# Intraoperative Intracranial Pressure Changes in Children With Craniosynostosis Undergoing Endoscopic-Assisted Strip Craniectomy

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**BACKGROUND AND OBJECTIVES:** Craniosynostosis can lead to progressive cranial and skull base deformities and can be associated with increased intracranial pressure (ICP), ophthalmological manifestations, behavioral changes, and developmental delay. Most published data on the incidence of elevated ICP include older children undergoing open surgical correction. Endoscopic-assisted release of fused sutures with postoperative helmet therapy is an established method for managing craniosynostosis presenting at an early age; however, the immediate effect of this approach on ICP in a young cohort has not been previously reported.

**METHODS:** Prospective data on 52 children undergoing endoscopic-assisted release of stenosed cranial sutures were included. Individuals were excluded if they underwent open correction or had previous cranial surgery. Individuals underwent a standardized endoscopic approach for each suture type. ICP was measured using an intraparenchymal sensor both before creation of the neosuture and after complete release of the stenosed suture. An ICP reading of >10 mm Hg was considered elevated.

**RESULTS:** The mean age was 5.3 months, range 1 to 32 months, and 94% was younger than 12 months. The mean opening pressure was 12.7 mm Hg, and the mean closing pressure was 2.9 mm Hg. Opening ICP ≥10 mm Hg was present in 58%, ≥15 mm Hg was present in 31%, and ≥20 mm Hg was present in 23%. No patient had an ICP above 10 mm Hg at closing. The mean percentage change in ICP among all craniosynostosis cases was a 64% decrease. Optic disk swelling was identified in 28 children preoperatively and improved in 22 children at follow-up.

**CONCLUSION:** Elevated ICP may occur in infants with craniosynostosis at higher rates than previously reported. Endoscopic-assisted craniectomy has an immediate effect on lowering ICP and improving postoperative ophthalmological findings.

**KEY WORDS:** Craniosynostosis, Endoscopic, Intracranial pressure, Strip-craniectomy

Craniosynostosis is the premature fusion of one or more of the cranial sutures and is estimated to occur in 5.9 per 10 000 live births.[1] Craniosynostosis can lead to progressive cranial and skull base deformities, increased intracranial pressure (ICP), and ophthalmological manifestations and has been associated with behavioral changes and developmental delay.[2] Although the indications for intervention were believed to be largely cosmetic in single suture involvement, more recently, evidence suggests that ICP increases are likely higher than previously reported.[3] This is critical in younger children, as measurements of ICP are not often standard practice, which may miss or lead to a delay in treating children with elevated ICP. Most available published data on this include older children undergoing cranial vault procedures. Endoscopic-assisted release with postoperative helmet therapy is an established method for managing craniosynostosis presenting at an early age and offers multiple advantages.[4] Intraoperative ICP measurements in this young

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population and the immediate effect of endoscopic release have not been previously reported. At our institution, we offer endoscopic-assisted craniectomy for any child with craniosynostosis presenting before 8 months of age and select cases thereafter with routine intraoperative pre- and postrelease ICP measurements. In this article, we report on our experience in managing children with craniosynostosis with endoscopic-assisted strip craniectomy and intraoperative ICP monitoring.



## METHODS

Prospective data are recorded on all children undergoing craniosynostosis release. We report on those performed between January 2022 and March 2024. Patients were excluded if they underwent open correction or had previous cranial surgery. Pre- and postoperative ophthalmological assessment is completed by the pediatric ophthalmologist using cyclopentolate hydrochloride and phenylephrine hydrochloride ophthalmic solution for mydriasis and captured using the RetCam ophthalmic imaging system (PanoCam SOLO V2™, Visunex Medical Systems, Inc and NIDEK VersaCam™ DS-20). Optic disk swelling is reported if present in any eye and in any section of the optic nerve. Although it is standard practice for our patients to complete an eye examination, some traveling from out of town/state/county could not complete this assessment. Surgical technique and perioperative protocol were standardized for each suture type.[5] Our anesthesia team uses the inhalation anesthetic sevoflurane with the minimum alveolar concentration maintained between 0.5 and 1. This low minimum alveolar concentration is achieved with the use of the paralytic rocuronium. This regimen aims to limit any anesthetic effect on cerebral blood flow and ICP. The patient also receives fentanyl, cefazolin (30 mg/kg) if no known allergy, and a tranexamic acid bolus (50 mg/kg). A brief description of our surgical technique is as follows. One to two incisions are used based on the suture type, approximately 2 to 3 cm in length, and dissection is performed in the subgaleal plane across the length of the planned craniectomy. A 7-mm pediatric craniotome is used to create 1 to 2 burr holes based on the suture type. The dura is opened 1 to 2 mm to allow placement of an intraparenchymal sensor (Pressio, Sophysa, Orsay, France) to a depth of 0.5 cm to obtain an opening pressure; this is performed at the burr hole site and is placed on the right when bilateral burr holes are needed. Endoscopic dissection along the epidural space is performed followed by creation of the neosuture with a bone scissor and/or rongeur. Immediately on achieving hemostasis, a postcraniectomy closing ICP is obtained and the small dural opening is closed. Informed surgical consent and consent for photo and image use were obtained from all parents. This report includes our surgical series, and Institutional Review Board exemption was approved by the Institutional Review Board committee.

Demographic data and suture type were collected and reported as frequency and percentage. Means and SD for age at surgery and ICP are reported. We considered an ICP ≥10 mm Hg as elevated. Paired sample *t*-tests were used to compare changes in ICP. Available preoperative and postoperative ophthalmological assessment of the optic nerve for disk swelling and pallor and retinal venous dilatation and tortuosity is included. $\chi^2$, Fisher's exact test, and one-way analysis of variance tests were used as appropriate. Perioperative blood work is reported as mean and SD along with pre- and postoperative mean change and standard error. An alpha level of < .05 was considered statistically significant, and all *P*-values were 2-sided. Data analysis was performed using SPSS Statistics v29 (IBM).

## RESULTS

A total of 52 consecutive craniosynostosis cases met the inclusion criteria; demographics and craniosynostosis types are shown in Table 1. Forty-nine children (94.2%) were younger than 12 months. There was a significant difference in gender distribution between craniosynostosis types (Table 2). There was a significant effect of craniosynostosis type on age at surgery (Table 2); post hoc comparisons using Tukey's *b* test indicated that the mean age at surgery for lambdoid craniosynostosis was significantly different from all other sutures.

The mean opening pressure was 12.46 ± 8.27 mm Hg (range 0-37), and the mean closing pressure was 2.98 ± 2.25 mm Hg (range 0-9), shown in Figure 1. Two patients had higher closing ICP (2-3 and 2-5 mm Hg) with no identifiable cause and had no complications postoperatively. Opening ICP ≥10 mm Hg was present in 57.7%, ≥15 mm Hg was present in 30.8%, and ≥20 mm Hg was present in 23%. No patient had an ICP above 10 mm Hg at closing. The mean percentage change in ICP among combined craniosynostosis cases was a 64.44% ± 43.1% decrease (Table 3). ICP did not significantly differ based on age ($P$ = .086), sex ($P$ = .548), or suture involved ($P$ = .205, Figure 2).

Preoperative ophthalmological assessment was completed on average 7.56 ± 8.24 days before surgery (range 1-28 days). Postoperative assessment occurred 2.58 ± 4.78 months from surgery (range 4 days-24 months) and varied because of out-of-town location and compliance. Preoperative optic disk swelling was identified in 28/36 (77.8%) children; it was bilateral in 19 (67.9%) and unilateral in 9 (32.1%). Twenty-four children had no ophthalmological examination data available. There was no significant correlation between ICP and preoperative optic nerve disk swelling ($P$ = .519), optic nerve pallor ($P$ = .896), retinal venous dilatation ($P$ = .807), or retinal venous tortuosity ($P$ = .798). Findings are shown in Table 4.

The average time for surgery was 1 hour and 33 minutes, and all but 3 children were discharged on postoperative day 1 (Table 5). One child experienced elevated systolic blood pressure postoperatively with a negative workup and was discharged home on day 2. The second child had low hemoglobin on day 1, was observed for an additional day with repeat blood work, which improved without transfusion, and was sent home on day 2. The third child had pan-suture craniosynostosis and was kept intubated because of a longer duration of surgery (4 hours and 3 minutes) and developed pneumonia. He was discharged home on day 41 after weaning oxygen, and a nasogastric tube was placed after identifying ongoing silent aspiration with feeds. Four patients received a blood transfusion (7.7%), 1 had an intraoperative sinus injury with change in blood pressure, 1 had low starting hemoglobin of 5.4, 1 because of low blood pressure in the postanesthesia care unit, and 1 prophylactically because of anticipated blood loss with pan-synostosis repair with elevated postoperative hemoglobin of 16 g/dL. There was no correlation between estimated blood loss and change in hemoglobin ($P$ = .929). Perioperative data are

**TABLE 1. Patient Demographics and Craniosynostosis Type (*n* = 52)[a]**

| Demographics | Mean (range) | SD |
|---|---|---|
| Gestational age at birth (wk) | 37.73 (30-42) | 2.45 |
| Head circumference (time of surgery) | 42.19 cm | 4.45 |
| Age (mo) | 5.33 (1-32) | 5.15 |
| Method of delivery | *N* | % |
| Vaginal | 17 | 54.8 |
| Cesarean | 14 | 45.2 |
| Head circumference percentile (WHO) | | |
| ≤25$^{th}$ | 10 | 20 |
| >25th-50th | 6 | 12 |
| >50th-75th | 9 | 18 |
| >75th | 25 | 50 |
| Age groups (months) | | |
| 0-3 | 23 | 44.2 |
| 4-6 | 18 | 34.6 |
| >6 | 11 | 21.2 |
| Sex | | |
| Female | 20 | 38.5 |
| Male | 32 | 61.5 |
| Ethnicity | | |
| Hispanic | 27 | 51.9 |
| Non-Hispanic | 21 | 40.4 |
| Other/unknown | 4 | 7.7 |
| Race | | |
| White | 43 | 82.7 |
| African American | 1 | 15.4 |
| Other | 8 | 1.9 |
| Craniosynostosis[b] | | |
| Sagittal | 18 | 34.6 |
| Metopic | 15 | 28.8 |
| Unicoronal (R/L) | 7 (4/3) | 13.5 (57.1/42.9) |
| Lambdoid (R/L) | 6 (1/5) | 11.5 (16.7/83.3) |
| Multisuture | 6 | 11.5 |
| Sagittal + metopic | 2 | 2.4 |
| Sagittal + unicoronal[c] | 1 | 1.7 |
| Sagittal + bicoronal | 1 | 1.7 |
| Bicoronal[d] | 1 | 1.7 |
| Sagittal + bicoronal + bilambdoid | 1 | 1.7 |

CT, computed tomography; l, left; n, number; R, right; VATER, vertebrae, anus, trachea, esophagus, and renal; WHO, World Health Organization.

[a]Data for children regarding gestational age at birth (n = 37), delivery method (n = 31), and head circumference at the time of surgery (n = 51) were missing.

[b]Available imaging was reviewed for tonsillar ectopia among lambdoid and multisuture craniosynostosis. Isolated lambdoid craniosynostosis included 6 children, 2 with preoperative skull x-rays and 4 with head CTs. Among those with available CTs, 2 children had no tonsillar ectopia both younger than 10 months, 1 child 19 months of age had ipsilateral 2.7-mm tonsillar ectopia, and 1 child 32 months of age had bilateral 4.9-mm tonsillar ectopia. Head CTs were available for 5 of the children with multisuture craniosynostosis, whereas 1 received a skull x-ray. None of the 5 had tonsillar ectopia.

[c]Diagnosed with VATER syndrome.

[d]Diagnosed with Apert syndrome.

shown in Table 6. Complications included 3 dural tears (5.8%) that were repaired intraoperatively.

## DISCUSSION

We found that 58% of children presenting with craniosynostosis have ICPs of 10 mm Hg or higher intraoperatively, which was most frequent among children with coronal, lambdoid, and multisuture craniosynostosis. Endoscopic-assisted strip craniectomy resulted in an immediate decrease in ICP by 64% in all children. The majority required an overnight stay in hospital, and the procedure was associated with minimal blood loss and low transfusion rates. To the best of our knowledge, this is the first report on the immediate effect of endoscopic-assisted release of stenosed cranial sutures on ICP and including mainly children younger than 1 year. At our institution, intraoperative ICP monitoring has become standard by the senior neurosurgeon for all craniosynostosis cases. This was found to be useful to the surgeon, child's family, and ophthalmologist as to the state of ICP at surgery and consideration during follow-up and was adopted by the group as part of our standard surgical approach. Although no complications have been identified, no procedure is risk-free. Therefore, we discuss with parents our approach, outcome data, and complications to make an informed decision about their child's care. We have found this information to be invaluable during the management of this complex disease.

**TABLE 2. Craniosynostosis Type by Gender Distribution and Mean Age (mo) at Surgery**[a]

| Suture | Female/Male | | Mean age at surgery (minimum, maximum) ± SD | | |
|---|---|---|---|---|---|
| | *n* | (%) | | | |
| Sagittal | 4/14 | 26.7/73.3 | 3.22 | (1, 9) | ±2.16 |
| Metopic | 4/11 | 22.2/77.8 | 4.4 | (1, 7) | ±1.64 |
| Unicoronal | 5/2 | 71.4/28.6 | 6.57 | (2, 17) | ±4.89 |
| Lambdoid | 5/1 | 83.3/16.7 | 12.83 | (3, 32) | ±10.98 |
| Multisuture | 2/4 | 33.3/66.7 | 5 | (2, 9) | ±3.1 |
| | $\chi^2(4, N = 52) = 11.27, P = .024$ | | | $F(4, 47) = 5.7, P < .001$ | |

ANOVA, analysis of variance; n, number.
[a]Chi-square and one-way ANOVA were used for sex and mean age, respectively.



Probe measurements are an accurate method of measuring ICP.[6] However, defining normal ICP in infants is less established. The limited nonexperimental studies on infants that included those beyond the neonatal age estimate a normal ICP of 3 to 7 mm Hg.[7,8] An often quoted upper limit of normal in infants is 5 mm Hg published by Minns[9] in 1984 based on review of studies involving head trauma, hydrocephalus, central nervous system infections, and asphyxia. In those with craniosynostosis, the ICP measurements in studies where infants formed approximately half the cohort report an ICP above 10 mm Hg in 55% to 73%[10,11] and above 15 mm Hg in 18,[11] 26,[12] and 35%.[10] Fifteen studies of mainly children with craniosynostosis totaling 1148 measurements combined report an ICP above 15 mm Hg in 376 children (33%).[10-25] These rates are similar to those found in our cohort, and depending on the cutoff of 15- or 10-mm Hg, ICP is likely increased in approximately one to two thirds of children with craniosynostosis, respectively, even before 1 year of age.

Recognizing that ICP may be elevated during the early course of craniosynostosis is paramount as ICP may continue to increase with age.[12,13,15,23,25] Monitoring children with craniosynostosis using clinical signs and symptoms or radiographic findings as an indication for intervention may miss those with elevated ICP as these measures may not accurately reflect the child's true pressure.[10,13,18,21,22,25,26] In addition, phenotype severity has been shown to poorly correlate with increased ICP.[13,17,24,27] We found that ICP varied based on the suture subtype and number of sutures involved. The higher rate of elevated ICP in multisuture craniosynostosis has been demonstrated across multiple studies.[10,14,15,25,26] The intracranial volume is likely not the driver for increased ICP in most of the cases,[16] which would explain why even in infants with craniosynostosis, before the cranial volume is significantly altered, increased ICP can occur. Venous outflow may play a significant role in elevated ICP as has been shown by Taylor et al,[28] and the effect of cranial vault release on venous drainage has also been demonstrated.[29] Therefore, earlier intervention may be of benefit for those with craniosynostosis diagnosed in infancy to alleviate these pressures. The immediate effect of surgery on ICP has been reported by others performing various cranial vault procedures in children with craniosynostosis and shows a decrease of 37% to 71%.[12,15,27,30-32] We have found that the minimally invasive endoscopic approach, ideal for this age group, has an immediate and significant effect on lowering ICP with the additional advantage of earlier intervention in the setting of potentially elevated pressures.

In addition to the high rate of increased ICP, the rate of any optic disk swelling in our cohort was high. This may be related to inclusion of disk swelling in any sector and if present in any eye. However, comparison with other studies is limited as the criteria for labeling papilledema, present or absent, are not often defined in studies concerning children with craniosynostosis. The rate of papilledema reported among children with craniosynostosis varies considerably from 7% to 48%.[12,15,16,21,24,25,27,31-34] The specificity seems to be high, but the sensitivity is low for this finding in craniosynostosis.[12,21,33] Perhaps the largest series examining elevated ICP and papilledema in craniosynostosis in 122 children found that those with papilledema were older and that sensitivity remained low until 8 years of age.[21] The method of papilledema detection may also play a role. Swanson et al found that the use of optic coherence tomography had a high sensitivity but lower specificity,[35] whereas fundoscopy had a very poor sensitivity.[25,35] The evaluation for papilledema in children presents many hurdles, including the inability to cooperate with an examination in some children, presence of optic disk drusen and pseudopapilledema, the description of optic disk swelling based on fundoscopy (eg, Frisén grading, unilateral or bilateral findings), inter-rater reliability, and the method of identification (eg, fundoscopy, optic coherence tomography, visual evoked potentials). We found a high rate of improvement in these findings during follow-up, which may reflect sustained normalization of ICP in our cohort; however, we do not have measurements to confirm this. We believe that identifying any ophthalmological findings, including other manifestations such as

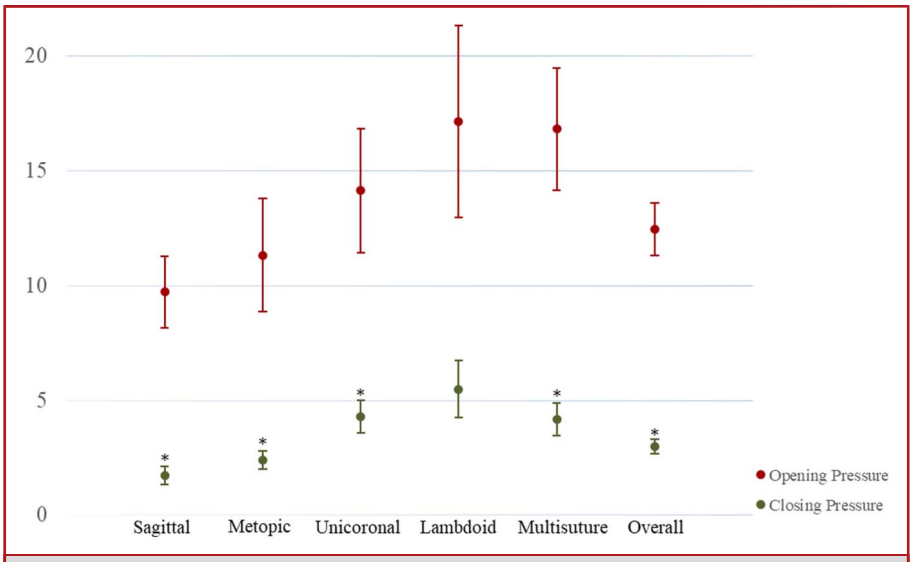



**FIGURE 1.** *Opening and closing intracranial pressure (mm Hg) mean and standard error of the mean reported for the craniosynostosis type and overall cohort.*

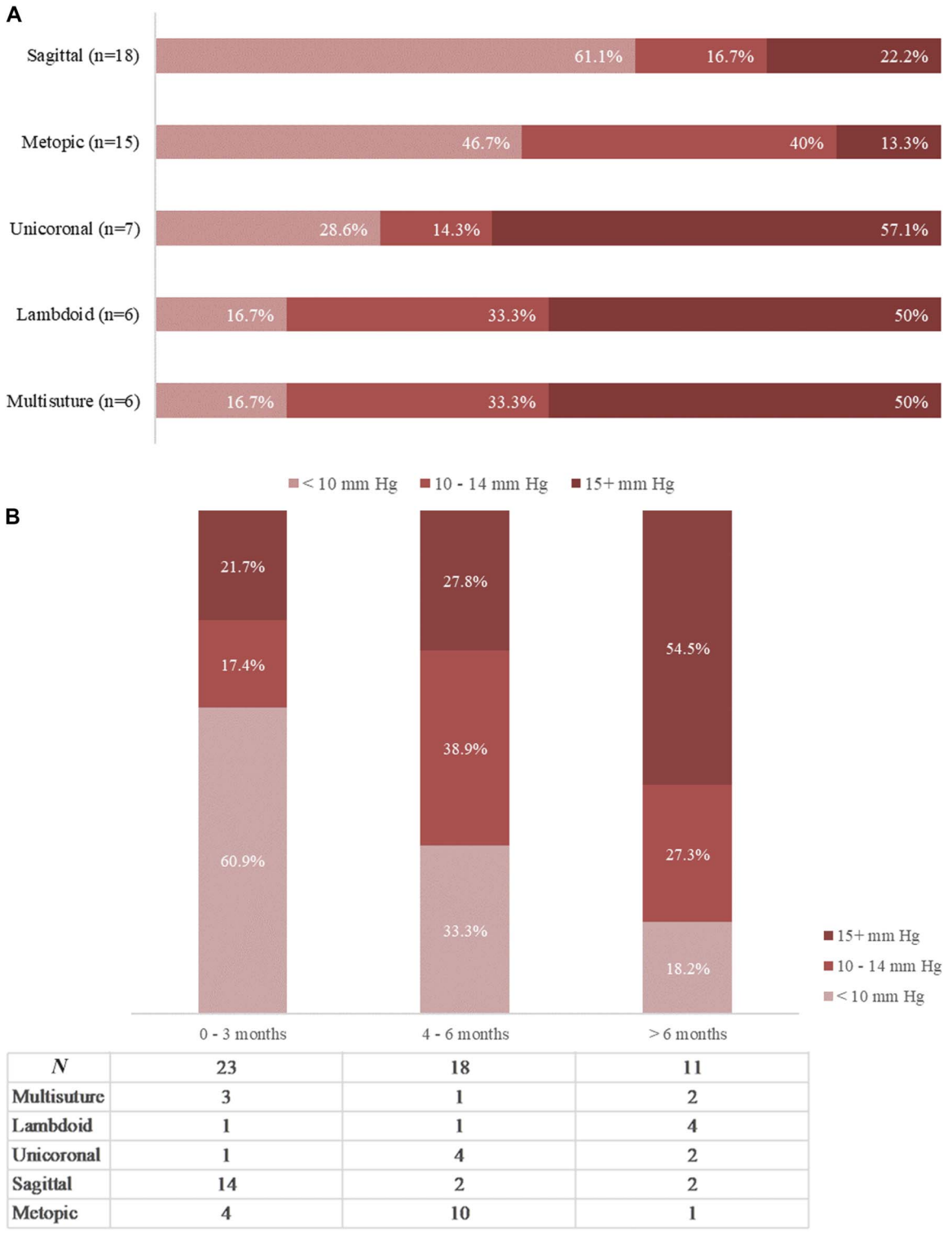
amblyopia, strabismus, refractive errors, and exposure keratitis, is an important part of the workup of children with craniosynostosis both before surgery and during postoperative follow-up.

Early intervention may help address elevated ICP and optic nerve compromise in children with craniosynostosis, but it remains less conclusive what effect early intervention has on neurocognitive outcomes. Renier et al[14] found a decrease in intelligence quotient (IQ) with increases in preoperative ICP that reached statistical significance. In milder craniosynostosis cases with elevated ICP, cranial vault release led to improvement in speech delays and behavior issues, and younger children showed better outcomes.[17] A neuropsychological assessment of children with sagittal craniosynostosis found a significantly higher performance on several domains in those operated on before 6 months of age compared with those operated on after 6 and 12 months.[36] This was demonstrated by another sagittal craniosynostosis study comparing neurodevelopmental changes by age at surgery whereby those intervened on before 7 months of age did significantly better than those intervened beyond 12 months of age.[37] A study by Hashim et al[38] showed this trend of better IQ scores on several parameters if surgery was conducted before 6 months of age and suggests that strip craniectomy did not do as well as whole vault reconstruction when performed in this age group. We believe that caution should be taken with this

**TABLE 3. Intraoperative Intracranial Pressure Measurements (mm Hg) and Changes (Δ) Presented as Mean ± SD**

| | | | | | Paired sample *t*-test | | |
|---|---|---|---|---|---|---|---|
| **Suture** | **Opening ICP** | **Closing ICP** | **Mean absolute Δ** | **Mean percentage Δ** | $T_{(df)}$ | **95% CI** | ***P* value** |
| All | 12.46 ± 8.27 | 2.98 ± 2.25 | 9.48 ± 7.91 | 64.44 ± 43.09 | $t_{51}$ = 8.68 | 7.28 to 11.68 | **<.001** |
| Sagittal | 9.72 ± 6.63 | 1.72 ± 1.67 | 8 ± 6.69 | 77.59 ± 23.4 | $t_{17}$ = 5.07 | 4.68 to 11.33 | **<.001** |
| Metopic | 11.33 ± 9.55 | 2.4 ± 1.55 | 8.93 ± 9.28 | 60.1 ± 44.56 | $t_{14}$ = 3.73 | 3.8 to 14.07 | **.002** |
| Unicoronal | 14.14 ± 7.15 | 4.29 ± 1.89 | 9.86 ± 7.18 | 59.14 ± 30.27 | $t_6$ = 3.64 | 3.22 to 16.49 | **.011** |
| Lambdoid | 17.17 ± 10.25 | 5.5 ± 3.08 | 11.67 ± 11.27 | 31.75 ± 90.81 | $t_5$ = 2.54 | −0.163 to 23.5 | .052 |
| Multisuture | 16.83 ± 6.52 | 4.17 ± 1.72 | 12.67 ± 5.39 | 74.71 ± 6.29 | $t_5$ = 5.76 | 7.01 to 18.33 | **.002** |
| ANOVA[a] | | | | F(4, 47) = .52, *P* = .723 | | | |

ANOVA, analysis of variance; df, degrees of freedom; ICP, intracranial pressure.
Significant *P* values < .05 are in bold.
[a]One-way ANOVA comparing mean change in ICP between craniosynostosis types.




| *N* | 23 | 18 | 11 |
|---|---|---|---|
| Multisuture | 3 | 1 | 2 |
| Lambdoid | 1 | 1 | 4 |
| Unicoronal | 1 | 4 | 2 |
| Sagittal | 14 | 2 | 2 |
| Metopic | 4 | 10 | 1 |

**FIGURE 2.** *Opening intracranial pressure (mm Hg) by* **A**, *craniosynostosis type and* **B**, *age. Frequencies for each craniosynostosis type are included under each category.*

**TABLE 4. Overall and Craniosynostosis Type Breakdown for Intraoperative Opening Intracranial Pressure, Preoperative Ophthalmological Findings, and Postoperative Optic Disc Swelling Changes**

| Suture N (%) | Opening ICP (mm Hg) | | | Ophthalmological findings[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Optic disk swelling | | | Optic disk pallor | Retinal venous dilatation | Retinal venous tortuosity |
| | <10 | 10-14 | ≥15 | Preoperatively | Improved | Stable | | | |
| All | 22 (42.3%) | 14 (26.9%) | 16 (30.8%) | 28/36 | 22/32 | 5/32 | 18/33 | 30/34 | 7/34 |
| Sagittal | 11 (61.1%) | 3 (16.7%) | 4 (22.2%) | 10/14 | 9/9 | 0/9 | 8/13 | 11/13 | 1/13 |
| Metopic | 7 (46.7%) | 6 (40%) | 2 (13.3%) | 7/8 | 4/5 | 1/5 | 2/8 | 8/8 | 2/8 |
| Unicoronal | 2 (28.6%) | 1 (14.3%) | 4 (57.1%) | 4/5 | 2/2 | 0/2 | 4/4 | 4/4 | 1/4 |
| Lambdoid | 1 (16.7%) | 2 (33.3%) | 3 (50%) | 5/6 | 3/5 | 2/5 | 3/6 | 5/6 | 3/6 |
| Multisuture | 1 (16.7%) | 2 (33.3%) | 3 (50%) | 2/3 | 2/2 | 0/2 | 1/2 | 2/3 | 0/3 |
| $\chi^2$ test | $P = .205$ | | | $P = .894$ | $P = .404$ | | $P = .166$ | $P = .517$ | $P = .247$ |

ICP, intracranial pressure; N, number; Preop, preoperatively.
[a]Presented as *n* per available ophthalmological examination results. Three reports did not comment on optic nerve pallor, and 2 did not comment on retinal venous dilatation or tortuosity. These patients were examined before including images for reference, and therefore, we are unable to report on the presence or absence of these findings.
$\chi^2$ test performed for any difference in opening pressure and ophthalmological findings between craniosynostosis types.

interpretation.[39-41] The surgical technique used in the study by Hashim et al for strip craniectomy differs from other centers including our own, and the average IQ results show several point increase in the whole vault cohort for general cognitive abilities but favor strip craniectomy in academic achievement. Perhaps less important than a statistically significant difference and risk of a type 2 error is the trend seen across these studies. Further research and better consensus on testing parameters and timing are needed in this area for more definitive answers. With or without a current consensus on neurocognitive effects, elevated ICP should not be ignored, and earlier intervention might have several benefits for those diagnosed and managed early.

Endoscopic procedures for craniosynostosis are often performed during the first year of life with postoperative helmet remodeling to take advantage of the rapidly growing brain. The use of endoscopic release has become well established for sagittal craniosynostosis,[42-45] and although evidence supports its use in other suture involvement,[46-52] its utilization and age cutoffs vary

**TABLE 5. Craniosynostosis Surgery Duration (hours:minutes), Hospital Length of Stay, and Strip Craniectomy Size**

| Suture | Surgery duration[a] | Length of stay (d) | Strip craniectomy (mm ± SD, min, max) | |
|---|---|---|---|---|
| | | | Width | Length |
| All | 1:33 ± 0:34, (0:43, 4:03) | 1.81 ± 5.55 | — | |
| Sagittal | 1:41 ± 0:28 (0:45, 2:31) | 1.06 ± 0.24[b] | 49.43 ± 16.72 (20, 90) | 122.76 ± 34.16 (87.5, 250) |
| Metopic | 1:19 ± 0:18 (0:48, 2:06) | 1 | 4.35 ± 0.49 (4, 5) | 88.24 ± 17.23 (50, 115) |
| Unicoronal | 1:21 ± 0:22 (0:43, 1:57) | 1 | 12.21 ± 15.07 (4, 40) | 97.29 ± 29.19 (54, 135) |
| Lambdoid | 1:24 ± 0:30 (0:45, 2:01) | 1 | 9.13 ± 12.48 (4, 40) | 97.88 ± 24.45 (60, 120) |
| Multisuture | 2:03 ± 1:10 (0:59, 4:03) | 7.83 ± 16.25[b] | Each suture was included in its respective category | |
| ANOVA | F(4, 47) = 2.6, $P = .048$ | F(4, 47) = 2.6, $P = .85$ | — | |

ANOVA, analysis of variance; max, maximum; min, minimum.
[a]Calculated from the time of incision to completion of skin closure, and reported as hour:minutes, standard deviation, minimum, and maximum.
[b]One child with sagittal synostosis and 2 with multisuture synostosis required more than 1 day in the hospital.

**TABLE 6. Perioperative Hgb and Hct Changes, Estimated Blood Loss (mL), and Blood Transfusions**

| Suture | Preoperative Hgb[a] (μ ± SD) | Postoperative Hgb (μ ± SD) | Mean Hgb Δ (μ ± SE) | Preoperative Hct[a] (μ ± SD) | Post-Hct (μ ± SD) | Mean Hct Δ (μ ± SE) | Estimated blood loss (μ ± SE) | Blood transfusion |
|---|---|---|---|---|---|---|---|---|
| All | 11.43 ± 1.55 | 9.72 ± 1.69 | 1.7 ± 0.24 | 33.69 ± 4.63 | 29.02 ± 5.08 | 4.67 ± 5.77 | 24.71 ± 1.95 | 4 (7.7%) |
| Sagittal | 11.36 ± 1.6 | 9.32 ± 1.51 | 2.04 ± 0.26 | 33.77 ± 4.75 | 28.04 ± 4.51 | 5.73 ± 3.27 | 28.06 ± 3.12 | 2 (11.1%) |
| Metopic | 11.3 ± 1.22 | 9.45 ± 1.35 | 1.85 ± 0.51 | 33.36 ± 3.27 | 27.92 ± 3.94 | 5.44 ± 5.62 | 22.2 ± 3.7 | 0 |
| Unicoronal | 11.79 ± 1.12 | 9.81 ± 0.99 | 1.97 ± 0.32 | 34.7 ± 3.61 | 28.96 ± 2.98 | 5.74 ± 0.9 | 18.86 ± 4.72 | 0 |
| Lambdoid | 11.94 ± 0.61 | 10.76 ± 0.58 | 1.18 ± 0.1 | 34.52 ± 1.26 | 31.64 ± 1.94 | 2.88 ± 0.33 | 15.83 ± 2.39 | 0 |
| Multisuture | 11.07 ± 2.92 | 10.6 ± 3.35 | 0.47 ± 1.61 | 32.33 ± 9.16 | 32.27 ± 10.11 | 0.07 ± 5.17 | 36.67 ± 6.54 | 2 (33.3%) |
| ANOVA | F(4, 45) = 1.02, $P$ = .409 | | | F(4, 44) = 1.38, $P$ = 1.38 | | | — | — |

μ, mean; ANOVA, analysis of variance; Hct, hematocrit; Hgb, hemoglobin; SE, standard error of the mean; Δ, change.
[a]Preoperative hemoglobin (g/dL) and hematocrit were not available for 3 and 4 children, respectively, and were excluded from analysis.

among surgeons. We included single and multisuture craniosynostosis to reflect our experience with endoscopic release for all types and its effect on ICP. We have presented our findings as a cohort and an individual suture type as we believe this to be the most informative. Some children were older than what others may consider for endoscopic surgery (3 children older than 10 months). In our experience, some older children with mild craniofacial manifestations, where an open approach in our opinion is unlikely to provide superior outcomes, have undergone endoscopic strip craniectomy, and we continue to appreciate an improvement in appearance over time.

The surgical performance measures between open and endoscopic-assisted techniques are well studied. Our endoscopic-assisted craniectomy procedures carry a low complication profile, short operative times, minimal blood loss, and a low rate of blood transfusions, requires an overnight hospital stay for most of the children, and can be used in all suture types. A large, multicenter study compared the results of 1382 infants undergoing endoscopic vs open techniques, which demonstrated significant advantages in the endoscopic-assisted group, including approximately half the surgical time, shorter hospital, intensive care unit stays, and lower volume of blood transfusion.[53] Similarly, a systematic review and meta-analysis that included a pooled cohort of 2064 patients with craniosynostosis found that the minimally invasive endoscopic-assisted technique demonstrated a significant difference in blood loss, operative time, length of stay, transfusion rates, and perioperative complications.[43] In addition, several studies have demonstrated the significant economic difference between the 2 approaches.[54-56] Our own experience with these cases and outcomes has been consistently favorable (**Supplementary Figure 1** [http://links.lww.com/NEU/E426], **Supplementary Figure 2** [http://links.lww.com/NEU/E427], **Supplementary Figure 3** [http://links.lww.com/NEU/E428], **Supplementary Figure 4** [http://links.lww.com/NEU/E429], **Supplementary Figure 5** [http://links.lww.com/NEU/E430]).

### Limitations

There are limitations to this report; although this is one of the larger cohorts for endoscopic-assisted strip craniectomies, larger numbers would further advance our understanding of the rate of increased ICP in children with craniosynostosis, especially before 1 year of age. The risk of recurrence of increased ICP was not studied in this cohort because this was not a long-term outcome report, remains poorly estimated in the literature, and warrants future investigation; we follow our patients with craniosynostosis up to and at times beyond 18 years of age to identify any concerns that may emerge. The reliability of fundoscopy findings to identify patients with or without increased ICP is also less defined, and well-designed studies including blinding and multiple physician review may help address this uncertainty. In addition, defining what outcome measures should be standard among children with craniosynostosis would help not only compare various endoscopic techniques but also contrast between open approaches and timing of intervention.

## CONCLUSION

Elevated ICP may occur in infants with craniosynostosis at higher rates and earlier ages than previously reported based on our pressure cutoff. Endoscopic-assisted craniectomy has an immediate effect on lowering ICP and improving postoperative ophthalmological findings. Optic nerve findings were common in our cohort, and we believe that multidisciplinary assessment should be the standard of care in working up children with craniosynostosis. Endoscopic-assisted strip craniectomy is a safe approach in infants with craniosynostosis with low transfusion rates and short hospital stays.

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**Supplementary Figure 1**. Sagittal craniosynostosis: preoperative (top row) and 9 months postoperative (bottom row).
**Supplementary Figure 2**. Metopic craniosynostosis: preoperative (top row) and 7 months postoperative (bottom row).
**Supplementary Figure 3**. Left coronal craniosynostosis: preoperative (left column), 2 months postoperative (middle column), and 6 months postoperative (right column).
**Supplementary Figure 4**. Right lambdoid craniosynostosis: preoperative (top row) and 3 months postoperative (bottom row).
**Supplementary Figure 5**. Multisuture (sagittal and bicoronal craniosynostosis): preoperative (top row), preoperative CT head 3D reconstruction (middle row), and 5 months postoperative (bottom row).