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Endoscopy-assisted wide-vertex craniectomy, barrel stave osteotomies, and postoperative helmet molding therapy in the management of sagittal suture craniosynostosis

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Object. Endoscopic techniques were introduced 7 years ago for the surgical management of patients with sagittal synostosis. In this study of 139 patients with sagittal synostosis, the authors assessed the efficacy, safety, complications, and outcomes after performing endoscopy-assisted wide-vertex craniectomies with bitemporal and biparietal barrel stave osteotomies.

Methods. The sample population consisted of a total of 99 boys and 40 girls who ranged in age from 0.4 to 9.2 months (mean 3.6 months). Two small incisions were made near the lambda and vertex. Using endoscopic visualization, wide-vertex craniectomies with bilateral temporal and parietal barrel stave osteotomies were performed. Postoperative treatment included custom-made surlyn cranial orthotic devices for cranial reshaping and maintenance.

The mean craniectomy width was 5.4 cm and the length was 10 cm. The overall blood transfusion rate was 9% (two intraoperative and 12 postoperative transfusions). The mean estimated blood loss was 29 ml (range 5–150 ml). The mean preoperative hematocrit was 32%, whereas the postoperative level was 27%. One hundred thirty-two patients were discharged the morning following surgery. The majority of patients did not experience facial swelling, and none suffered postoperative fevers. Anthropometric cephalic index measurements indicated that excellent results were obtained in 87% of the patients (cephalic index > 75); good results in 8.7% (cephalic index 70–75); and poor results in 4.3% (cephalic index > 70). There were no cases of intraoperative death, infection, hemorrhage, or venous sinus injury.

Conclusions. Analysis of the results indicates that use of the aforedescribed procedure in the early treatment of infants with sagittal synostosis provides excellent outcomes and that the morbidity rate is lower than that associated with traditional cranial vault reconstruction. Detailed anthropometric and radiographic analyses demonstrated that with adequate helmet therapy in our patients normocephaly was achieved and maintained without the need for secondary operations.

KEY WORDS • sagittal suture • craniosynostosis • endoscopy • craniectomy • orthotic helmet • scaphocephaly

SAGITTAL synostosis continues to constitute the most common type of craniosynostosis affecting infants. Since the introduction of surgical techniques for the management of scaphocephaly associated with this condition approximately 112 years ago, various procedures have been advocated and performed. During the last three decades, extensive craniectomies and cranial vault remodeling have been popularized by craniofacial and neurological surgeons.

The purpose of this study was to assess the efficacy, safety, complications, and outcomes associated with treating patients with sagittal suture synostosis in whom endoscopy-assisted wide-vertex craniectomies were performed with bitemporal and biparietal barrel stave osteotomies. Postoperatively custom-made cranial molding helmets were placed to achieve and maintain normocephaly.

The results of using endoscopic techniques in the management of sagittal synostosis are presented. We present follow-up data after the original introduction of the technique several years ago.[20]

Clinical Material and Methods

Patient Population

One hundred thirty-nine consecutive children in whom sagittal synostosis was diagnosed were treated during a 7-year period (May 1997–September 2003). The same surgical team performed all corrective interventions, which

Abbreviations used in this paper: AP = anteroposterior; CT = computerized tomography; CVR = calvarial vault remodeling; EBL = estimated blood loss.

helped to ensure consistent use of techniques throughout the study. There were 99 boys and 40 girls who ranged in age from 0.4 to 9.2 months (mean 3.6 months).

Preoperative and Postoperative Therapies

All patients underwent endoscopy-assisted wide-vertex strip craniectomies of the sagittal suture, as well as biparietal and bitemporal barrel stave osteotomies. One hundred nine patients underwent precordial Doppler monitoring for the occurrence of venous air embolism. Postoperatively a custom-made surlyn molding helmet was fitted and the therapy was continued for 12 months. The design of the helmet included a stocking cap that was placed over the child's head, and a fiberglass cast that, once applied, was allowed to set and harden. The cast was prepared and filled with plaster. The plaster mold pressure points were then marked and additional plaster was added to obtain the desired head contour. The mold was then polished using a dry window screen, placed under a propylene sheet, and heated. Once heated, a vacuum was used to seal and shape the propylene over the mold. After this procedure, ear holes and positioning slots were made and edges polished. Ethylene vinyl acetate lining and padding were applied to pressure points. Finally, light foam was inserted at the sides to prevent the helmet from shifting or rotating. All helmets were fabricated inhouse by members of the orthotics department. Each helmet costs $848. All patients required three to four helmets, making the total cost for this therapy between $2544 and $3392.

Measurements and Objectives

Anthropometric cephalic index measurements were determined preoperatively and during follow-up visits. Using cranial anthropometric spreading calipers (GPM Instruments, Zurich, Switzerland), the euryon–euryon and glabellar–opisthocranium measurements were obtained. By dividing the former by the latter and multiplying by 100, an index of cranial proportionality was obtained. All cephalic index values were compared with established age-matched normal values.

An initial objective was to track the temporal pattern of the cephalic indices that occurred over time. This was achieved by examining the children during a preoperative baseline visit and at follow-up examinations while they wore their molding helmets. The cephalic indices were used as an objective anthropometric outcome measurement.

Without taking into consideration patient age, these data were analyzed by stratifying the measurements obtained during clinical visits according to 1-month intervals for 20 months. This postoperative course was tracked and plotted using the monthly cephalic index mean and their respective two-tailed 90% confidence intervals.

The Student t-test with a predetermined corresponding alpha of 0.01 was used to determine the time interval in which a statistically significant postoperative change in mean cephalic index may have occurred for the sample population. Each monthly mean cephalic index was compared with the subsequent mean monthly cephalic index values.

We also examined significant surgery-related risks: 1) EBL; 2) duration of hospitalization; 3) duration of operation; 4) maximum postoperative body temperature; 5) infection rate; 6) the risk of air emboli; 7) injury to the sagittal sinus; 8) dural tears; 9) intraparenchymal injuries; 10) postoperative hematomas; 11) seizures; and 12) coagulopathies. These were described using descriptive statistics.

Standard photographs (AP, posteroanterior, lateral, and aerial) were taken during each postoperative visit. The majority of patients underwent CT scanning prior to surgery. Postoperative CT scans were obtained in some patients to permit radiographic comparison. Follow-up duration ranged from 1 to 93 months (mean 39 months). In the 1st postoperative year, cephalic index was measured, photographs obtained, and helmet adjusted monthly or bimonthly. Thereafter, the patients were followed annually.

Surgical Technique

After induction of inhalational sevoflurane a single 22-gauge intravenous line was placed. Nondepolarizing neuromuscular blockade was produced using a 0.3-mg/kg dose of cisatracurium. Fentanyl was given at 1 to 2 μg/kg along with a Tylenol (40-mg/kg) suppository for pain control. General anesthesia was maintained with continuous sevoflurane. The patients were positioned in a modified prone position on a heated and padded pediatric beanbag. A Bair Hugger heating unit (Augustine Medical, Inc., Eden Prairie, MN) was used to maintain normothermia throughout the procedure. A single 50-mg/kg dose of intravenous Cefazolin was administered immediately prior to beginning the procedure and the scalp was prepared with Betadine solution. A 2- to 2.5-cm incision was made behind the anterior fontanelle with its epicenter over the sagittal suture. A Bovie electrocautery unit (Valleylab, Inc., Boulder, CO) with a pencil tip set at low wattage (15 W) was used to develop a dissecting plane between the galea and the pericranium in a bloodless fashion. Visualization of this plane was established using a 0˚ 4-mm rigid rod lens Hopkins endoscope (GAAB Neuroendoscope; Codman and Shurtleff, Raynham, MA) and an Aufrichat rhinoplasty lighted retractor (Techman, Charlton City, MA). The dissection plane was directed posteriorly to the area of the lambda and laterally 3 to 4 cm on either side of the midline. A second midline transverse incision (2–2.5 cm) was made immediately anterior to the lambda. The subgaleal dissection was extended between the anterior and posterior incisions.

A burr hole was made on the lateral aspect of each incision by using a 7-mm cranial perforator (Acracut, Acton, MA). The dura mater from the bone beneath the stenosed sagittal suture was separated using a No. 1 Penfield dissector. An osteotomy across the midline, tailored to the width of the proposed strip craniectomy, was created with Kerrison rongeurs. At the midline, the osteotomy was extended anteriorly to reach the anterior fontanelle and fully release the closed suture in this area. In a similar fashion, a transverse midline osteotomy was made posteriorly in front of the lambda. A 30˚ angled 4-mm rigid endoscope was then inserted beneath the osseous edge of the anterior osteotomy and advanced posteriorly. The dura was gently moved away from the overlying bone by using a small (No. 7 French) malleable metal suction tip as a dissector. The suction tip was also used to remove any venous oozing from the endoscopic view. Because the normal dural interdigitation fibers that extend into an open suture are absent in craniosynostosis, the dura over the sagittal sinus was easily stripped off the stenosed sagittal suture. Occasionally, small perforating veins extending into the overlying bone were encountered. These were easily cauterized and sharply incised under direct endoscopic visualization without complication. Dural dissection was continued until the posterior osteotomy was reached.

After complete dissection of the bone from the dura and scalp, bone-cutting or Mayo scissors were used to connect the lateral aspects of anterior and posterior osteotomies. The wide-strip craniectomy material was then removed via the anterior incision in either one or two segments. Dissection of the dura from the bone extending from the lateral edge of the craniectomy toward the squamosal suture was accomplished using an insulated brain retractor or a blunt dissector. Curved Mayo scissors were used to create barrel stave osteotomies laterally and inferiorly toward the squamosal suture in the temporal and parietal regions. A small wedge of bone was removed, and a linear osteotomy was extended to the squamosal suture. These osteotomies were placed immediately behind the coronal sutures and immediately anterior to the lambdoid sutures. No osteotomies or bone resection were used for the frontal or occipital bones. Although overall hemostasis was obtained using thrombin and Gelfoam, osseous hemostasis was achieved using a suction coagulator (Valleylab, Inc.) set at 50 W. In infants with thin bone, a single pass with the suction electrocautery unit usually sufficed. In patients with thicker bone, multiple passes were needed to obtain complete coagulation. To prevent injury to the dura or scalp, insulated brain bands were used for protection during cauterization. The wounds were closed with a galeal 0000 vicryl and the skin sealed with Mastisol and a single steristrip. The criteria used for blood transfusion included a hematocrit less than 19% as well as tachycardia ($>$ 170 beats/minute) and/or hypotension or oxygen saturation less than 90%. Within 1 week of surgery, after scalp swelling had subsided, a mold of the patient's head was created with plaster-of-Paris and a custom helmet was made of durable surlyn. These helmets were designed to correct and minimize growth in the AP direction, at the frontal and occipital bones, while allowing expansion of the cranium in the transverse and lateral dimensions. After appropriate parental training, the patients wore the helmets for approximately 11 to 12 months. As the child's head grew and the helmet was outgrown, new helmets were fitted to continue correction and maintain normocephaly.

Results

One hundred thirty-nine children were treated with the aforementioned procedure. There were 99 boys (71%) and 40 girls (29%). Multiple-suture synostosis was present in seven patients. The mean age at the time of surgery was 3.6 months (median 3.2 months; range 0.4–9.2 months; Fig. 1 *upper left*). The mean weight at the time of surgery was 6.32 kg (median 6.35 kg; range 2.98–9.54 kg). The estimated blood volume mean was 510 ml (median 509 ml, range 264–763 ml). The size of the strip craniectomy varied inversely with the patient's age. The mean width was 5.4 cm (range 1.5–8 cm) and the mean length was 10 cm (range 4.5–15 cm). In all cases the procedure was successfully performed without need for discontinuation or conversion to an open procedure.

The mean intraoperative infusion of crystalloids was 227 ml (range 40–680 ml). Only two patients (1.4%) required intraoperative blood transfusion (160 and 75 ml, respectively). Postoperatively, 12 patients required blood transfusions (mean 56 ml, range 45–230 ml) for reasons that were not life threatening. The mean EBL was 29 ml (median 25 ml, range 5–150 ml; Fig. 1 *upper right*). The estimated percentage of blood loss mean was 5.7% (median 4.9%, range 1.3–26.4%). One hundred thirty-two patients (95%) were discharged on the 1st postoperative day, five (3.6%) on the 2nd day, one patient (0.7%) on the 3rd day, and one patient (0.7%) on the 4th postoperative day (Fig. 1 *lower left*). The mean operative time was 59.6 minutes (median 56 minutes, range 30–150 minutes) (Fig. 1 *lower right*). Longer operative times were required in the seven patients with multiple-suture synostosis. No infections occurred. Pyrexia was uncommon with a mean maximum postoperative temperature of 37.6˚C (range 36.1–39.5˚C). No patient suffered an air embolus; therefore, air embolus was not an observed risk. There were no direct injuries or tears to the sagittal sinus. There were no dural tears or intraparenchymal injuries, postoperative hematomas, seizures, or intraoperative deaths.

Five patients developed small areas of superficial skin irritation along sections of the incision line. These appeared to be secondary to skin moisture and helmet lining–induced maceration. Removal of the helmet for several days resolved this problem. There were no residual scars or areas of alopecia. In four patients, the area of the anterior fontanelle reossified abnormally, leading to a raised calvaria. The amount of osseous elevation was approximately 5 mm and has significantly resolved in older patients. In all patients the anterior fontanelles were persistently raised and pulsatile. The cephalic index was used in an attempt to quantify the overall changes in cranial shape pre- and postoperatively. A low cephalic index ($<$ 75) indicated scaphocephaly, whereas a high cephalic index ($>$ 80) indicated brachycephaly. In our patients, the mean preoperative cephalic index was 67.4 and varied between 61 (5th percentile) and 90 (95th percentile). Cephalic indices greater than 75 were found in the seven patients who presented with concomitant coronal or lambdoid synostosis. The greatest change in postoperative cephalic index occurred during the initial 2 months. After the 2nd postoperative month, the mean cephalic index reached a consistent plateau near 80 (Fig. 2). The temporal pattern of cephalic index was statistically significant between Months 0 and 1 ($p < 0.0001$) and Months 1 and 2 ($p = 0.0007$) (Table 1).

Discussion

Although Stahl and Hyrtl appear to be the originators of the concept that skull deformities are due to premature calvarial suture closure, in 1851 Virchow first proposed an organized and cohesive theory regarding the pathophysiology of craniosynostosis.[36] Thirty-seven years later, the

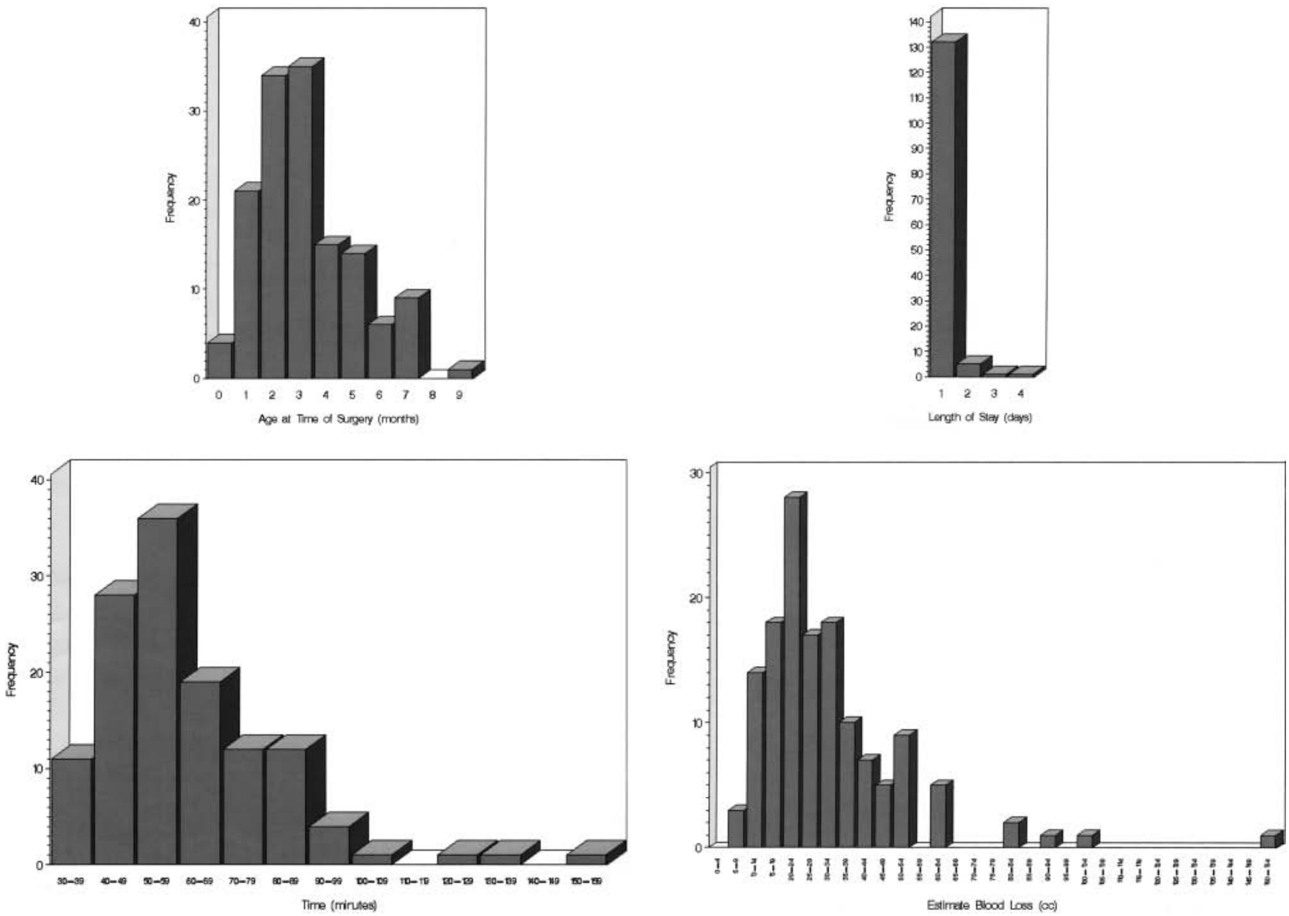

FIG. 1. Bar graphs. *Upper Left:* Distribution of patient ages at time of surgery. The mean age was 3.5 months (range 0.5–9.5 months) *Upper Right:* Estimated blood loss. The mean EBL was 29 ± 19 ml (range 5–150 ml). This gaussian curve is skewed to the left showing that surgery favored a low EBL. *Lower Left:* Length of hospital stay. The majority (94.5%) of the patients stayed in the hospital 1 day. A single patient with a history of premature birth was hospitalized for 4 days. *Lower Right:* Duration of surgery. Operative time is depicted in minutes compared with frequency. The mean operative time was 58 minutes (range 30–133 minutes). The data plot is skewed to the left favoring short operative times and reduced anesthesia risks.

first attempt at treating a 9-month-old patient with craniosynostosis and microcephaly was reported by Lane.[24] He described removing a 1-in strip of bone extending from the anterior to the posterior fontanelle and following this with bilateral parietal osteotomies "resembling a cross." His report was preceded in the literature by Lannelongue,[25] who in 1890, described a linear craniectomy that involved removing a strip of bone from the calvaria parallel to the obliterated sagittal suture. In 1894, Jacobi[18] reported significant morbidity and mortality rates in a series of 33 patients, and this ultimately led to discontinuation of craniosynostosis surgery for the next three decades. Faber and Towne[11] reintroduced the practice of surgical intervention in patients with craniosynostosis for the prevention of blindness and other complications. In that and in a later report,[12] they stressed the need to operate in infants between the age of 1 and 3 months.

Subsequently, neurosurgeons opted to treat craniosynostosis surgically by performing strip craniectomies or other various modifications.[2,3,8–10,15,23,38,39,41] Inconsistent results achieved using simple strip craniectomies led surgeons to develop more complex and invasive procedures.[6,14,21,29,31,35,43] Some of these have included midline vertex craniectomy,[4] π and reverse-π procedures,[6,17,19,21] total vertex craniectomy,[10] bilateral parietal flap craniectomies,[37] sagittal strip with circular occipital and parietal wedge craniectomies,[1] keyhole craniectomy,[30] and various other types of CVR.[7,26–29,42]

Calvarial vault remodeling is currently the technique of choice in many craniofacial centers. The reported CVR-related blood loss is significant, ranging from 300 to 1500 ml.[13,19,22,32] Operative times range between 4 and 8 hours.[16,33] Hospitalization rates range between 4 and 7 days. Blood transfusions are a universal necessity, ranging from 25 to 500% of the patient blood volume.[7,14,16,18,22,33] Complications include syndrome of inappropriate secretion of antidiurectic hormone, hypotension, and cardiovascular collapse secondary to unrecognized hemorrhage,[6] dural tears,[10] embolism,[16] sagittal sinus tears, hypophosphatemia,[18] hyponatremia, and residual calvarial defects.[7]

Although previous authors have proposed that the problem with sagittal craniosynostosis rests with skull base

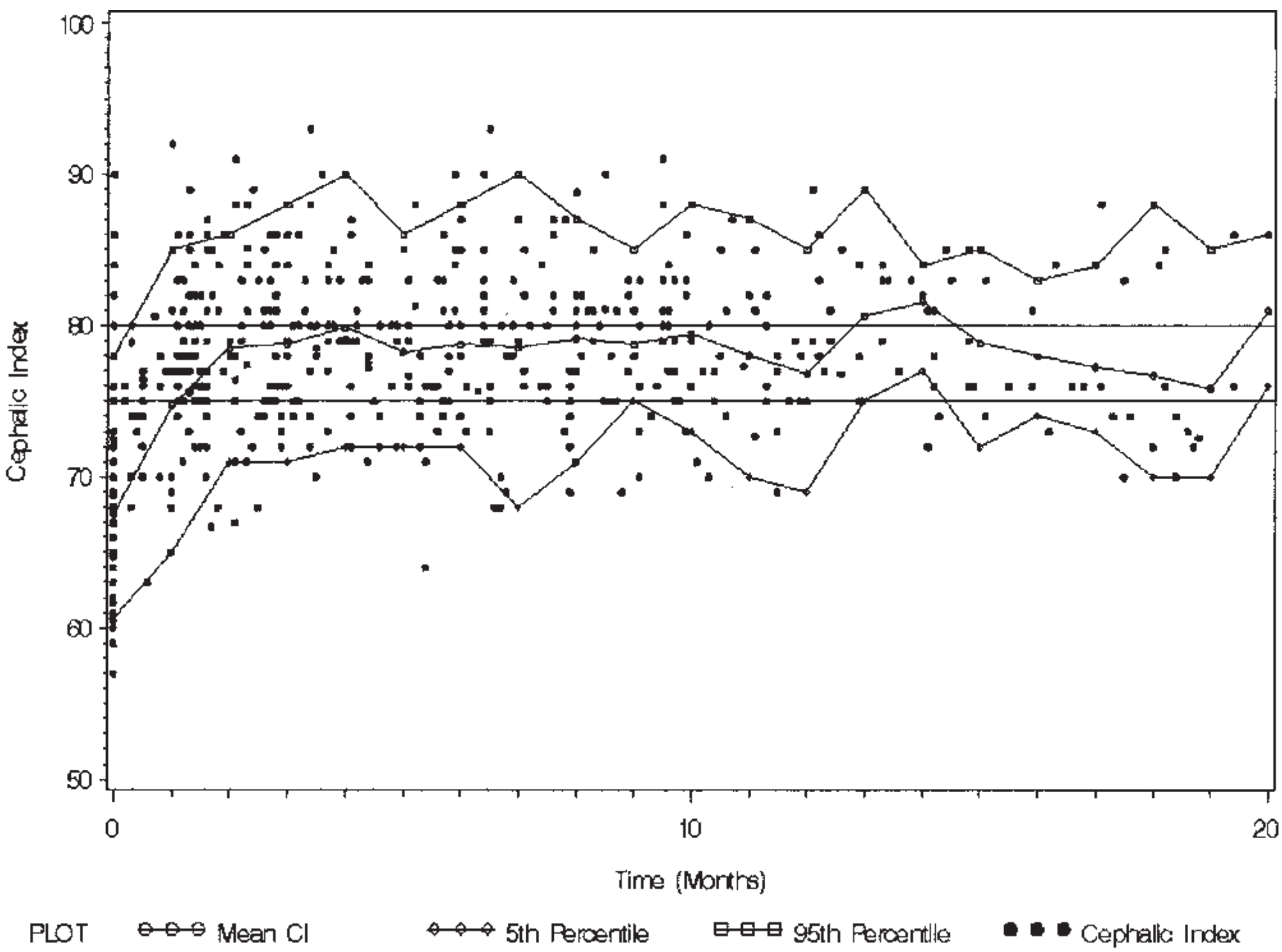

FIG. 2. Scatter plot showing changes of cephalic index over time in months (mean, 5th percentile, and 95th percentile).

abnormalities,[42] careful review of modern high-resolution CT scans failed to demonstrate closure of any of the skull base synchondroses or sutures. Calvarial deformities appear simply to be due to restrictive calvarial growth and the associated compensatory changes following closure of the sagittal suture. The type of deformity is directly related to which part(s) of the suture is stenosed and how early the closure occurs. We are in agreement with many authors that early release of the stenosed suture will halt the progressive deformity and lead to a certain degree of correction. There is, however, a tendency for the skull to resume a scaphocephalic shape within the 1st year of life. Premature reossification is also a problem when performing small-strip craniectomies and synostectomies.

Significant controversy remains in the neurosurgery, plastic surgery, and craniofacial surgery literature regarding the optimal procedure for treating sagittal synostosis. Proponents of both camps have cited the benefits of each procedure.[34,40] We have performed a large number of CVR procedures and have significant experience with these types of interventions. Excellent results can indeed be achieved but often at a significant cost to the patient. Long operative times, increased blood loss, long hospitalizations and significant scalp and facial swelling, fevers, and pain are universally seen in these cases. Microtitanium plates and screws or wires have been extensively used in craniofacial surgery. A number of these plates and screws, however, have been found to migrate through the bone, dura, and into the brain, necessitating removal.[5] Other causes for explantation include loosening of the plates and screws as well as cyst formation around them. Inappropriate fusion of the bone graft often leads to uneven ossification producing many "bumps and lumps." Fortunately, in recent years, these problems have been addressed by placing absorbable fixation systems. Nevertheless, the long-term results associated with these systems will determine their efficacy.

The procedure presented in this study was developed to decrease the problems commonly associated with CVR procedures. There is, however, a learning curve, particularly with the use of endoscopes. Surgeons not familiar with endoscopic techniques and the associated equipment will find it demanding. With experience, we have simplified the operation and operative time is now approximately 45 to 60 minutes, and EBL ranges from 10 to 30 ml. A key to decreasing blood loss has been the generous use of Gelfoam and thrombin spray. Additionally, most bleeding occurs from the diplöe after the osteotomies. Significant decrease in blood loss has occurred since the introduction of the suction coagulator for direct cauterization of the bone. Perhaps the most challenging cases have been those in which bridging emissary veins extend from the sagittal sinus into overlying osseous channels. With endoscopic assistance and bipolar cautery, however, we have been successful in cauterizing and sectioning those veins without causing bleeding, adverse effects, or injury to the sinus itself. Although concerns exist about injury to the sagittal sinus during dissection of the stenosed bone, by definition, the dural attachments to the suture disappear in craniosynostosis. This fact allows for a relatively atraumatic dissection of the dura. We did not observe any case in which the sagittal sinus was injured in our population.

There has been no need for repeated operation in any of our patients, except for three patients requiring ventriculoperitoneal shunts who presented with headaches, elevated intracranial pressure, and ventriculomegaly. Cosmetically, smooth cranial and forehead contours have been achieved in all cases except in the five patients in whom mild hyperostosis developed over the anterior fontanelle. One patient underwent a procedure to remodel the area of hyperostosis.

We graded our results using changes in cephalic index as the end point. These results were also corroborated by evaluating pre- and postoperative standardized photographs. The results were considered to be excellent in patients in whom a cephalic index of 75 or greater was achieved; good results in those in whom the cephalic index was 70 to 75; and poor in those in whom the cephalic index was less than 70. In cases in which the initial cephalic index was greater than 70, the degree of correction of frontal bossing, turricephaly, or widening of the forehead was used to judge results. We found excellent results were achieved in 87% of patients, good results in 8.7%, and poor results in 4.3%. The results indicate that the best outcomes were obtained in patients younger than 3 months of age with fully compliant parents (Fig. 3). Very good results, however, were also observed in patients who were younger than 6 months of age when surgery was performed (Fig. 4). Consistent excellent long-term results were demonstrated in a patient with one of the longest follow-up periods and in whom surgery was performed when he was 2 months of age. His 6.5-year follow-up photographs are shown in Fig. 5. Factors associated with poor results were found to include: 1) small-strip craniectomies; 2) parental noncompliance in terms of the cranial orthosis; and 3) improper helmet shape. An example of what we considered to be our worst result is seen in Fig. 6. This patient had undergone a small-strip craniectomy (1.5-cm) and improper helmet fitting during the 1st postoperative year.

Changes in cranial shape occur immediately after surgery is initiated and are noted postoperatively. Bifrontal bossing, commonly seen in sagittal synostosis, is due to a compensatory growth response of the frontal lobes to the restrictive forces placed on the posterior frontal and parietal lobes by the stenosed sagittal suture. There are no intrinsic pathological or anatomical abnormalities associated with the frontal bones. By restricting AP growth while allowing bilateral expansion of the brain, the malleable head deformity of an infant can be easily corrected using a properly fitted helmet. There is no need to address frontal or occipital bossing surgically; molding helmet therapy has corrected these conditions.

TABLE 1

Summary of data stratified by respective follow-up months

Comparison Mos	t Test Statistic	p Value	Statistically Significant
0–1	−6.75	<0.0001	yes
1–2	−3.51	0.0007	yes
2–3	−0.27	0.7878	no
3–4	−0.92	0.3582	no
4–5	+1.41	0.1642	no
5–6	−0.43	0.6660	no
6–7	+0.14	0.8911	no
7–8	−0.39	0.6984	no
8–9	+0.32	0.7536	no
9–10	−0.58	0.5663	no
10–11	+0.89	0.3796	no
11–12	+0.75	0.4575	no
12–13	−2.66	0.0126	no
13–14	−0.55	0.5886	no
14–15	+1.54	0.1418	no
15–16	+0.38	0.7098	no
16–17	+0.26	0.7988	no
17–18	+0.14	0.8885	no
18–19	+0.29	0.7797	no
19–20	−1.12	0.2936	no

Based on our results, it appears that there is no need to undertake frontal or occipital craniotomies and reshaping in these patients because these bones do not have intrinsic osseous anomalies and all other sutures are open. Complete correction can be achieved after release of the stenosed sagittal suture and postoperative helmet-based remolding. Increases in the euryon–euryon distance are evident immediately after removing the bone and creating barrel stave osteotomies. The mean cephalic index increase was 1.3%, from 67.4 to 68.7, on closure of the scalp. Recession of a prominent forehead is also evident soon after surgery.

The molding helmets have helped to achieve normal cephalic indices and calvarial proportions. Because of the significant immediate postoperative changes in the head shape and because of a small amount of subgaleal swelling seen in the early postoperative period, helmet therapy is not instituted until the 4th or 5th postoperative day. The helmets are worn 11 to 12 months after surgery. The tendency to resume a scaphocephalic shape, often seen in these patients, can be successfully counteracted by applying a molding helmet, which is worn during the critical period of rapid brain growth during the first 12 months of life. Thereafter, there is significant deceleration of brain growth, thereby decreasing the possibility of relapse. Close follow-up examination and proper helmet shaping and fitting are of utmost importance, because an improperly fitting helmet will certainly yield poor results. We believe that the high percentage of good and excellent results are due to the combination of early suture release and helmet therapy (Fig. 7). Our observations support the use of molding helmets for up to 12 months. Postoperative helmet therapy can be roughly divided into three phases: Phase I, Months 1 to 2, when the first helmet is used to achieve a normal cephalic index; Phase II, Months 3 to 6, when the second helmet is used to overcorrect cephalic index; and Phase III, Months 6 to 12, when the third helmet is used to maintain normocephaly and a normal cephalic index. We have

FIG. 3. Photographs of a 7-week-old girl. A: Sagittal synostosis and early frontal bossing. B: Bifrontal bossing and occipital cupping. C: The cephalic index was 70, indicative of significant scaphocephaly. D: Early results at 6 weeks showing marked improvement and lateral expansion of the frontal and parietal bones. E and F: Six weeks after surgery, the cranial vault has been overcorrected and a round shape obtained. Early overcorrection is needed to counteract normal tendencies to regain scaphocephalic shape. G: Anteroposterior view shows normalization of head shape at 8 months. H and I: With the aid of molding helmets, normal head shape was achieved at 8 months. Cephalic index was 82.

observed that once a patient reaches 18 months of age, cephalic index will be maintained in the long term with very little, if any, drop off. Cranial shape in patients who have reached 3 years of age, in whom normocephaly and normalized cephalic index have been achieved, tends to be maintained. It is extremely unlikely that the cranial shape will revert to abnormal shape because most cranial growth (85%) has been achieved by this age. Although we understand that the cephalic index is only a crude measure of overall skull shape, it nevertheless provides the observer

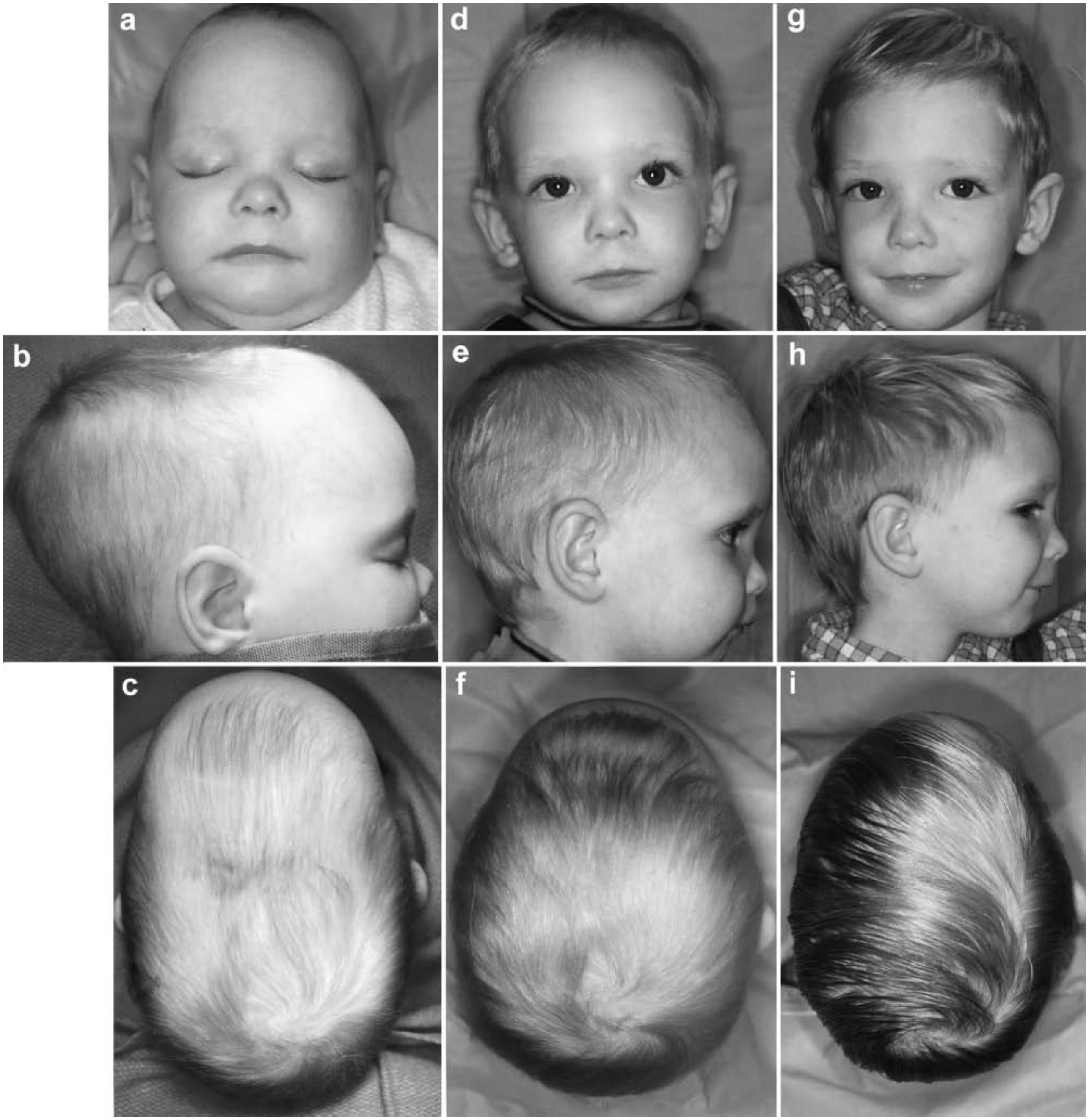

FIG. 4. Photographs obtained in a patient with craniosynostosis. A: Preoperative view of 5.5-month-old infant demonstrating classic narrowing of the frontotemporoparietal areas. B: Lateral view showing marked scaphocephaly. Occipital bossing is noted secondary to synostosis of the mid- to posterior sagittal suture. C: Coronal view showing the scaphocephalic shape. The preoperative cephalic index was 68. D: Image obtained 15 months postoperatively demonstrating expansion of cranial vault laterally. A residual amount of bitemporal narrowing remains. E: Significantly less occipital bossing is noted at 15 months after endoscopic surgery. F: Coronal view showing marked expansion of the biparietal diameter and normalization of cephalic index to 76. G–I: At 2.7 years after surgery excellent correction of severe scaphocephalic deformity has been achieved.

with a relative objective anthropometric measurement that can be used to follow trends in head morphology and skull proportionality.

In this study we found that the surgery-related risks were low or negligible in this sample population. The mean EBL was low (29 ml). The overall blood transfusion rate (intra- and postoperative) was 9%. In the majority (95%) of cases hospitalization stay ended on postoperative Day 1. The mean operative time was less than 1 hour, with the longer operative times representing surgery in

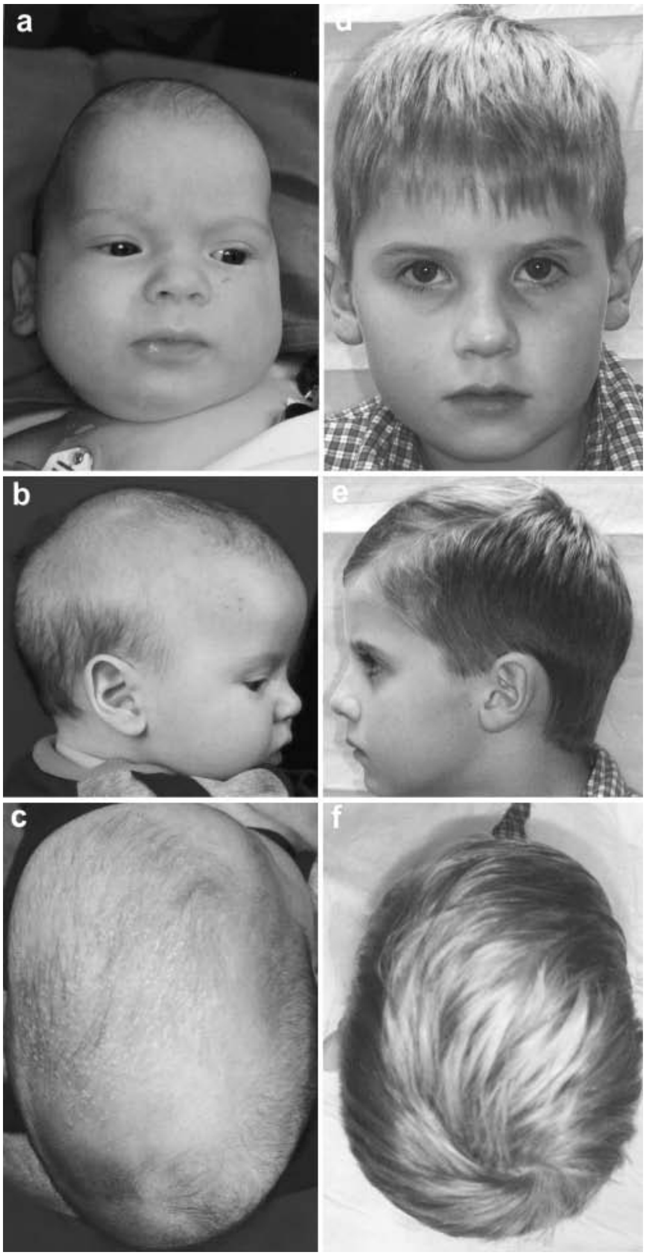

FIG. 5. Photographs obtained in a 3-month-old boy. A: Severe bifrontal bossing and bitemporal narrowing can be seen. B: Preoperative view showing scaphocephalic shape, occipital cupping, and upward calvarial expansion anterior to the lambda. C: The scaphocephalic shape is evident in this coronal image prior to surgical release of sagittal suture. D: Seven-year postoperative image. Correction of bifrontal bossing was achieved at 3 months postoperatively and maintained to 7 years. E: Appropriate cranial proportion has been attained. The cephalic index normalized at 18 months at 75.7, and at 7 years after surgery it was 72. F: Complete normalization of head shape was successfully achieved by 7 years.

FIG. 6. Photographs of a patient treated early in our series. A: At 2 weeks of age, immediately prior to surgery, a prominent midline ridge was palpated and early scaphocephaly was seen. B: Closure of posterior sagittal suture shows narrowing of occipital area with relatively wide posterior frontal area. C: Given early age at diagnosis, the frontal area is not protruding, but the occiput does show posterior expansion. D: Five years after surgery persistent vertex peaking is present. A less than optimal result is seen in this patient who underwent a small-strip craniectomy (1.5-cm) and inadequate helmet therapy. E: Slight turricephaly is noted as well as occipital prominence. The patient developed headaches and ultimately required placement of a ventriculoperitoneal shunt. F: Results in this case were considered poor. At 5 years his cephalic index was 70. He remains asymptomatic and is well after shunt placement.

patients with multiple-suture synostosis. The risk of anesthesia-related complications was diminished because operative time was reduced. The rates of infection, air embolus, injury to sagittal sinus, dural tear, intraparenchymal injury, postoperative hematoma, seizure, and coagulopathy were zero in this study. Therefore, the overall morbidity rate was low.

The same surgical team performed all corrective interventions. Thus, variability among surgeons and technique could not be examined. Statistically significant change in a patient's cephalic index occurred during the first 2 postoperative months. The cephalic index was thereafter maintained. It was assumed that these patients adhered to

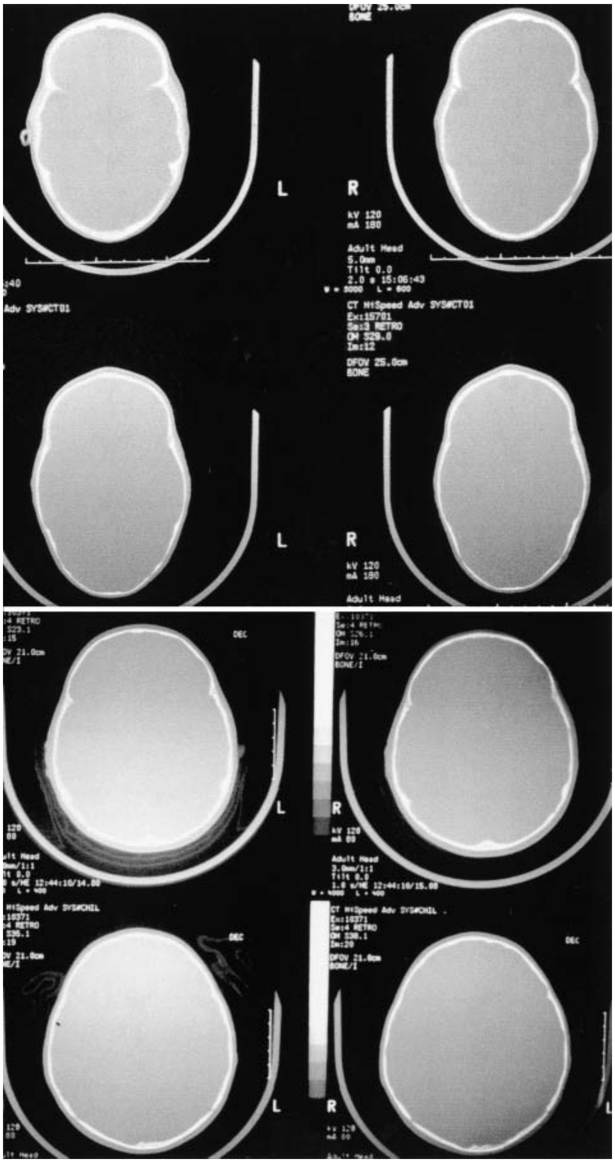

FIG. 7. Axial CT scans. *Left:* Preoperative scans revealing significant scaphocephaly in a 6-week-old infant. *Right:* Scans obtained 16 months after surgery demonstrating correction of the preoperative deformity.

the use of the molding helmet through the 12th postoperative month. After that time, no statistical change in cephalic index was found.

In this study a concern regarding when to remove the molding helmet without affecting the cephalic index was raised. Its premature removal might precipitate a return or near return to a scaphocephalic head shape. The only way to assess a temporal threshold for the molding helmet's removal would be to evaluate a population within which different groups would be stratified to wear these helmets for different periods of time.

Conclusions

Endoscopy-assisted wide-vertex craniectomies, bilateral barrel stave osteotomies, followed by custom-molded helmet therapy in infants with craniosynostosis provided the treating surgeon with an excellent alternative for the treatment of this disorder. Our results indicate superior outcomes can be achieved in a great proportion of the patients. In addition to the excellent results, this procedure was associated with significantly lower morbidity, blood loss, transfusion rates, and hospital stays.

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