INTRODUCTION
The occipital bone is formed from the union of four primary cartilaginous centers in the chondrocranium adjacent to the foramen magnum, and a fifth membranous center located more superiorly.\(^1\) The mendosal, or biasternal, suture is derived from the Latin word mendosus, meaning “faulty” or “incorrect” and lies between the interparietal (superior squama above the suture) and supraoccipital portions of the occipital bone (inferior squama below the suture).\(^2\)–\(^6\) It is situated slightly superior to the transverse sinus, the large draining vessel that arises near the mastoid fontanelle (posterior lateral) and runs horizontally from the medial side of the lambdoid suture toward the midline.

Previous studies have suggested that the fusion of the mendosal suture begins in utero and is completed within the first few months of life.\(^7\)–\(^11\) Awareness of this suture and its morphologic variations are important for several reasons. First, mendosal suture patency can result in bathrocephaly, an abnormally protrusive occiput that can be confused with scaphocephaly, the phenotypic presentation of sagittal craniosynostosis.\(^3\) Second, this suture may

Background: The mendosal suture joins the interparietal and inferior portions of the occipital bone. Persistent patency of this suture can result in bathrocephaly, an abnormal occipital projection. This study aims to determine normal temporal fusion of the mendosal suture and cranial shape of the patients with persistent suture patency.

Methods: A retrospective review of head CT scans in patients aged 0–18 months who presented to the emergency department between 2010 and 2020 was completed. Presence and patency of the mendosal suture were assessed. Cranial shape analysis was conducted in the cases that presented with 100% suture patency and age-matched controls. An exponential regression model was used to forecast the timing of suture fusion.

Results: In total, 378 patients met inclusion criteria. Median age at imaging was 6.8 months (IQR 2.9, 11.6). Initiation of mendosal suture fusion was observed as early as 4 days of age and was completed in all instances except one by age 18 months. Most patients had either a complete or partial suture fusion (66.7% versus 30.7%, respectively), and 2.6% of patients had 100% suture patency. Cranial shape analysis demonstrated increased occipital projection in patients with 100% suture patency compared with their controls. Exponential regression model suggested that the mendosal suture closure begins prenatally and typically progresses to full closure at the age of 6 months.

Conclusions: Prevalence of a patent mendosal suture was 2.6% overall. Mendosal suture fusion initiates in-utero and completes ex-utero within the first 18 months of life. Delayed closure results in greater occipital projection. (Plast Reconstr Surg Glob Open 2022;10:e4383; doi: 10.1097/GOX.0000000000004383; Published online 14 June 2022.)
be mistaken for a fracture on X-ray and/or CT scans and mischaracterized as a non-accidental trauma, resulting in legal and emotional consequences.\textsuperscript{4,5,10,12-17} Lastly, an open mendosal suture can be confused with a lambdoid suture during a retromastoid suboccipital approach to the brain, resulting in an errant surgical approach.\textsuperscript{18} The purpose of this study was to (1) characterize closure of the mendosal suture among infants younger than 18 months of age; (2) determine if prolonged patency of the suture is associated with increased occipital projection (ie, bathrocephaly); and (3) elucidate the normal timing and pattern of mendosal suture fusion.

**PATIENTS AND METHODS**

**Data Acquisition**

This cross-sectional study was conducted after institutional review board approval. We collected CT scans of children from 0 to 18 months of age who presented to our pediatric emergency department between July 2010 and March 2020. A panel of two craniofacial surgeons reviewed the CT scans to evaluate the percent of mendosal suture patency. Patients with a history of craniostenosis, ventriculoperitoneal shunt placement, skull fractures, or syndromes associated with cranial/brain abnormalities were excluded. Data on the demographic information, prior medical and family history, prematurity status, chief complaint, and date of the CT scan were recorded.

Axial CT scan cuts were reviewed and analyzed by two pediatric craniofacial surgeons (G.F.R. and A.K.O.); the senior author blindly reviewed all the conflicting scans. The mendosal suture was considered 100% open only if the CT scan displayed a patent suture that arose from one asterion and was contiguous to the other asterion. For the scans that were completely fused or 100% patent, there was 100% agreement among the readings for the two reviewers. For sutures that were partially open, the percentage of patency was estimated and measured relative to the total length of the suture on a three-dimensional scan. The number, frequency, and percentages of sutures that were open, partially fused, and completely fused were then tabulated by month and year of age. (See Table 1, Supplemental Digital Content 2, which displays the percentage of sutures that were open, partially fused, and completely fused were then tabulated by month and year of age. (See figure, Supplemental Digital Content 2, which displays the cranial suture closure pattern, Supplemental Digital Content 1, which displays the percentage of patent mendosal suture across age groups. [http://links.lww.com/PRSGO/C57.](http://links.lww.com/PRSGO/C57))

**Cranial Shape and Statistical Analysis**

Cranial shape analysis (CSA) was performed in all the cases with 100% patency of the mendosal suture and representative age- and sex-matched controls that had complete fusion of the suture. This analysis was conducted with a registered method of semi-automated computerized cranial shape.\textsuperscript{19,21} Briefly, this technique systematically sections the cranial bones from CT images using thresholding based on Hounsfield units of bone tissue. Then, the surface of the cranial shape is created using a proprietary graph-cut-based algorithm.\textsuperscript{19,21} Each cranial shape is then compared with its closest age- and sex-adjusted normal shape, based on a cranial shape atlas developed from the cranial profile of 539 healthy subjects. (See figure, Supplemental Digital Content 2, which displays the cranial suture closure pattern. [http://links.lww.com/PRSGO/C58.](http://links.lww.com/PRSGO/C58).)

Absolute malformations were computed by the absolute distance between the patients’ cranial shape and the “closest normal shape.” The precision and accuracy of correctly determining abnormalities of the cranium using this method have been previously established by Mendoza et al.\textsuperscript{19} To examine the presence of occipital projection, we calculated the difference between the absolute malformation of the occiput relative to the patient’s cranial shape taken from the right parietal bone, which is unaffected by this condition.

**Statistical Analysis**

The baseline demographic information was summarized using median with interquartile range (IQR) for continuous data, and frequencies with percentages for categorical data. The prevalence of a patent mendosal suture was calculated by age group. The chi-square test and Fisher exact tests were used to compare categorical data as appropriate.

To extrapolate the suture closure pattern, we fitted a prediction trajectory along with 95% confidence and prediction interval using an exponential regression model between the percentage of patency for the cranial suture after birth and the infant’s age in months. Adjusted Rsquared was used to assess the goodness of fit of the regression model. All statistical analyses were performed using R statistical software, version 4.0.0.\textsuperscript{23}

**RESULTS**

We identified 378 patients between the ages of 4 days and 18 months at the time of CT scan with a median age of 6.8 months (interquartile age range, 2.9–11.6 months). Most patients were men (53.7%) and full-term (70.0%). The most common indication for CT scan was trauma (83.8%), which included accidental and non-accidental trauma. Recorded baseline descriptive demographic information is shown in Table 1.

Complete fusion of the mendosal suture was observed in most patients (n = 252, 66.7%), whereas 30.7% (n = 46x138}
(n = 116) of patients had a partially fused suture, and 2.6% (n = 10) had 100% suture patency at the time of CT scan. The pattern of suture fusion was demonstrated on 3D reconstruction as starting in the midline of the occiput and extending laterally with increasing age.

The distribution mendosal suture patency was further analyzed by age group. As shown in Figure 1, the initiation of fusion was evident as early as 4 days of age and was completed in all subjects by 18 months of age. In CT scans obtained before 8 months of age, the proportion of patients with varying degrees of suture fusion (48.1%, n = 101) and with complete closure were similar (47.14%, n = 99). However, 4.76% of patients for this age group (10 out of 210 patients) had a 100% patency. For CT scans obtained after 8 months of age, most patients had a completely fused suture (91.1%, n = 153) and a smaller number had incomplete fusion (8.9%, n = 15) (Table 2). Of note, one patient with 100% suture patency noticed at 4.56 months of age continued to be completely patent in a follow-up scan at 24 months of age.

Detailed CSA failed to analyze two cases due to poor CT quality (2/10). From the eight remaining cases with a completely open mendosal suture, six patients (75%) demonstrated a relative increase in occipital projection (Figs. 2, 3) compared with the right parietal control, and on average those cases with an open mendosal suture had greater projection of the occiput compared with their matched-controls (2.70 ± 1.77 mm versus 1.06 ± 1.28 mm, 95%CI -0.0164 mm to 3.2964 mm; P value 0.052) (Table 3).

To estimate the inception of normal mendosal suture fusion and the trajectory of suture closure over time, we produced an exponential regression model comparing the infant age at CT scan and the percentage of patency.

Table 1. Summary of the Baseline Demographic Information in Our Cohort

| Patients Characteristics            | Frequency (%) |
|------------------------------------|---------------|
| Total sample                       | 378 (100%)    |
| Median age (IQR)                   | 6.8 mo (2.9–11.9) |
| Age range                          | 4 d–18 mo     |
| Gender                             |               |
| Men                                | 203 (53.7%)   |
| Women                              | 175 (46.3%)   |
| Race                               |               |
| African American                   | 223 (59.0%)   |
| Hispanic/Latino                    | 61 (16.1%)    |
| White                              | 60 (15.9%)    |
| Asian                              | 4 (1.1%)      |
| American Indian                    | 1 (0.3%)      |
| Unknown                            | 29 (7.7%)     |
| Perinatal medical history          |               |
| Full-term at birth                 | 272 (70.0%)   |
| Preterm birth                      | 36 (9.5%)     |
| Unknown                            | 70 (18.5%)    |
| Chief complaints                   |               |
| Trauma-related incidents           | 317 (83.8%)   |
| Accidental trauma                  | 230 (60.8%)   |
| Non-accidental trauma              | 87 (23.0%)    |
| Generalized of focal neurologic disorder | 12 (3.17%) |
| Other                              | 49 (13%)      |

Fig. 1. Prevalence of mendosal suture patency by age (in months).
of cranial suture after birth (Fig. 4). In this regression model, we excluded 10 patients with 100% patent suture who were considered statistical outliers. Our model implies that the suture closure process begins prenatally, 2.0 months (95% CI: 1.7, 2.3) before birth, and approaches full closure (0% patency) at the age of 6 months in the majority of patients.

**DISCUSSION**

The mendosal suture lies between the endochondral and membranous portions of the occipital bone and like other cranial sutures, ossification starts in the endochondral center and progresses laterally. The superior portion of the squamosal segment, or the occipital plate, typically has two ossification centers which appear during early fetal life (weeks 8–12) and at some point, in utero, the suture begins to fuse from the central portion of the suture and extends laterally. This lateral portion can sometimes remain evident up to several years of age. Indeed, our assessment of over 300 CT scans confirms that fusion of the mendosal suture appears to begin centrally and extends laterally in an age-dependent fashion.

Onset of fusion and timing of normal closure of the mendosal suture has been a topic of debate. While the inception of suture closure has been hypothesized to occur as early as 12 weeks after conception, our regression analysis implies that the closure begins much later, around 32 weeks of gestation. Furthermore, evidence regarding the progression and completion of suture closure is variable and conflicts with our findings. Pawlik found that the mendosal suture was seen open in up to 10% of skulls between the ages of 16 and 20 years. Similarly, Tubbs et al found an open mendosal suture in eight (16%) out of 50 skulls in specimens greater than 30-years-old. However, these anatomical studies use *ectocortical* markings to determine sutural patency.

![Table 2. Patency of Mendosal Suture before and after the Age of 8 Months](image)

| Age      | Fused     | Partially Open | Completely Open | Total |
|----------|-----------|----------------|-----------------|-------|
| <8 mo    | 99 (47.14%) | 101 (48.1%)    | 10 (4.76%)      | 210 (100%) |
| >8 mo    | 153 (91.1%) | 15 (8.9%)      | 0.0 (0%)        | 168 (100%) |
| *P*      | <0.001    | <0.001         | 0.004           |       |

![Fig. 2. CSA comparison of age-matched 4-month-old case (patent mendosal suture) and control (fused mendosal suture). Case shows positive deflections (excess development) in occipital bone and negative deflections (deficient development) in both parietal bones that were not present in the control.](image)
which can be misleading as the suture closure invariable begins on the endocortex.\textsuperscript{25–27} Thus, visible ectocortical markings on the surface of a dry skull does not imply complete suture patency because endocortical fusion cannot be excluded. Indeed, our high-resolution CT analysis found only one subject older than 8 months who had a persistently patent mendosal suture at 24 months of age.

Based on imaging data, other groups have described the normal mendosal suture closure between the second\textsuperscript{9} and fourth year of life,\textsuperscript{28} with reports of a persistently patent suture beyond 6–10 years of age in some patients.\textsuperscript{5,8} However, many of these studies relied on comparatively inaccurate standard skull X-rays. Nakahara et al used plain radiographs and identified open lateral portions of the mendosal suture in 80% of infants younger than 1 year old, with patency decreasing with age, and up to 6% of 4- and 5-year-olds had some residual lateral patency.\textsuperscript{5} Our study demonstrates an age-related progression of suture fusion that began in utero and was completed in all patients except one by the age of 18 months. Persistent lateral suture patency was seen in a small subset of subjects between 12 and 18 months of age, but the degree of patency was very limited, ranging between 5% and 40%. Because we did not extend our investigation past 18 months, it is conceivable that a minor percentage of subjects beyond this age could exhibit some lateral patency. These remaining regions of mendosal patency can usually be distinguished from non-accidental cranial fractures because they usually are noncontiguous and bilateral,\textsuperscript{13,29} and unaccompanied by other findings seen in cranial trauma such as intracranial and retinal hemorrhage.\textsuperscript{4}

Cranial shape analysis confirmed that subjects with persistent mendosal patency indeed demonstrated

**Table 3. Quantitative Occipital Projection in Patients with 100% Patency of the Mendosal Suture Compared with Their Matched Controls**

| Case | Gender | Age (mo) | Difference (mm) | AMO (mm) | AMRPB (mm) | Control | Gender | Age (mo) | Difference (mm) | AMO (mm) | AMRPB (mm) |
|------|--------|----------|----------------|----------|-------------|---------|--------|----------|----------------|----------|-------------|
| Case 1 | M | 4.3 | — | — | — | Control 1 | M | 4.2 | 0.78 | 1.64 | 0.86 |
| Case 2 | F | 0.1 | 1.25 | 1.44 | 0.19 | Control NA | — | — | — | — | — |
| Case 3 | M | 1.3 | 0.98 | 2.79 | 1.81 | Control 3 | M | 1.5 | 2.95 | 3.35 | 0.4 |
| Case 4 | F | 3.32 | 3.62 | 0.3 | Control 4 | F | 2.1 | 1.95 | 3.68 | 1.73 |
| Case 5 | M | 3.6 | 4.43 | 5.28 | 0.85 | Control 5 | M | 3.7 | 1.95 | 3.68 | 1.73 |
| Case 6 | F | 3.7 | — | — | — | Control 6 | F | 3.2 | 0.92 | 1.31 | 0.39 |
| Case 7 | M | 4.6 | 0.84 | 1.92 | 1.08 | Control 7 | M | 4.5 | 1.52 | 3.44 | 1.92 |
| Case 8 | F | 5.3 | 6.11 | 6.48 | 0.37 | Control 8 | F | 5.3 | 1.82 | 3.18 | 0.64 |
| Case 9 | F | 7.1 | 1.56 | 2.27 | 0.71 | Control 9 | F | 7 | −1.58 | −2.16 | −0.58 |
| Case 10 | M | 7.5 | 3.14 | 3.46 | 0.32 | Control 10 | M | 7.6 | 0.09 | −0.46 | −0.55 |

*Failed to analyze due to poor image quality.
AMO, absolute malformation of the occiput; AMRPB, absolute malformation of the right parietal bone; F, feminine; M, masculine; NA, not available.
increased occipital projection (bathrocephaly) relative to an unaffected parietal landmark, and this was not observed in the control cases. This finding provides quantitative support for the heretofore anecdotal association between bathrocephaly and delayed mendosal closure. Although the mean absolute difference in occipital projection did not reach a significant difference between groups, there was a clear trend for the patent suture cohort and an increased sample could strengthen this association. The very minor and focal cranial shape changes seen with bathrocephaly have no known medical or neurocognitive consequences, yet the phenotype should be distinguished from other conditions with a prominent occiput such as sagittal craniosynostosis, Edwards syndrome (>50%), and Beckwith-Wiedemann syndrome (72%). Fortunately, most cases of bathrocephaly can be diagnosed with clinical examination (isolated occipital projection with no other cranial shape changes and a palpable transverse ridge across the occiput) and do not require a confirmatory CT scan.

Limitations

The primary limitation of our study is its retrospective design. Consequently, sutural patency was assessed at only one point in time (presentation to the emergency department) for each patient, and conclusions about the timing of suture closure can only be extrapolated from trends in our aggregate data. Although longitudinal evaluation would be preferred and more convincing, it is impractical and, perhaps, unethical to subject patients to serial CT scans to assess this benign condition. Moreover, the cross-sectional design limits information about the clinical presentation and natural history of this condition. In addition, our cohort was not homogeneously distributed across ages, had a significant fraction of outliers, and followed a non-Gaussian random distribution, which limited the statistical modeling. To estimate the inception of fusion, we removed the few outliers (100% patent) from our regression to allow a better fit of the data. Despite this, we believe that the regression provides a useful estimate of when the mendosal suture begins to close in-utero. Furthermore, data concerning in-utero suture fusion are nonexistent in our cohort. Nevertheless, with the current model, in-utero closure pattern is being extrapolated from the postgestational CT scans, assuming that suture fusion follows the same dynamic both antepartum and postnataally.

CONCLUSIONS

In this study, the point prevalence of complete patent mendosal suture between the age of 0 and 18 months was nearly 3%. Complete patency of the mendosal suture was observed only in one subject past age 8 months. Based on regression analysis, the mendosal suture normally begins to fuse around 32 weeks gestation, and is typically completed within the first year of life. Delayed closure past 6
months of age can result in greater occiput projection or bathrocephaly.

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