and an IFA of 114.3–136.1 degrees was categorized as mild-to-moderate.

Postoperative 3D photographs were taken using a Canfield Vectra H2 camera (Canfield, Fairfield, N.J.) and anthropometric measurements were made by a single rater using the Canfield Vectra Analysis Module (Canfield)

(SDC 1, **http://links.lww.com/PRSGO/B914**). Glabellar angle was estimated as described by Nguyen et al.[19] Frontal width and intercanthal width were measured as described by the 3D Facial Norms database and normalized by age and sex using their population standards.[21] Subjects were measured twice with an intraclass correlation coefficient of 0.88, indicating good intrarater reliability.

All patients' parents completed surveys assessing satisfaction with the postoperative outcome and quality of their child's social life. Satisfaction was assessed on a five-point Likert scale, from "very unsatisfied" to "very satisfied." Adverse social outcomes, such as bullying, were assessed on a five-point Likert scale, from "never" to "always." Qualitative open-ended comments were also recorded.

To assess subjective appearance, independent adolescents and craniofacial surgeons blinded to patients' treatment groups rated projections of each patient's 3D photographs in seven different angles (**see figure 2, Supplemental Digital Content 3**, which displays projections of 3D photographs. Three-dimensional photographs were taken of each SCOT patient (A) and OCVR patient (B) using a Canfield Vectra H2 camera. Two-dimensional projections from seven different angles were made from each 3D model and displayed to independent layperson and craniofacial surgeon raters, **http://links.lww.com/PRSGO/B916**).

Each subject's hair was pulled back and the scar was not displayed, allowing full visualization of the face while concealing the treatment group. Images of normal controls (NCs) were included. Adolescents rated each patient's forehead, eyes, and overall appearance on a four-point Likert scale from "completely abnormal" to "completely normal." The self-identified ethnic makeup of the 151 adolescent raters was 48% White, 11% Black, 11% Asian, 24% Hispanic/Latino, and 6% others. Interrater reliability was poor, with an intraclass correlation coefficient of 0.31. Independent craniofacial surgeons from outside institutions and not involved in the care of the patients or familiar with the study rated the Whitaker classification of each individual. Interrater reliability among craniofacial surgeon raters was moderate, with an intraclass correlation coefficient of 0.53.

Statistical Analysis

Descriptive statistics were calculated. Comparisons between groups were made using Student's *t* tests and Mann–Whitney U as appropriate. Chi-square tests and Fisher exact tests were used to compare categorical outcomes. The Benjamini–Hochberg correction was applied to account for multiple group comparisons being conducted. R version 3.6.3 (R Foundation, Vienna, Austria) was used for all statistical analysis. All tests were two-tailed, and the null hypothesis was rejected in cases with a *P* value less than 0.05.

RESULTS

Population Characteristics

Of 155 patients who underwent surgery for metopic craniosynostosis, 58 met inclusion criteria (Fig. 1). Ninety-six patients were excluded for multiple suture synostosis (n = 15), undergoing surgery less than 3 years ago (n = 32), and lacking adequate preoperative imaging (n = 50). Ultimately, 35 patients were included, of which 15 underwent SCOT and 20 underwent OCVR. Among eligible patients, there were no differences in baseline characteristics or clinical outcomes between respondents and nonrespondents (**See table, Supplemental Digital Content 4**, which displays comparisons of baseline characteristics and clinical outcomes between respondents and nonrespondents, **http://links.lww.com/PRSGO/B917**).

Most patients were male (Table 1). Both groups were racially diverse, with a high proportion of Hispanic/Latino patients (SCOT 33.3% versus OCVR 70.0%, *P* =

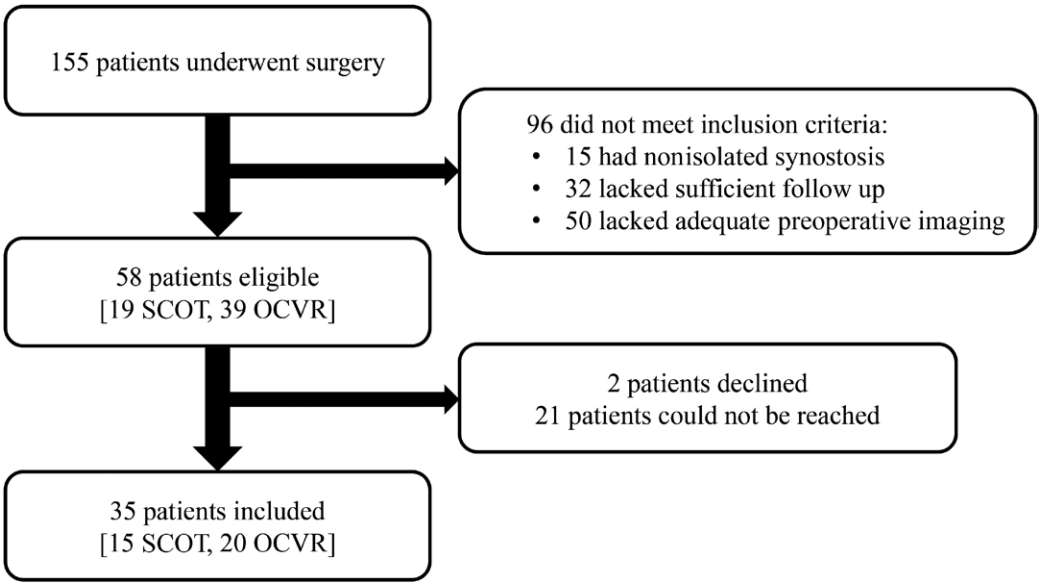

Fig. 1. Patient flowchart.

0.31). Patients undergoing SCOT were younger (median SCOT 4.8 versus OCVR 9.6 months, $P = 0.01$). Six patients (40.0%) underwent SCOT older than 6 months of age. SCOT patients underwent orthotic helmet therapy for an average of 195 days postoperatively, whereas none of the OCVR patients wore an orthotic helmet. The follow-up period was similar across groups, at 7.9 ± 3.2 years among SCOT patients and 9.1 ± 4.1 years among OCVR patients ($P = 0.33$).

Clinical Outcomes

Operative time, estimated blood loss, length of hospital stay, and length of intensive care unit stay were all significantly lower in the SCOT group than that in the OCVR group ($P < 0.05$, all comparisons) (Table 1). There were three intraoperative dural tears, one during SCOT and two during OCVR, which were all primarily repaired. There were no further complications or revisions after SCOT. In the OCVR group, one patient experienced wound breakdown and another developed secondary bicoronal synostosis, both of which required revision surgeries. Three OCVR patients (15.0%) underwent fat transfers to treat temporal hollowing.

Anthropometric Measurements

Representative preoperative and postoperative photographs are exhibited in Figure 2. The baseline severity of deformity was assessed using the IFA and IZFD (Table 2). The mean preoperative IFA for the SCOT group was 116.6 ± 8.8 degrees versus 110.5 ± 10.1 for the OCVR group ($P = 0.07$). The mean IZFD was similar across groups (SCOT 67.5 ± 6.8 mm versus OCVR 66.5 ± 8.6 mm, $P = 0.75$). There were nine SCOT patients and seven OCVR patients with mild-to-moderate synostosis, and six SCOT patients and 13 OCVR patients with moderate-to-severe synostosis ($P = 0.14$). Within each severity subgroup, the IFA and IZFD did not significantly differ between treatment groups ($P > 0.05$, all comparisons).

Postoperatively, the glabellar angle, frontal width, and intercanthal width were equivalent across treatment groups and severity subgroups (Table 2). The postoperative frontal width in both groups was lower than age- and sex-matched unaffected controls (Z-score SCOT −0.8 ± 1.5 versus OCVR −1.7 ± 1.5, $P = 0.09$). The average intercanthal width was equivalent to matched controls (SCOT 1.2 ± 1.2 versus OCVR 0.5 ± 1.1, $P = 0.11$).

Patient-reported Outcomes

Of parents surveyed, 97.1% were very satisfied with the overall results, with no differences between groups in any of the domains assessed ($P > 0.99$, all comparisons) (Fig. 3A). One SCOT patient (6.7%) and three OCVR patients (15.0%) experienced frequent bullying ($P = 0.81$; Fig. 3B). One SCOT patient (6.7%) and four OCVR patients (20.0%) were stared at frequently ($P = 0.53$). Three parents whose children underwent OCVR (15.0%) commented that bullying resulted from the appearance of the postoperative scar, which was visible in some patients with short hair.

Subjective Appearance

Independent adolescents (n = 151) rated the subjective appearance of SCOT patients, OCVR patients, and NCs without craniosynostosis (n = 9) (Fig. 4A). Among patients with mild-to-moderate synostosis, SCOT was associated with superior ratings in forehead ($P = 0.003$), eye ($P = 0.003$), and overall appearance ($P = 0.000005$). Among patients with moderate-to-severe synostosis, SCOT was associated with superior forehead ($P = 0.00007$) and overall appearance ($P = 0.00001$). Raters were generally unable to distinguish which patients were born with a skull deformity, estimating correctly in about half of all cases.

Three independent craniofacial surgeons assigned Whitaker classifications to all groups (Fig. 4B). Among patients with mild-to-moderate synostosis, Whitaker class I was assigned to similar proportions of the NC, SCOT,

Table 1. Demographic and Clinical Characteristics

	SCOT (n = 15)	OCVR (n = 20)	*P*
Population Characteristics			
Masculine gender, n (%)	14 (93.3%)	14 (70.0%)	0.20
Race, n (%)			0.31
Non-Hispanic White	5 (33.3%)	5 (25.0%)	
Non-Hispanic Black	2 (13.3%)	1 (5.0%)	
Asian or Pacific Islander	2 (13.3%)	0 (0%)	
Hispanic/Latino	4 (26.7%)	14 (70.0%)	
Multiple races	2 (13.3%)	0 (0%)	
Age at surgery, mo, median (IQR)	4.8 (3.9–9.9)	9.6 (8.8–11.7)	0.01*
Length of orthotic helmet wear, d, mean ± SD	194.9 ± 88.2	0 ± 0	1.50E-10*
Follow-up period, y, mean ± SD	7.9 ± 3.2	9.2 ± 4.1	0.33
Clinical Outcomes			
Operative time, min, median (IQR)	124.0 (91.0–147.5)	273.0 (175.0–389.0)	0.001*
Estimated blood loss, mL, median (IQR)	45.0 (30.0–75.0)	180.0 (150.0–257.50	0.0003*
Blood transfusion, n (%)	8 (53.3%)	17 (85.0%)	0.09
Length of hospital stay, d, mean ± SD	3.1 ± 0.9	4.8 ± 1.3	0.0002*
Length of ICU stay, d, mean ± SD	2.3 ± 0.8	2.8 ± 1.2	0.03*
Revision surgery, n (%)	0 (0%)	5 (25.0%)	0.06

* denotes statistical significance, where $P < 0.05$.

All SCOT procedures were performed by a single surgeon, senior author P.P.S. OCVR procedures were performed by four craniofacial surgeons at our institution with no differences in patient age at surgery, estimated blood loss, operative time, preoperative or postoperative morphologic measurements, clinical outcomes, or aesthetic metrics ($P > 0.05$, all comparisons).

ICU, intensive care unit; IQR, interquartile range; SD, standard deviation.

Table 2. Baseline and Postoperative Morphologic Metrics

	Overall			Mild–Moderate			Moderate–Severe		
	SCOT (n = 15)	OCVR (n = 20)	P	SCOT (n = 9)	OCVR (n = 7)	P	SCOT (n = 6)	OCVR (n = 13)	P
Baseline									
IFA (degree)	116.6±8.8	110.5±10.1	0.07	121.7±4.7	121.2±4.1	0.82	109.0±8.0	104.8±7.0	0.26
IZFD (mm)	67.5±6.8	66.5±8.6	0.75	69.3±7.0	68.7±3.7	0.85	63.3±4.6	65.5±10.1	0.72
Postoperative									
Glabellar angle (degree)	122.2±4.2	123.9±6.0	0.45	122.3±4.6	123.4 ± 6.8	0.71	122.7±4.0	124.1±5.8	0.60
Frontal width (Z-score)	−0.8±1.5	−1.7±1.5	0.09	−0.5±1.2	−1.6±1.5	0.12	−1.4±1.8	−1.8±1.6	0.61
Intercanthal width (Z-score)	1.2±1.2	0.5±1.1	0.11	1.1±1.3	0.1±1.2	0.16	1.3±1.1	0.7±1.0	0.29

IFA, interfrontal angle; IZFD, interzygomaticofrontal distance; OCVR, open cranial vault reconstruction SCOT, strip craniectomy with orthotic helmet therapy.

and OCVR groups (NC 74.1% ± 7.4% versus SCOT 77.8% ± 11.1% versus OCVR 61.9% ± 15.3%%; $P > 0.05$, all comparisons). However, among patients with moderate-to-severe synostosis, a significantly higher proportion of SCOT patients were assigned to Whitaker class I compared to OCVR patients (72.2% ± 5.6% versus 33.3% ± 9.2%, $P = 0.01$). Over half of OCVR patients were assigned Whitaker class II or above (56.7%), compared with less than one-quarter of SCOT patients (24.4%).

DISCUSSION

The results of this study show that SCOT was equivalent or superior to OCVR in all outcomes assessed. After stratifying by baseline severity, three anthropometric measurements were similar among SCOT and OCVR. All patients reported high satisfaction with their outcome, with low rates of bullying and social exclusion. Craniofacial surgeons assigned superior Whitaker classifications to SCOT patients, and adolescents rated the appearance of SCOT patients as normal more frequently than OCVR patients.

Our finding that SCOT and OCVR have equivalent anthropometric outcomes extends data from prior reports. Pressler et al[17] followed a cohort of patients with metopic synostosis over 2 years, finding that SCOT and OCVR were associated with equivalent improvements in forehead contour. Similarly, Ha et al[16] found that the 5-year IFA and frontal width were equivalent between groups, though patients undergoing OCVR more frequently had persistent lateral frontal retrusion. This was

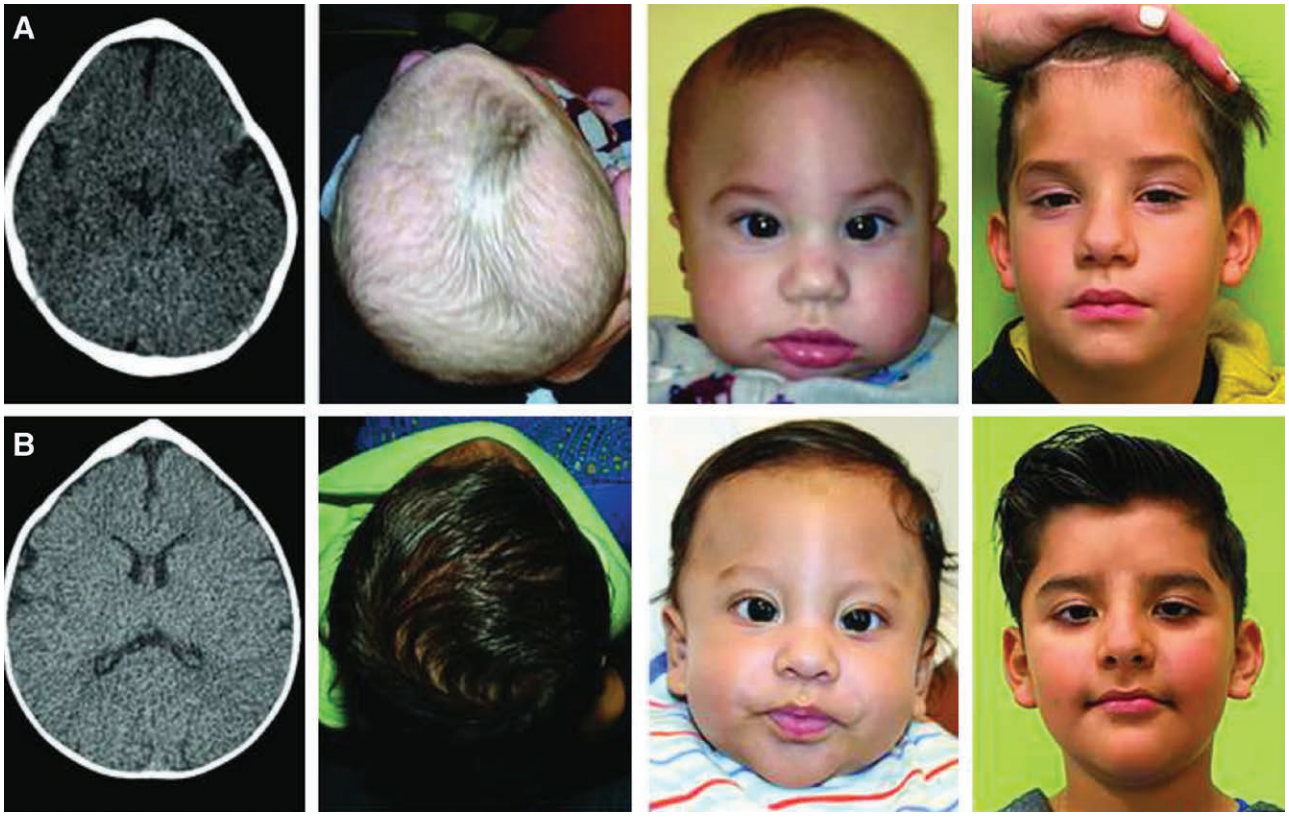

Fig. 2. Representative patient photographs. Preoperative CT scans (left panels), preoperative photographs (center panels), and postoperative photographs (right panels) of one patient each who underwent SCOT (A) and OCVR (B) are shown. Both presented with moderate-to-severe synostosis and have 7 years of follow-up.

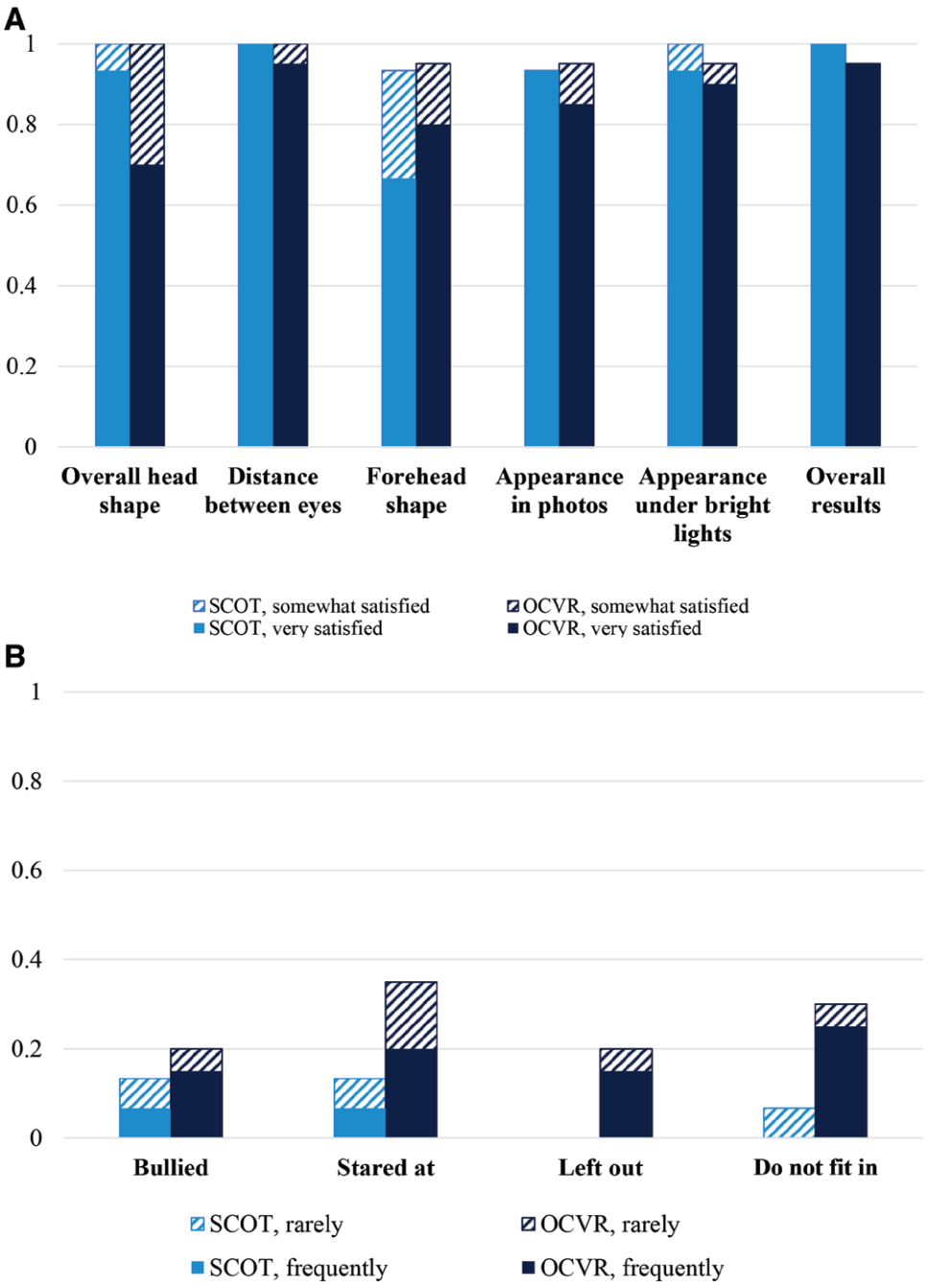

Fig. 3. Patient-reported outcomes. Parents of all patients completed surveys assessing (A) postoperative satisfaction or (B) quality of their child's social life. A, Each domain was assessed on a five-point Likert scale, from "very unsatisfied" to "very satisfied." B, Each domain was assessed on a five-point Likert scale, from "never" to "always." The proportion of parents reporting a frequency greater than "never" is displayed.

the most common reason that our OCVR patients were assigned higher Whitaker classes as well.

Though anthropometric measurements have been used to objectively characterize skull morphology, they remain insufficient to comprehensively assess aesthetic outcomes.[16,17,19,22] No described measurement captures adverse aesthetic outcomes that are commonly observed following craniosynostosis repair, such as irregularities of the forehead contour. Since aesthetic and social concerns are among the primary indications for surgery, this represents a meaningful deficiency in the literature.[23] Thus, we incorporated feedback on patients' postoperative appearance from three groups: patients' families, adolescent peers, and independent surgeons.

Our satisfaction data suggest that some patients may prefer the aesthetic appearance associated with SCOT

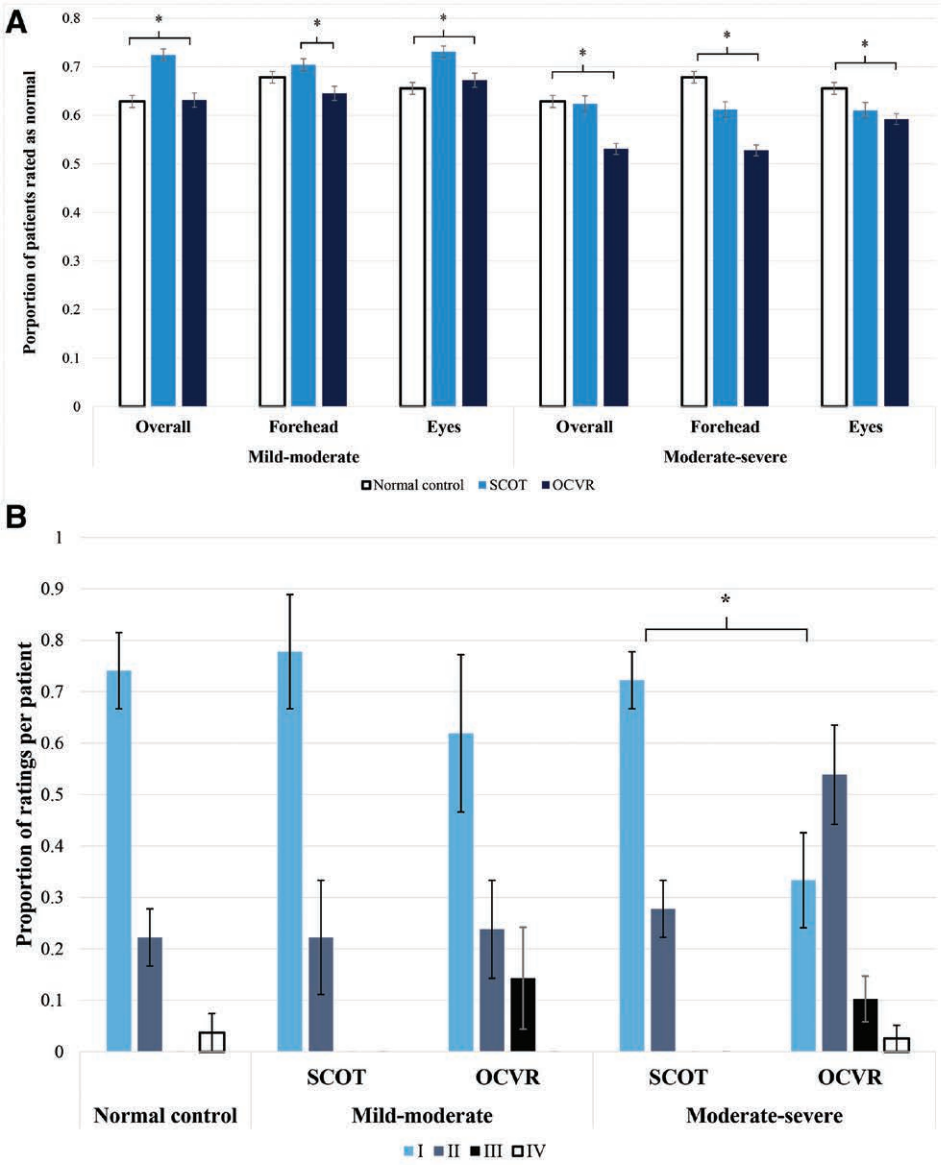

Fig. 4. Independent layperson and surgeon assessment of postoperative appearance. Two-dimensional projections of 3D patient photographs were shown to independent (A) adolescents (n = 151) and (B) surgeons (n = 3), who were blinded to the identity and treatment of each patient. Bar height represents mean; error bars represent standard error. *Significant difference between groups, $P < 0.05$. A, Demonstrates the proportion of patients rated as "normal" or predicted not to have been born with a skull deformity by raters. B, Demonstrates the proportion of patients assigned to each Whitaker class, stratified by baseline severity.

over that of OCVR due to the scar. Parents of the SCOT group were no more likely to report their children were stared at, left out of social plans, or feel that they did not fit in compared with patients in the OCVR group. As in previous reports, parents in our OCVR group felt that the zig-zag bicoronal scar was a source of stigma, especially in boys with short hair where it was more visible.[24] Given that metopic craniosynostosis is diagnosed in boys over three times more often than in girls, this should influence the choice of surgical technique.[25]

This study is the first to recruit adolescents to assess aesthetic outcomes in patients with craniosynostosis. The social stigma associated with craniosynostosis deformities is an indication for repair, and prior studies have shown that children with craniofacial anomalies are at high risk for adverse psychosocial outcomes, primarily due to bullying from peers.[26,27] Our finding that patients who underwent OCVR were less likely to have a "normal" overall appearance has substantive implications for their mental health. The poor agreement between adolescent raters was likely due to the nature of the population surveyed. Even when NCs were isolated, there was little agreement between raters. Teenagers can have disparate opinions for a variety of reasons. Thus, the variation between adolescent raters

is not unexpected and likely reflects success using either surgical approach.

Although Whitaker classifications are also an imperfect measure, they often indicate whether further surgical treatment is warranted.[16] Counterintuitively, we found that SCOT and OCVR were equivalent among patients with mild-to-moderate synostosis, but SCOT was associated with superior Whitaker classifications among patients with moderate-to-severe presentations. Ha et al[16] similarly found that a higher proportion of SCOT patients were Whitaker class I than OCVR patients, though this finding did not reach statistical significance. Collectively, available data directly refute the argument that severe presentations of metopic synostosis require open reconstruction of the calvaria.

Patient selection is key to the long-term success of SCOT because patients must wear orthotic helmets for months, and adherence can vary.[28] Surgeons should consider patient factors such as long travel distances, unstable access to insurance, or a history of poor adherence. In contrast, evidence from this study suggests that the severity of synostosis is not a predictor of the long-term success of SCOT, as patients in both severity groups were similar in their postoperative measurements.

Establishing the optimal age range for SCOT is of significant interest. Patients over the age of 4–6 months are typically considered ineligible.[8,16] Although we have individuals with successful outcomes after surgery over 6 months of age, we aim to perform SCOT in patients less than 4 months of age. We review each on an individual basis without a strict upper age limit. In this study, two patients underwent SCOT younger than 3 months of age, seven patients were between 3 and 6 months, and six patients were older than 6 months. This study's primary outcomes appeared roughly similar across age groups, though the size of this cohort limited our ability to conduct a direct comparison. Future work should examine this question, which has implications for the optimal age at diagnosis as well.

Alternative strategies to treat single-suture craniosynostosis, including distraction and spring-assisted remodeling, are not routinely used at our center for isolated metopic craniosynostosis. Given the multidimensional nature of the metopic deformity, conventional uniplanar distraction methods may be insufficient to produce a natural, rounded forehead.[29] However, one case series found an improvement in skull morphology using this method,[30] so additional investigation is merited.

The results of this study have informed our shared decision-making with patients' families. Our findings establish that both SCOT and OCVR effectively address the metopic craniosynostosis deformity. SCOT is also associated with lower costs and superior perioperative outcomes, making it an attractive option for many families and health systems.[14,31–33] SCOT may be preferable in patients with short hair, because the postoperative scar is less visible and was never a source of social stigma in this cohort. However, caretakers must be highly motivated to pursue SCOT, as adherence to orthotic helmet therapy is necessary. Because clinically apparent elevated intracranial pressure is exceedingly rare in infants with isolated metopic craniosynostosis, there is little rationale supporting a benefit of rapid vault expansion. Although one report found that the neurodevelopmental outcomes of SCOT were inferior to those of OCVR in sagittal synostosis,[34] this has not been assessed in a controlled fashion among metopic craniosynostosis patients, warranting further investigation.

Adjusting for baseline severity impacted the power of the present analyses. Our sample size was limited primarily due to our inclusion criteria, which required both preoperative imaging and a long follow-up period. Our stratified analysis further split each treatment group in two. As a result, post hoc analyses revealed that power was limited for our comparison of anthropometric outcomes (**see figure, Supplemental Digital Content 5**, which displays post hoc power analysis of primary outcome measures, **http://links.lww.com/PRSGO/B918**). This analysis underscores the confidence of our statistically significant findings, but indicates limitation in interpretation of comparisons where no significant difference was found.

This was a retrospective study subject to associated limitations, including ascertainment bias. We were unable to directly compare preoperative and postoperative anthropometric measurements to assess the degree of improvement within each individual, as 3D photography was not available at our institution until recently. Accordingly, in future studies, we intend to conduct craniometric analyses of postoperative outcomes within study subjects. Appearance-related outcomes were assessed using 2D projections in multiple views, as proprietary software unavailable to most laypersons is required to view the interactive 3D photographs. Finally, our subjective appearance assessments were limited by the interrater reliability of the Whitaker classification,[35] the demographic differences between our subject cohort and raters, and the absence of any validated survey that measures the effect of congenital skull deformities on quality of life in the pediatric population. These limitations likely contributed to the suboptimal concordance between raters observed here, but do not detract from the central finding of this study.

CONCLUSIONS

In this comparative analysis of SCOT and OCVR in metopic craniosynostosis, patients' objective skull morphology and satisfaction were equivalent across treatment groups. However, SCOT was associated with superior clinical outcomes and Whitaker classification ratings. Given the superior perioperative outcomes, lower cost, preferable aesthetic outcomes, and potential for psychosocial benefit, we conclude that SCOT should be considered in all patients presenting younger than 6 months of age.

Jason H. Pomerantz, MD
Division of Plastic and Reconstructive Surgery
University of California, San Francisco
350 Parnassus Ave., Suite 509
San Francisco, CA 94143
E-mail: jason.pomerantz@ucsf.edu

Peter P. Sun, MD
Department of Neurosurgery
University of California, San Francisco
744 52nd Street
Suite 5203
Oakland, CA 94609
E-mail: Peter.Sun@ucsf.edu

ACKNOWLEDGMENT

We thank Kayla Lewis and Melissa Hirschhorn for their support in the execution of this study. This work was supported by the UCSF Yearlong Inquiry Program (R.K.B.), John S. & Sherry H. Chen Endowment at UCSF Benioff Children's Hospital Oakland (P.P.S.), and the Caroline Damsky Award (J.H.P.).

REFERENCES

1. Birgfeld CB, Heike CL, Saltzman BS, et al. Clinical characteristics and surgical decision making for infants with metopic craniosynostosis in conjunction with other congenital anomalies. *Plast Reconstr Surg Glob Open.* 2013;1:e62.
2. Dempsey RF, Monson LA, Maricevich RS, et al. Nonsyndromic craniosynostosis. *Clin Plast Surg.* 2019;46:123–139.
3. Fearon JA. Evidence-based medicine: craniosynostosis. *Plast Reconstr Surg.* 2014;133:1261–1275.
4. Jaskolka MS. Current controversies in metopic suture craniosynostosis. *Oral Maxillofac Surg Clin North Am.* 2017;29:447–463.
5. Kunz M, Lehner M, Heger A, et al. Neurodevelopmental and esthetic results in children after surgical correction of metopic suture synostosis: A single institutional experience. *Childs Nerv Syst.* 2014;30:1075–1082.
6. Sidoti EJ Jr, Marsh JL, Marty-Grames L, et al. Long-term studies of metopic synostosis: frequency of cognitive impairment and behavioral disturbances. *Plast Reconstr Surg.* 1996;97:276–281.
7. Yee ST, Fearon JA, Gosain AK, et al. Classification and management of metopic craniosynostosis. *J Craniofac Surg.* 2015;26:1812–1817.
8. Jimenez DF, Barone CM. Endoscopic craniectomy for early surgical correction of sagittal craniosynostosis. *J Neurosurg.* 1998;88:77–81.
9. Shah MN, Kane AA, Petersen JD, et al. Endoscopically assisted versus open repair of sagittal craniosynostosis: the St. Louis Children's Hospital experience. *J Neurosurg Pediatr.* 2011;8:165–170.
10. Magge SN, Bartolozzi AR, Almeida ND, et al. A comparison of endoscopic strip craniectomy and pi craniectomy for treatment of sagittal craniosynostosis. *J Neurosurg Pediatr.* 2019;23:708–714.
11. Jimenez DF, Barone CM. Early treatment of anterior calvarial craniosynostosis using endoscopic-assisted minimally invasive techniques. *Childs Nerv Syst.* 2007;23:1411–1419.
12. Cohen SR, Holmes RE, Ozgur BM, et al. Fronto-orbital and cranial osteotomies with resorbable fixation using an endoscopic approach. *Clin Plast Surg.* 2004;31:429–42, vi.
13. Gociman B, Agko M, Blagg R, et al. Endoscopic-assisted correction of metopic synostosis. *J Craniofac Surg.* 2013;24:763–768.
14. Braun TL, Eisemann BS, Olorunnipa O, et al. Safety outcomes in endoscopic versus open repair of metopic craniosynostosis. *J Craniofac Surg.* 2018;29:856–860.
15. Jimenez DF, McGinity MJ, Barone CM. Endoscopy-assisted early correction of single-suture metopic craniosynostosis: a 19-year experience. *J Neurosurg Pediatr.* 2018;23:61–74.
16. Ha AY, Skolnick GB, Chi D, et al. School-aged anthropometric outcomes after endoscopic or open repair of metopic synostosis. *Pediatrics.* 2020;146:e20200238.
17. Pressler MP, Hallac RR, Geisler EL, et al. Comparison of head shape outcomes in metopic synostosis using limited strip craniectomy and open vault reconstruction techniques. *Cleft Palate Craniofac J.* 2021;58:669–677.
18. Kellogg R, Allori AC, Rogers GF, et al. Interfrontal angle for characterization of trigonocephaly: part 1: development and validation of a tool for diagnosis of metopic synostosis. *J Craniofac Surg.* 2012;23:799–804.
19. Nguyen DC, Patel KB, Skolnick GB, et al. Are endoscopic and open treatments of metopic synostosis equivalent in treating trigonocephaly and hypotelorism? *J Craniofac Surg.* 2015;26:129–134.
20. Anolik RA, Allori AC, Pourtaheri N, et al. Objective assessment of the interfrontal angle for severity grading and operative decision-making in metopic synostosis. *Plast Reconstr Surg.* 2016;137:1548–1555.
21. Weinberg SM, Raffensperger ZD, Kesterke MJ, et al. The 3D facial norms database: Part 1. A web-based craniofacial anthropometric and image repository for the clinical and research community. *Cleft Palate Craniofac J.* 2016;53:e185–e197.
22. Farber SJ, Nguyen DC, Skolnick GB, et al. Anthropometric outcome measures in patients with metopic craniosynostosis. *J Craniofac Surg.* 2017;28:713–716.
23. Mathijssen IM. Guideline for care of patients with the diagnoses of craniosynostosis: working group on craniosynostosis. *J Craniofac Surg.* 2015;26:1735–1807.
24. Roy T, Chavez J, Reid RR. Skin deep: perception of scars after cranial vault reconstruction. *Cleft Palate Craniofac J.* 2020;58:1376–1381.
25. Lajeunie E, Le Merrer M, Marchac D, et al. Syndromal and nonsyndromal primary trigonocephaly: analysis of a series of 237 patients. *Am J Med Genet.* 1998;75:211–215.
26. Bous RM, Hazen RA, Baus I, et al. Psychosocial adjustments among adolescents with craniofacial conditions and the influence of social factors: a multi-informant study. *Cleft Palate Craniofac J.* 2020;57:624–636.
27. Riklin E, Calandrillo D, Blitz A, et al. Examining the psychosocial needs of adolescents with craniofacial conditions: a mixed-methods approach. *Cleft Palate Craniofac J.* 2020;57:177–185.
28. Chan JWH, Stewart CL, Stalder MW, et al. Endoscope-assisted versus open repair of craniosynostosis: a comparison of perioperative cost and risk. *J Craniofac Surg.* 2013;24:170–174.
29. Han K, Jeong W, Kim J, et al. Subsegmental osteotomy technique with distraction osteogenesis for natural frontal contouring in metopic synostosis. *Cleft Palate Craniofac J.* 2019;56:101–104.
30. Fawzy HH, Choi JW, Ra YS. One-piece fronto-orbital distraction with midline splitting but without bandeau for metopic craniosynostosis: craniometric, volumetric, and morphologic evaluation. *Ann Plast Surg.* 2019;83:285–292.
31. Zubovic E, Lapidus JB, Skolnick GB, et al. Cost comparison of surgical management of nonsagittal synostosis: traditional open versus endoscope-assisted techniques. *J Neurosurg Pediatr.* 2020;25:1–10.
32. Bennett KG, Hespe GE, Vercler CJ, et al. Short- and long-term outcomes by procedure type for nonsagittal single-suture craniosynostosis. *J Craniofac Surg.* 2019;30:458–464.
33. Yan H, Abel TJ, Alotaibi NM, et al. A systematic review of endoscopic versus open treatment of craniosynostosis. Part 2: the nonsagittal single sutures. *J Neurosurg Pediatr.* 2018;22:361–368.
34. Hashim PW, Patel A, Yang JF, et al. The effects of whole-vault cranioplasty versus strip craniectomy on long-term neuropsychological outcomes in sagittal craniosynostosis. *Plast Reconstr Surg.* 2014;134:491–501.
35. Wes AM, Naran S, Sun J, et al. The Whitaker classification of craniosynostosis outcomes: an assessment of interrater reliability. *Plast Reconstr Surg.* 2017;140:579e–586e.