Sagittal Synostectomy With Tension Band Sutures for Correction of Sagittal Craniosynostosis

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Received, April 10, 2023; **Accepted,** May 31, 2023; **Published Online,** August 14, 2023.

BACKGROUND AND OBJECTIVES: Premature fusion of the sagittal suture is the most common form of craniosynostosis and can be treated using a variety of open or endoscopic approaches. Existing approaches have varying degrees of effectiveness. Open approaches, whether performed early or late, can be associated with significant blood loss and the need for transfusion. Endoscope-assisted approaches are minimally invasive but require months of postoperative helmet therapy to help remodel the skull. Implantation of springs or distractors requires a second operation for removal of the devices. Here, we present an alternative technique for early correction of sagittal craniosynostosis combining sagittal synostectomy with tension band sutures to remodel the skull without need for transfusion or helmet therapy.
METHODS: We retrospectively reviewed the medical records of all patients treated for sagittal craniosynostosis using a synostectomy with tension band sutures at a single tertiary care institution. Data on patient demographics, operative factors, and postoperative course were collected.
RESULTS: Thirty-four patients underwent the novel procedure. The median preoperative cephalic index was 68 and improved to 76 immediately postoperatively. The median blood loss was 10 mL while the operative duration was 112 minutes. No blood transfusions were needed. One small dural laceration was encountered that was promptly repaired. There were no postoperative complications. Patients presenting for follow-up visits showed continued improvement in head shape and cephalic index.
CONCLUSION: A modified sagittal craniectomy with tension band sutures to remodel the skull is effective in achieving immediate correction of sagittal craniosynostosis. The correction remains durable over long-term follow-up. Importantly, the technique can be performed with minimal blood loss and reduces transfusion risk, operative time, and overall morbidity compared with traditional open approaches while avoiding the need for helmet therapy necessitated by endoscopic approaches.

KEY WORDS: Cranial vault reconstruction, Craniosynostosis, Sagittal synostosis, Scaphocephaly, Strip craniectomy, Synostectomy, Transfusion

Operative Neurosurgery 00:1–9, 2023 https://doi.org/10.1227/ons.0000000000000851

Sagittal craniosynostosis refers to premature fusion of the sagittal suture resulting in abnormal elongation and narrowing of the skull.[1] A predictable cranial deformation of scaphocephaly is seen on physical examination, referring to the elongated inverted "boat-shaped" appearance of the head with a "keel" along the sagittal suture.[2] Premature fusion of the sagittal suture is the most common form of craniosynostosis, affecting nearly 40% to 60% of cases, with a greater prevalence in men.[1] Although sporadic cases are most common, syndromic craniosynostosis occurs in 10% to 20% of patients and can present with involvement of multiple sutures.[3] Most children with sagittal craniosynostosis are neurologically and developmentally normal; however, some studies raise concern for potential neurocognitive deficits and delay of developmental milestones.[4,5] Scaphocephaly may also cause significant psychological impairment in children.[6,7]

Surgical intervention is recommended in most cases.[8] Surgery can be performed early or late using several open approaches. Endoscope-assisted approaches have gained popularity because they reduce blood loss, operative time, and cost and can be performed safely in infants within the first several months of life.[5,9] However, patients and caregivers must adhere to cumbersome postoperative helmet therapy for months after surgery to achieve optimal results.[10] Open procedures (eg, cranial vault reconstructions) can be

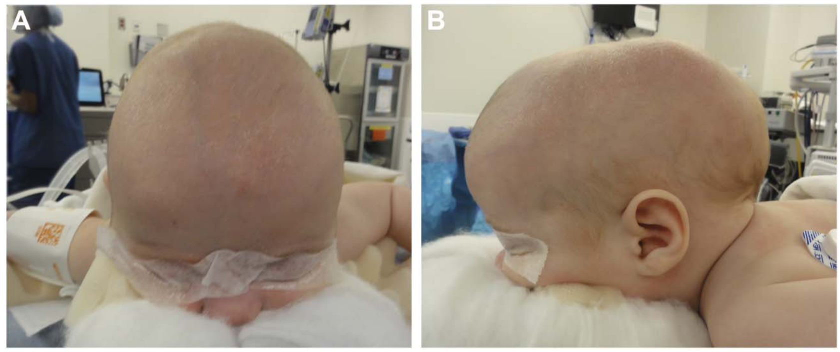

FIGURE 1. **A**, *Anterior and* **B**, *sagittal views of an infant in the sphinx position with the head extended and supported on a horseshoe rest.*

performed for older children but are associated with greater morbidity and blood loss.[11]

Here, we describe our experience with an alternative technique for achieving early correction of sagittal craniosynostosis using a modified sagittal synostectomy with tension band sutures to remodel the skull. The sutures place tension on the bone, shortening the anteroposterior diameter of the skull encouraging it to regenerate from the dura in a more rounded fashion. The technique can be performed in young infants with minimal blood loss and a short hospitalization without the need for blood transfusion or postoperative helmet therapy.

METHODS

Data Collection

After obtaining Institutional Review Board (IRB) approval (IRB00337491), we retrospectively reviewed the medical records of all patients treated for sagittal craniosynostosis using a modified synostectomy with tension band sutures at a single tertiary care institution between June 2017 and July 2022. Patient consent for the review was not deemed required by the IRB. Information on patient demographics, operative factors, and postoperative course was collected. Preoperative and postoperative hemoglobin levels were collected, along with complications, length of stay, and need for reoperation. More recently, we have measured the cephalic index preoperatively and immediately postoperatively and at follow-up visits using measuring tape. Patients/legal guardians consented to publication of their images.

Surgical Technique

The procedure is performed under general endotracheal anesthesia. An arterial line is not routinely used, although is sometimes placed at the request of the anesthesia team. Blood is available for transfusion because the procedure involves bone removal directly over the superior sagittal sinus, but transfusion has not been necessary. Intravenous cefazolin is administered along with tranexamic acid to reduce blood loss. The patient is placed prone in a sphinx position on chest rolls with the head extended and supported on a horseshoe rest with foam padding under the malar eminences (Figure 1A-1B). A thin swath of hair is shaved, and the patient

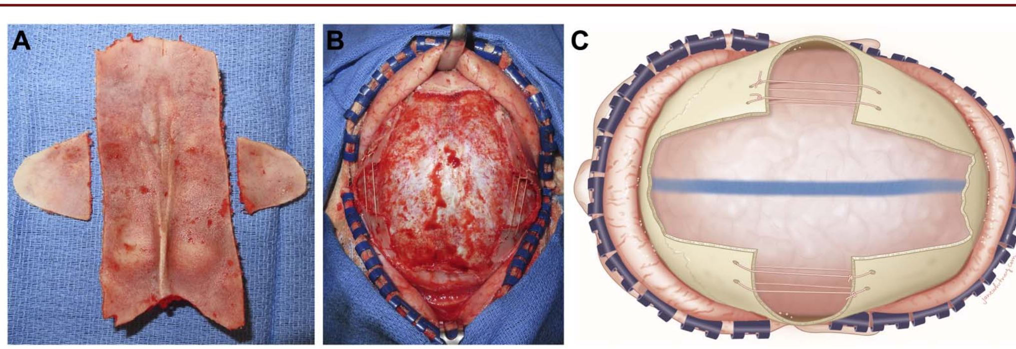

FIGURE 2. **A**, *Excised undersurface of fused sagittal suture with U-shaped cuts in the bone positioned laterally.* **B**, *Holes are drilled in the U-shaped cuts, allowing for placement of sutures in the anteroposterior dimension to provide tension. The extent of the craniectomy is also visible, along with the Raney clips for hemostasis.* **C**, *Illustrated representation of the sutures connecting the U-shaped cuts and providing tension.*

is prepared and draped in a sterile fashion. The scalp is infiltrated with a dilute solution of bupivacaine and epinephrine. An incision is made in the coronal plane from pinna to pinna midway between the bregma and lambda. The subcutaneous tissue is opened with a Colorado monopolar needle. Raney clips are applied over sterile sponges to maintain hemostasis. The scalp is mobilized anteriorly and posteriorly in the supra-pericranial plane taking care to avoid bleeding.

The fused sagittal suture is identified. A biparietal craniectomy is fashioned from the coronal sutures to the lambdoid sutures extending about 2.5 to 3 cm off midline on each side. This is performed by making suturectomies at the coronal sutures using a small curette or Dingman #9 dissector. Suturectomies can sometimes be made posteriorly at the lambdoid sutures, though occasionally small burr holes are created here, where the skull is thicker, using a matchstick drill. Next, a line of bone is removed from side to side using Kerrison punches. Anteriorly this is done just posterior to the coronal sutures and posteriorly just anterior to the lambdoid sutures. Bone bleeding is controlled with Floseal (Baxter). Lateral cuts are made on each side of the parietal bones with a power craniotome and the parietal bones along with the fused sagittal suture are carefully stripped and removed from the underlying dura and superior sagittal sinus (Figure 2A). Epidural bleeding, if present, is controlled with a bipolar forceps and warmed saline irrigation, minimizing suctioning or touching of the dura. The bone is not replaced.

A lateral U-shaped segment of the parietal bone is removed on each side using a craniotome midway between the coronal and lambdoid sutures. Small drill holes are made medially at the front and back ends of the U-shaped craniectomies, and 2-0 Vicryl sutures are inserted to place tension on the bone in the anteroposterior dimension to promote regrowth of the skull from the dura in a more rounded fashion (Figure 2B-2C). Care is taken not to kink the superior sagittal sinus.

The scalp is closed using interrupted inverted 3-0 Vicryl sutures for the galea and 4-0 absorbable Rapide sutures for the scalp. No drain is used. A sterile headwrap is placed. The child is extubated, and postoperative monitoring is performed on the ward in an intermediate care facility. The intensive care unit is not used.

The cephalic index is recorded at the beginning of the procedure and immediately after closing. Preoperative and postoperative hemoglobin are drawn, and a single follow-up heel stick hemoglobin is checked after 12 hours.

Statistical Analysis

Data were analyzed using STATA version 16. Summary data are presented as counts and percentages for categorical and ordinal data while continuous variables are represented as median and IQR.

RESULTS

Thirty-four patients were identified as having undergone modified sagittal synostectomy with tension band sutures at our institution. Summary statistics are provided in Table. The median age at the time of operation was 14 (IQR: 5) weeks, and 26 (76%) patients were male. The median head circumference was 42 (IQR: 2) cm and cephalic index was 68 (IQR: 4). The median operative duration was 112 (IQR: 39) minutes. Tranexamic acid was used in 24 (71%) patients, and all patients remained hemodynamically stable during surgery and in the postoperative period. No patients required a transfusion. One patient had a small dural laceration that was promptly repaired. The hemoglobin dropped from a median of 10.0 g/dL preoperatively to 8.9 g/dL postoperatively.

TABLE. Demographic and Operative Characteristics for 34 Patients Undergoing Sagittal Synostectomy With Tension Band Sutures

Variable	Count (%)	Median (IQR)
Demographics		
Age (wk)		14 (5)
Sex		
Male	26 (76)	
Female	8 (24)	
Family history	6 (18)	
Head circumference (cm)		42 (2)
Operative		
ASA score		
1	12 (35)	
2	21 (62)	
3	1 (3)	
Operative time		112 (39)
Transfusion	0 (0)	
Estimated blood loss (mL)		10 (7)
Intraoperative complications	1 (3)	
Dural laceration	1 (3)	
Hemoglobin		
Preoperative (g/dL)		10.0 (2)
Postoperative (g/dL)		8.9 (2)
Cephalic index		
Immediate preoperative		68 (4)
Immediate postoperative		76 (4)
Postoperative		
Complications	0 (0)	
Length of stay		2 (0)
Reoperation	0 (0)	

ASA, American Society of Anesthesiology.

There were no postoperative complications, and all patients were discharged home after a median length of stay of 2 days. Toward the end of this series (after 27 cases), our protocol was modified to allow discharge after 1 day, owing to the promising results and safety profile of the procedure. The average

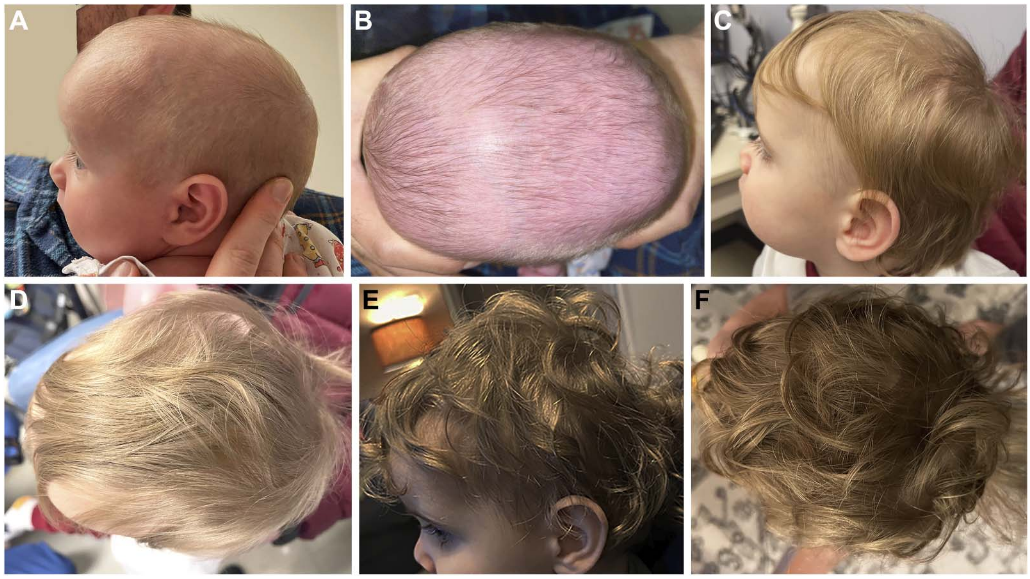

FIGURE 3. *Preoperative* **A**, *sagittal and* **B**, *superior view of the infant demonstrating significant scaphocephaly with frontal bossing, temporal hollowing, and occipital cupping.* **C**, *Sagittal and* **D**, *superior view 8 months postoperatively demonstrating significant improvement in scaphocephaly.* **E-F**, *Long-term follow-up at 15 months confirmed maintenance of the improvement.*

follow-up duration was 8.5 months (range: 1.2-48.6 months), and no patients required reoperation. The cephalic index was recorded at the end of each case with a median value of 76 (IQR: 4), representing an immediate 12% improvement in the cephalic index. The cephalic index further improved to a median value of 82 (IQR: 5) among 11 patients who had the index recorded at the 1-month follow-up visit. Similarly, the head circumference was measured in 19 patients and improved to a median of 44 cm (IQR: 1.0 cm) at the 1-month visit. Both measurements continued increasing over time, as detailed below in illustrative cases.

Illustrative Case 1

This 11-week-old infant boy presented with scaphocephaly and a palpable ridge along the sagittal suture, along with frontal bossing, temporal hollowing, and occipital cupping (Figure 3A-3B). The preoperative cephalic index was 69 with a head circumference of 45 cm. The patient underwent modified sagittal synostectomy with tension band sutures placed on each side to shorten the anteroposterior diameter. The immediate postoperative cephalic index in the operating room was 77, representing a 12% increase. The estimated blood loss was 15 mL, and the patient was discharged home after 2 days. The patient returned for follow-up after 6 weeks, and the cephalic index was recorded at 83, with an unaltered head circumference. Subsequently, the patient returned 9 months after surgery, and the cephalic index was recorded at 84. Continued improvement in his scaphocephaly was noted over a 15-month period (Figure 3C-3F).

Illustrative Case 2

This 2-month-old infant boy presented with scaphocephaly, significant frontal bossing, mild temporal hollowing, and moderate occipital cupping (Figure 4A-4C). He underwent a modified sagittal synostectomy with tension band sutures. The cephalic index improved from 69 preoperatively to 79 immediately postoperatively and increased further to 82 at the 6-week follow-up visit, representing a 19% increase. The head circumference increased from 40.5 to 41.5 cm, an increase of 2.5% (Figure 4D-4F).

Illustrative Case 3

A 12-week-old infant boy presented with scaphocephaly and a preoperative head circumference of 41.5 cm (Figure 5A-5C). His cephalic index improved by 15% from 65 to 75 after a modified sagittal synostectomy. A subsequent 6-week follow-up visit showed continued improvement in the cephalic index to 78, which improved to 80 at the 6-month follow-up visit, representing a 23% increase over time. The head circumference improved to 44 and 46.5 cm at the 6-week and 6-month visits, respectively, representing a 12% increase (Figure 5D-5F).

Illustrative Case 4

An 18-week-old infant girl with family history notable for a maternal uncle who underwent surgical correction of sagittal synostosis presented with scaphocephaly (Figure 6A-6C). The preoperative head circumference was 41 cm with a cephalic index of 69, which increased to 80 immediately after surgery, representing a 12% increase. The cephalic index further improved to

FIGURE 4. *Preoperative* **A**, *frontal,* **B**, *sagittal, and* **C**, *superior view demonstrating significant scaphocephaly with frontal bossing, occipital cupping, and mild temporal hollowing. The cephalic index improved immediately at the end of the operation.* **D**-**F**, *Continued improvement in scaphocephaly was noted at the 6-week follow-up, along with rapid wound healing.*

83 at the 6-week follow-up visit. Six months after surgery, the cephalic index was recorded at 85, representing a 23% increase over a 24-week period, and the head circumference increased to 46 cm, representing a 12% increase. Significant improvement in scaphocephaly was noted (Figure 6D-6F).

Illustrative Case 5

A 12-week-old infant boy presented with scaphocephaly, with a preoperative head circumference of 41 cm and cephalic index of 65 (Figure 7A-7C). The cephalic index improved to 75 immediately postoperatively, representing a 15% increase, and continued improving to 85 at the 7-month follow-up visit, marking a total increase of 31%. The head circumference improved to 44 cm at the 6-week follow-up and 47 cm at the 7-month follow-up, representing a 15% increase (Figure 7D-7F).

DISCUSSION

Premature fusion of the sagittal suture is the most common form of craniosynostosis and can be treated with a variety of surgical techniques, including both open and endoscopic approaches. Here, we present a novel technique that allows for early treatment of sagittal craniosynostosis with immediate improvement in scaphocephaly while minimizing perioperative morbidity and avoiding the need for blood transfusion or helmet therapy. Thirty-four patients were treated with this technique, and all families reported favorable outcomes. The cephalic index improved from a median of 68 preoperatively to 76 immediately postoperatively, and the estimated blood loss was minimal at 10 mL. Favorable results were obtained in all patients with no postoperative complications or need for reoperation.

Traditional Techniques

Surgical treatment of sagittal craniosynostosis was first performed in 1890 and consisted of a strip craniectomy to release the fused suture.[12] However, the procedure was associated with extensive morbidity and a high failure rate from early reossification of the suture, contributing to a decline in popularity.[13] By contrast, open approaches used by surgeons in the modern era for cranial vault remodeling include the Pi and H techniques and total cranial vault reconstruction.[5,13] Although these approaches are effective, they can be associated with significant blood loss and postoperative morbidity.[14] A retrospective review of 10 patients undergoing cranial vault remodeling after 1 year of age found that

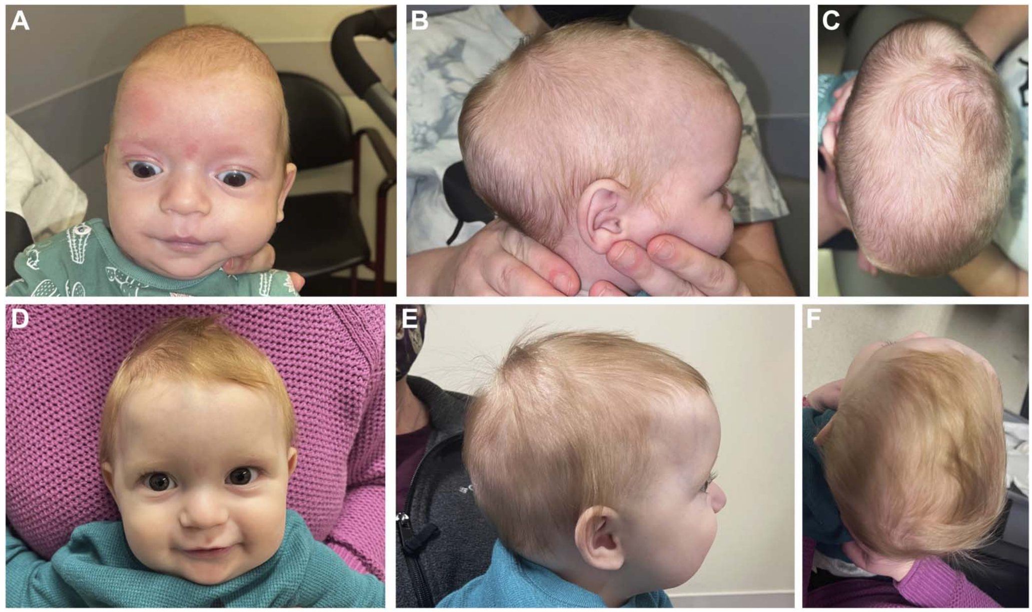

FIGURE 5. *Preoperative* **A**, *frontal,* **B**, *sagittal, and* **C**, *superior views of the infant demonstrating significant scaphocephaly with frontal bossing, temporal hollowing, and occipital cupping.* **D-F**, *The cephalic index was noted to immediately increase postoperatively and continued increasing by the 6 month follow-up with significant improvement in the scaphocephaly.*

red blood cell transfusions were needed in 67% of cases, with an average transfusion volume of 423 mL, and postoperative transfusions were needed by 30% of patients.[15] Younger patients may also suffer from extensive blood loss, with a review of 72 patients operated on at 4.1 months of age finding that cranial vault remodeling was associated with blood transfusions in 81% of patients.[16]

More recently, endoscopic strip craniectomy has become a popular modality for young infants with scaphocephaly.[17] The endoscopic approach is traditionally performed using a wide vertex suturectomy with barrel-stave osteotomies of the biparietal and bitemporal bones, although recently narrow vertex suturectomies have also been described.[18] The minimally invasive nature of these techniques shortens the operative length and hospitalization compared with the open cranial remodeling approaches.[19,20] Transfusion rates and intraoperative blood loss are also lower compared with open techniques, although transfusions are still reported in approximately 20% to 33% of patients.[17,21] However, the endoscopic approach requires postoperative helmet therapy to reshape the rapidly growing head over time. Adjustments to the helmet may be made over time to improve remodeling. Iyer et al[22] determined that a peak cephalic index is obtained after 7 to 9 months of helmet therapy. Therefore, helmet compliance can significantly affect treatment outcomes but can also impose a burden for patients and caregivers.[23]

Another technique uses cranial expander springs to provide dynamic correction of the skull and avoid the need for helmet therapy.[24] The technique can be performed using open or endoscopic approaches, and it is similarly associated with reduced morbidity compared with open cranial vault reconstruction.[25] For maximal effectiveness, the procedure should be performed in early infancy when the skull is thin. However, a second surgery is required for removal of the springs.[26]

Tension Band Sutures

Our approach consists of a generous craniectomy with tension band sutures and takes advantage of the benefits of the open and endoscopic approaches while avoiding some of their limitations. We recommend performing the surgery in early infancy, optimally at around age 2 to 3 months, to allow the rapid growth of the brain to help reshape the head before the skull is reconstituted from the dura. Compared with open approaches that remodel the cranial vault, our approach is less invasive and reduces operative morbidity, blood loss, and the need for a transfusion. Blood loss is further minimized by injecting a dilute solution of bupivacaine and epinephrine into the scalp, using the Colorado needle and Raney clips, and mobilization of the scalp in the avascular suprapericranial plane. The median blood loss in our series was only 10 mL, and no patients required a transfusion intraoperatively or postoperatively. In comparison, rates of transfusion have been reported as high as 67% to 81% of patients undergoing open cranial vault remodeling.[15,16] Furthermore, length of stay is reduced compared with more extensive approaches.[15,16] Families are counseled about longer incisions compared with endoscopic

FIGURE 6. *Preoperative* **A**, *frontal,* **B**, *sagittal, and* **C**, *superior views of the infant demonstrating significant scaphocephaly with frontal bossing, temporal hollowing, and occipital cupping.* **D-F**, *Improvements in the scaphocephaly and cephalic index were noted immediately postoperatively and maintained at the 6-month follow-up.*

techniques, although wound healing is typically satisfactory, as illustrated in Figure 4.

The sagittal synostectomy/tension band procedure has a safety profile comparable with the endoscopic approach. Critically, our technique avoids the need for postoperative helmet therapy. The internal tension band sutures substitute for the external helmet orthoses. Furthermore, any dural or sinus injuries, should they occur, can be readily repaired given the open exposure. Meticulous attention to hemostasis can achieve blood loss comparable or even better than endoscopic approaches and avoid the need for intraoperative transfusions.[17,21] Our technique for minimizing blood loss can be adapted to other forms of open repair for craniosynostosis. Hospitalization is slightly longer compared with the endoscopic approach because our practice was to monitor patients for 2 days after surgery, while many endoscopic approach studies report hospitalizations of 1 day.[10,27-29] More recently, we have modified our protocol to allow discharge on postoperative day 1, owing to the safety profile and promising results. Although endoscopic narrow vertex suturectomies can achieve a smaller suturectomy width, we have had no cases of persistent cranial vault defects in our series.

The internal tension band sutures help shorten the anteroposterior diameter of the head while widening the biparietal diameter and provide immediate improvement in head shape. The sutures are absorbed over several weeks; nonetheless, an immediate and sustained correction is achieved that would otherwise likely be less significant without the sutures. The improvement in the cephalic index to a median of 76 immediately postoperatively is consistent with correction of the scaphocephaly, and repeat follow-up visits illustrated continued improvements in the cephalic index.[30]

Limitations

A limitation of the technique is that optimal results are best achieved in young infants around 2 to 3 months of age while the head is still rapidly growing. We have not performed this operation in children older than 6 months and favor alternative calvarial remodeling for older children. Long-term recordings of the cephalic index were limited by restrictions on in-person visits because of the COVID-19 pandemic; however, photographs provided by the families assisted in qualitatively evaluating resolution of scaphocephaly. In addition, as a single-institutional retrospective study, this study is subject to institutional bias that might limit the generalizability of our results. Larger cohorts with longer-term follow-up are warranted to confirm the durability of the postoperative improvement in the cephalic index.

FIGURE 7. *Preoperative* **A**, *frontal,* **B**, *sagittal, and* **C**, *superior views of the infant demonstrating significant scaphocephaly with frontal bossing and mild temporal hollowing.* **D-F**, *The cephalic index improved postoperatively and significant improvements in scaphocephaly were maintained at the 6-month follow-up.*

CONCLUSION

Early generous sagittal craniectomy with tension band sutures and meticulous attention to hemostasis is a useful technique for correction of sagittal craniosynostosis. It can be performed safely with minimal blood loss and creates an immediate improvement in head shape that improves further over time related to the rapid growth of the brain. Postoperative helmet therapy is unnecessary. There were no complications in this series. No patient required reoperation, and all families were pleased with the aesthetic result.

Funding

This study did not receive any funding or financial support.

Disclosures

The authors have/author has no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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