CLINICAL REPORT Guidance for the Clinician in Rendering Pediatric Care

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN®

Identifying the Misshapen Head: Craniosynostosis and Related Disorders

Mark S. Dias, MD, FAAP, FAANS,[a] Thomas Samson, MD, FAAP,[b] Elias B. Rizk, MD, FAAP, FAANS,[a] Lance S. Governale, MD, FAAP, FAANS,[c] Joan T. Richtsmeier, PhD,[d] SECTION ON NEUROLOGIC SURGERY, SECTION ON PLASTIC AND RECONSTRUCTIVE SURGERY

Pediatric care providers, pediatricians, pediatric subspecialty physicians, and other health care providers should be able to recognize children with abnormal head shapes that occur as a result of both synostotic and deformational processes. The purpose of this clinical report is to review the characteristic head shape changes, as well as secondary craniofacial characteristics, that occur in the setting of the various primary craniosynostoses and deformations. As an introduction, the physiology and genetics of skull growth as well as the pathophysiology underlying craniosynostosis are reviewed. This is followed by a description of each type of primary craniosynostosis (metopic, unicoronal, bicoronal, sagittal, lambdoid, and frontosphenoidal) and their resultant head shape changes, with an emphasis on differentiating conditions that require surgical correction from those (bathrocephaly, deformational plagiocephaly/brachycephaly, and neonatal intensive care unit-associated skill deformation, known as NICUcephaly) that do not. The report ends with a brief discussion of microcephaly as it relates to craniosynostosis as well as fontanelle closure. The intent is to improve pediatric care providers' recognition and timely referral for craniosynostosis and their differentiation of synostotic from deformational and other nonoperative head shape changes.

INTRODUCTION

Pediatric health care providers evaluate and care for children with a variety of head shapes, some of which represent craniosynostosis and other craniofacial disorders, some of which are deformational in nature, and some of which are simply normal variants. Identifying the various types of head shape abnormalities is important for aesthetics, to identify candidates for future monitoring, and, at least in some, to prevent increases in intracranial pressure (ICP) and allow proper brain development. This report reviews several of the important head shape abnormalities and normal variants that pediatric health care providers are

abstract

[a]Section of Pediatric Neurosurgery, Department of Neurosurgery and [b]Division of Plastic Surgery, Department of Surgery, College of Medicine and [d]Department of Anthropology, College of the Liberal Arts and Huck Institutes of the Life Sciences, Pennsylvania State University, State College, Pennsylvania; and [c]Lillian S. Wells Department of Neurosurgery, College of Medicine, University of Florida, Gainesville, Florida

DOI: https://doi.org/10.1542/peds.2020-015511

Address correspondence to Mark S. Dias, MD, FAAP, FAANS. E-mail: mdias@pennstatehealth.psu.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

To cite: Dias MS, Rizk EB, et al. AAP SECTION ON NEUROLOGIC SURGERY, SECTION ON PLASTIC AND RECONSTRUCTIVE SURGERY. Identifying the Misshapen Head: Craniosynostosis and Related Disorders. *Pediatrics*. 2020;146(3):e2020015511

likely to see, describes their salient clinical and radiologic features, and discusses the optimal timing for referral and surgical correction. The report begins with an overview of the normal development of the skull and sutures and the pathophysiology of craniosynostosis.

NORMAL DEVELOPMENT OF THE CALVARIUM AND MOLECULAR DETERMINANTS OF CRANIOSYNOSTOSIS

The skull is a complex skeletal system that meets the dual needs of protecting the brain and other sensory organs while allowing its ongoing growth during development. The calvarial vault (Fig 1) is composed of paired frontal, parietal, and temporal bones and a single occipital bone. The paired frontal bones are separated from each other by the midline metopic suture, and the paired parietal bones are separated from each other by the midline sagittal suture. The frontal and parietal bones are separated by the paired coronal sutures, the parietal and temporal bones are separated by the paired squamosal sutures, and the parietal and occipital bones are separated by the paired lambdoid sutures. There are also a number of sutures and synchondroses involving the skull base. The anterior fontanelle (bregma) forms at the junction of the paired frontal and parietal bones, whereas the posterior fontanelle (λ) forms at the junction of the paired parietal bones with the midline occipital bone.

The skull encompasses the skull base, calvarial vault, and pharyngeal skeleton.[1,2] The bones of the skull base mineralize through endochondral ossification involving the replacement of a fully formed cartilaginous anlagen with bone matrix. In contrast, the bones of the calvarial vault form by intramembranous ossification involving the mineralization of bone matrix from osteoblasts without a cartilaginous intermediate. Craniosynostosis involves the abnormal mineralization of suture(s) and fusion of one or multiple contiguous bones of the cranial vault and can include additional abnormalities of both the soft and hard tissues of the head.[3] The role of cartilage growth disturbance within the cranial base in craniosynostosis is still a matter of debate.[4–7]

The bones of the cranial vault ossify directly from undifferentiated mesenchyme.[8,9] Differentiating osteoblasts accumulate on the leading edges of cranial vault bones as the brain expands during prenatal and early postnatal growth.

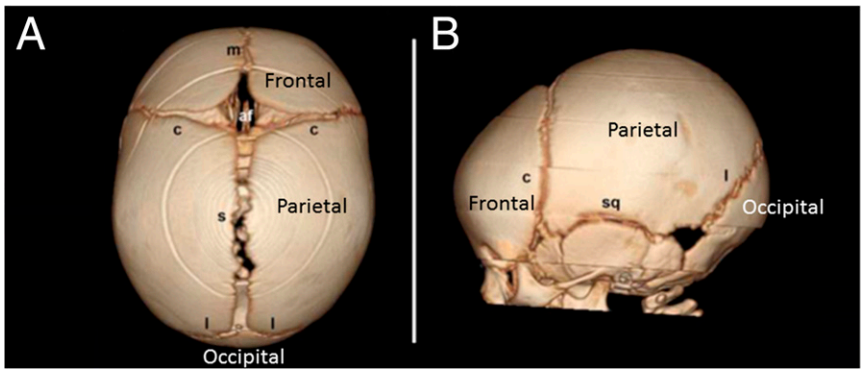

FIGURE 1
Three-dimensional CT scan showing (A) top and (B) side views of the skull bones with metopic (m), sagittal (s), coronal (c), lambdoid (l), and squamosal (sq) sutures, as well as the anterior fontanelle (af). Reproduced with permission from Governale LS. Craniosynostosis. *Pediatr Neurol.* 2015;53(5): 394-401.

Undifferentiated cells between these osteogenic bone fronts form the cranial vault sutures, which function to keep the suture patent while allowing rapid and continual bone formation at the edges of the bone front until brain growth is complete.[10] Sutures are fibrous "joints" that allow temporary deformation of the skull during parturition or trauma, inhibit bone separation for the protection of underlying soft tissues, and, perhaps most importantly, enable growth along the edges of the 2 opposing bones until they ossify and fuse later in life.[10,11] Sutures normally remain unossified well into adolescence. When sutures mineralize (close) abnormally, growth is prevented at the fused suture and is instead redirected to other patent sutures, which, in turn, alters the shape of the skull in predictable ways.

Research has revealed multiple genetic factors, involving several major cellular signaling pathways such as wingless and Int-1 (WNT), bone morphogenetic protein (BMP), fibroblast growth factor (FGR), and others, that interact to direct the behavior of particular subpopulations of cells within the suture. In craniosynostosis, these cells receive and emit signals that stimulate osteogenic differentiation far earlier than expected,[12] resulting in mineralization and progressive ossification that unites the bones on either side of the suture. Pathogenic variants of fibroblast growth factor receptors (*FGFR*s) are the most common genetic variants associated with craniosynostosis.[13–15] *FGFR*s are transcription factors that initiate and regulate the transcription of multiple genes throughout prenatal development.[16–21] Various mouse models expressing *FGFR* pathogenic variants have been developed and demonstrate phenotypes analogous to the human craniosynostosis syndromes, including premature coronal suture closure and midface

flattening (retrusion).[22–31] Pathogenic variants in *TWIST1* (twist family basic Helix-Loop-Helix transcription factor 1) gene, another transcription factor associated with craniosynostosis,[32–34] directly affect BMP signaling of skull preosteoblasts, leading to variations in cerebral brain angiogenesis.[35] These animal models as well as studies of cellular behavior in human craniosynostosis cell lines provide the means to examine the structural, cellular, and molecular changes that occur during prenatal development.[36,37]

THE EFFECT OF CRANIOSYNOSTOSIS ON ICP AND DEVELOPMENT

Aesthetic consequences aside, there are concerns that craniosynostosis, in some cases, affects brain growth and intellectual development. A recent systematic review strongly suggests that craniosynostosis is associated with a higher risk for presurgical neurocognitive deficits compared with the population unaffected by craniosynostosis; these deficits persist postoperatively, suggesting that they may occur independent of surgical correction.[38] Generalized IQ is shifted downward with increased learning disabilities, language delays, and behavioral difficulties.[39] At least 4 mechanisms have been proposed: (1) globally elevated ICP, (2) global brain hypoperfusion, (3) localized compression and deformity, and (4) genetic predisposition. It has proven difficult to extract the exact contributions of each factor, and studies have provided conflicting data. Moreover, many studies suffer from a variety of methodologic flaws, including the inclusion of several types of craniosynostosis, varying definitions of ICP elevations (and lack of normative data), the use of different neurocognitive testing strategies, lack of randomization, inconsistent operative approaches, variations in operative timing, and small study cohorts, to name a few.

To what extent, if any, treatable causes contribute to neurocognitive deficits in craniosynostosis, and whether prompt surgical treatment can improve neurobehavioral outcomes, is a matter of debate. Elevated ICP is present in 4% to 42% of children with single-suture craniosynostosis and approximately 50% to 68% with multisutural involvement[40–44]; the incidence of intracranial hypertension is higher among older untreated individuals.[42,44] Elevated ICP correlates with developmental and cognitive outcomes in some studies[40] but not others.[39,45,46] Neither has the severity of the deformity correlated with the presence of neurocognitive deficits.[39] A few studies have suggested that earlier treatment of craniosynostosis may result in better early and late neurocognitive outcomes,[45,47] but the majority have not found such an association.[12,48–50] Finally, genes involved in craniosynostosis syndromes have recently been found to be involved in brain development,[51] and syndromic craniosynostosis syndromes having virtually identical patterns of skull fusion may carry widely different risks for neurodevelopmental deficits (see below).

THE IMPACT OF SUTURAL SYNOSTOSIS ON DIRECTED CALVARIAL GROWTH

Single sutural synostosis results in predictable changes in skull shape (Fig 2, Table 1). Persing et al[52] proposed 4 rules that govern calvarial growth and predict the head shape in cases of craniosynostosis. These rules are based on the principle that calvarial growth occurs by osseous deposition from calvarial bones lying adjacent to each suture, and this deposition is oriented perpendicular to the intervening suture:

1. Bones that are fused as a result of craniosynostosis act as a "combined growth plate," having reduced growth potential at all of the margins of the plate;
2. Bone is, therefore, deposited asymmetrically, with greater osseous deposition in the bones opposite the perimeter sutures of the combined growth plate;
3. Non-perimeter sutures that are in-line with the combined bone plate deposit bone symmetrically at their suture edges; and
4. Both perimeter and in-line (abutting) sutures nearest the combined bone plate compensate with greater osseous deposition than more distant sutures.

To use sagittal synostosis as an example, the fused parietal bones act as a single, combined growth plate with reduced growth perpendicular to the sagittal suture; accelerated bone deposition occurs within the frontal and occipital bones. The metopic suture, as an abutting in-line suture, deposits bone symmetrically at an accelerated rate. The result is an elongated head (scaphocephaly) with parietal narrowing as well as frontal and occipital bossing. A similar analysis predicts the head shape for the other sutural synostoses (Fig 2). Multisutural synostosis can be appreciated as the combined effect of fusion involving each of the individual component sutures.

SCAPHOCEPHALY (SAGITTAL SYNOSTOSIS), DOLICHOCEPHALY (NICUCEPHALY), AND BATHROCEPHALY

Sagittal synostosis is the most common form of craniosynostosis, accounting for approximately 40% to 45% of cases[53–55] and having a prevalence of 2 to 3.2 per 10 000 live births.[53,56,57] Sagittal synostosis has a distinct male predominance of 2.5 to 3.8:1.[53,55] Sagittal synostosis produces scaphocephaly, characterized by both an elongated head and biparietal narrowing that is evident at birth. The head elongation is best appreciated by looking at the infant from the side (Fig 3). Some patients have an associated saddle deformity at the vertex, giving an

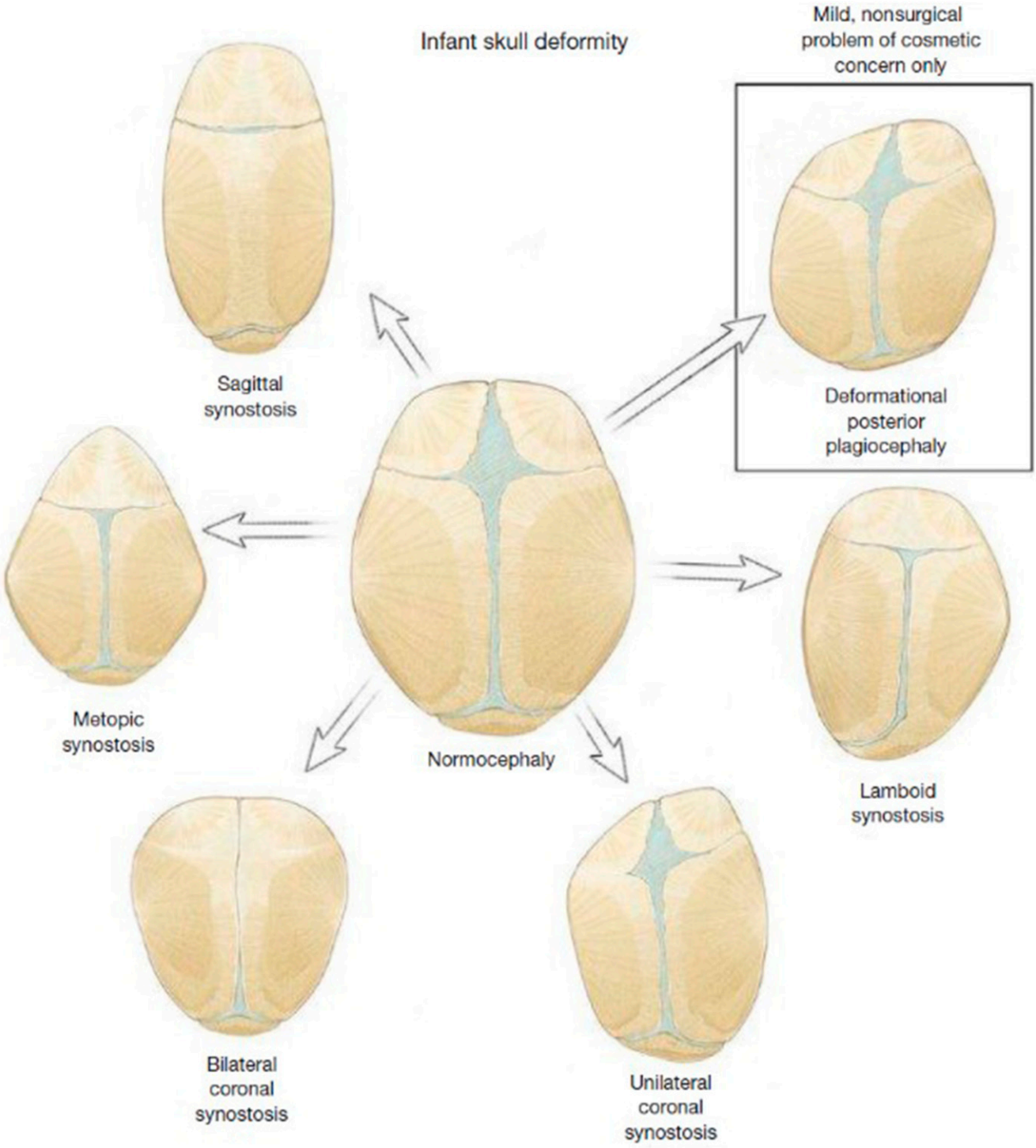

FIGURE 2

Drawing showing the various head shape changes that occur with single-suture synostosis and deformational posterior plagiocephaly. Reproduced with permission from the cover of the May 2016 issue of the *Journal of Neurosurgery: Pediatrics*. ©2016 American Association of Neurologic Surgeons. Artist: Stacey Krumholtz.

overall "peanut" shape to the head. The second consistent abnormality is the biparietal narrowing when looked at from the front or from above. Normally, the parietal bones project straight up or even bowed outward from the temporal region. Biparietal narrowing in sagittal synostosis produces a "cone-head" or bullet-shaped head when viewed from the front and a bicycle racing helmet shape when viewed from above

TABLE 1 Head Shapes Resulting From Craniosynostosis and Positional Deformations

Type	Head Shape Name	1° Change	2° Change(s)
Sagittal	Scaphocephaly	Elongated AP distance	Biparietal narrowing, frontal and/or occipital bossing, and occasional saddle deformity
NICUcephaly	Dolichocephaly	Elongated AP distance	Lack of biparietal narrowing and frontal/occipital bossing
Metopic	Trigonocephaly	Triangular forehead	Bilateral orbital retrusion, bitemporal narrowing, and hypotelorism
Unicoronal	Plagiocephaly	Trapezoid	Flattened ipsilateral forehead, retruded and elevated ipsilateral orbit (Harlequin eye), ipsilateral nasal root and contralateral nasal tip deviation, and anterior displacement of ipsilateral ear
Bicoronal	Brachycephaly and turricephaly	Shortened AP distance; flat, tall, and wide forehead	Exorbitism if associated midface hypoplasia is present
Unilambdoid	Plagiocephaly	Trapezoid	Bulge behind ipsilateral ear or mastoid and ear displaced posterior and inferior
Bilambdoid	Brachycephaly	Shortened AP distance, flat occiput	Bulge behind both ears or mastoid and both ears displaced posterior and inferior
Frontosphenoidal	Plagiocephaly	Trapezoid	Retruded and depressed ipsilateral orbit and contralateral nasal root and ipsilateral nasal tip deviation
DP	Plagiocephaly	Parallelogram	Ipsilateral occiput, ear, and forehead all displaced anteriorly
DB	Brachycephaly	Shortened AP distance	Flattened occiput with normal forehead and orbits

(Fig 3). Frontal or occipital bossing is a variable feature and tends to worsen as the infant ages. Physical examination also demonstrates a prominent midline interparietal, or sagittal, ridge that extends between the anterior and posterior fontanelles; the sagittal suture is longer, as measured from the anterior to the posterior fontanelles. Partial synostosis may cause an incomplete ridge involving only a portion of the suture. One may demonstrate the fusion of the 2 parietal bones by placing a thumb on each of them near the midline and alternatingly depressing each of them; there should be no independent movement.

Sagittal synostosis produces an elongated head on lateral radiographs and a bullet-shaped head on anterior-posterior (AP) radiographs (Fig 4A and B). The normal sagittal suture tapers toward the midline on AP radiographs; in sagittal synostosis, the fused sagittal suture may not be visible, but, more commonly, it appears to have an abrupt, more squared-off appearance (Fig 4B), paradoxically appearing to be open when, in fact, it is not. Computed tomography (CT) scans demonstrate the elongated head with biparietal narrowing (Fig 4C); the fused sagittal suture is best appreciated on coronal reconstructions by using bone algorithms (Fig 4D); three-dimensional reconstructions are particularly well suited to demonstrate the midline sagittal ridge (Fig 4E) but may involve more radiation exposure, particularly with thin slices.

It is important to distinguish scaphocephaly from dolichocephaly. Although these 2 terms have been used interchangeably by many, dolichocephaly refers to an elongated head without associated biparietal narrowing and is caused by positioning. Dolichocephaly most commonly occurs in preterm infants in the NICU: so-called NICUcephaly. Of course, there is no midline sagittal ridge as there is in sagittal synostosis, and, with the thumb maneuver described above, the parietal bones will move independently, often making the infant cry because this appears to be painful.

Infants with frontal bossing from hydrocephalus or chronic subdural hematomas or hygromas may generate confusion. However, these infants have neither an elongated head nor biparietal narrowing, and they have no midline sagittal ridge. Metopic synostosis is readily differentiated from sagittal synostosis by the presence of a prominent midline ridge that extends from the nasion to the anterior fontanelle, anterior to the sagittal suture, and is often associated with a triangular or keel-shaped forehead (trigonocephaly) with recession of the lateral orbits and narrow set eyes.

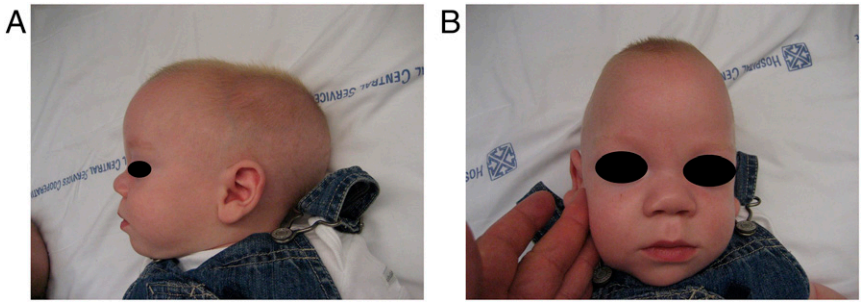

FIGURE 3
Scaphocephaly attributable to sagittal synostosis. A, Lateral view shows elongated antero-posterior dimension with modest frontal bossing and saddle deformity at vertex. B, Frontal view in same child shows parietal bones that curve inward giving a conical head shape attributable to parietal narrowing.

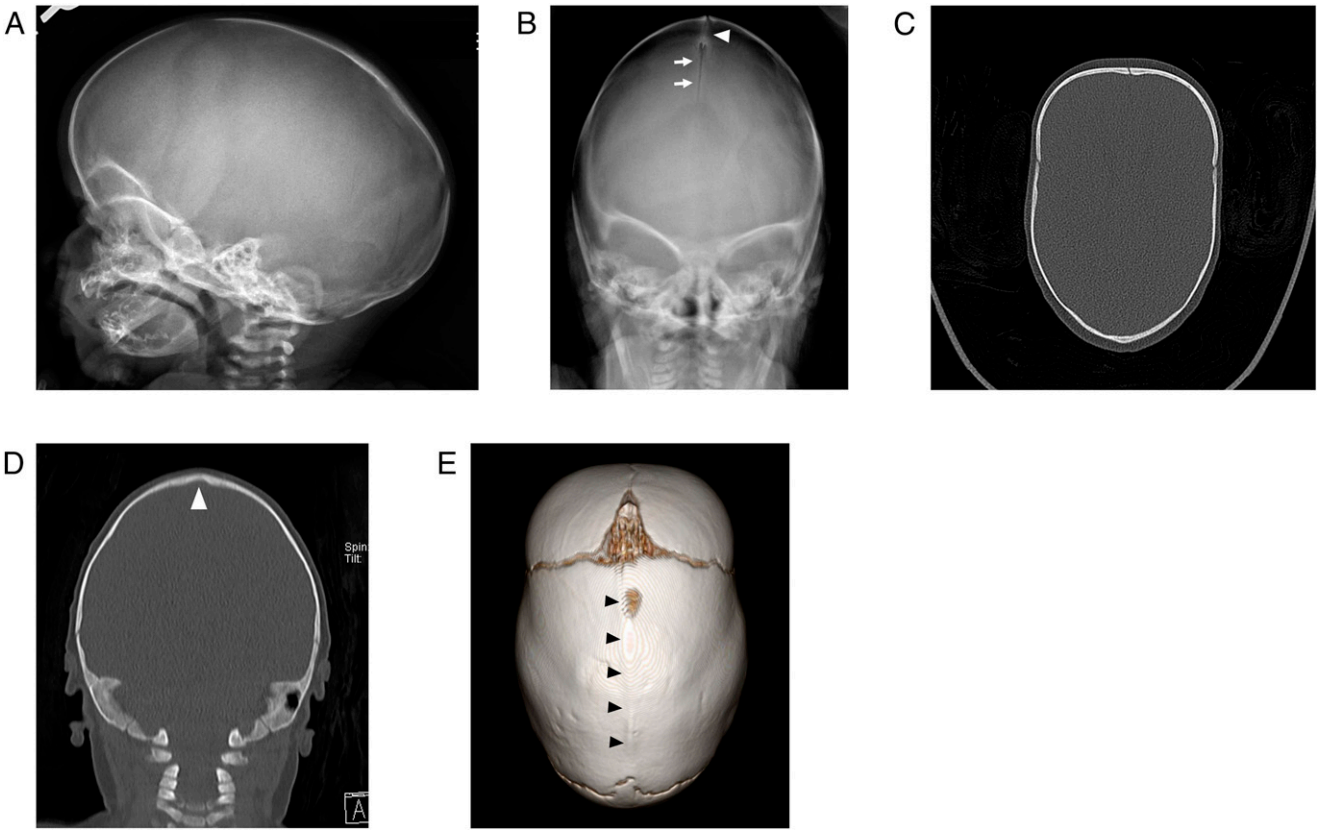

FIGURE 4

Radiologic features of sagittal synostosis. A, Lateral skull radiograph demonstrates an elongated head (sagittal suture is difficult to see from this perspective). B, Anteroposterior skull radiograph shows conical head shape. Note that part of the sagittal suture appears fused (arrowhead), whereas some appears open with sharp borders and adjacent hyperdensities (arrows). The entire suture was fused at surgery. C, Axial CT scan shows elongated head shape with prominent frontal bossing and fused posterior sagittal suture (arrowhead). D, Coronal CT scan shows conical shape of head with fusion of the sagittal suture (arrowheads). E, Three-dimensional CT scan shows prominent midline ridged sagittal suture (arrowheads); both coronal and lambdoid sutures are patent.

Bathrocephaly is another condition that can produce confusion. Bathrocephaly results in a prominent occiput that angles sharply inward toward the neck but without frontal bossing, biparietal narrowing, or sagittal ridging (Fig 5). Bathrocephaly is associated with a persistent mendosal suture, an embryonic suture that extends transversely between the 2 lambdoid sutures and, normally, is gone by birth Fig 5C.[58] Bathrocephaly does not require treatment.

Infants who have sagittal synostosis should be referred to a specialist for repair as early as possible because surgical correction is usually performed much earlier (often at 6–12 weeks of age) than for other forms of synostosis. Surgical management options include both open and endoscopic repairs; adjunctive postoperative helmet therapy is recommended for up to 1 year postoperatively, after more limited endoscopic repairs.[59,60] The importance of early recognition and referral for surgical management cannot be overemphasized because infants treated after 6 to 10 months of age increasingly require more extensive and morbid complete calvarial vault remodeling to achieve adequate correction.

TRIGONOCEPHALY (METOPIC SYNOSTOSIS)

Metopic synostosis is presently the second most common form of craniosynostosis, accounting for 19% to 28% of cases[53–55] and having a prevalence of 0.9 to 2.3 per 10 000 live births.[53,57] The prevalence of metopic synostosis may have increased over the past decades (without a corresponding increase in other synostoses) for uncertain reasons.[54] Metopic synostosis also has a distinct male preponderance of 1.8 to 2.8:1.[53,55] Metopic synostosis produces trigonocephaly with reduced growth potential perpendicular to the metopic suture, a pronounced metopic ridge, and hypotelorism; the forehead forms a keel, similar to the prow of a boat, with bilateral orbital retrusion and bitemporal narrowing (Fig 5). Reduced bifrontal and accelerated biparietal growth along the coronal

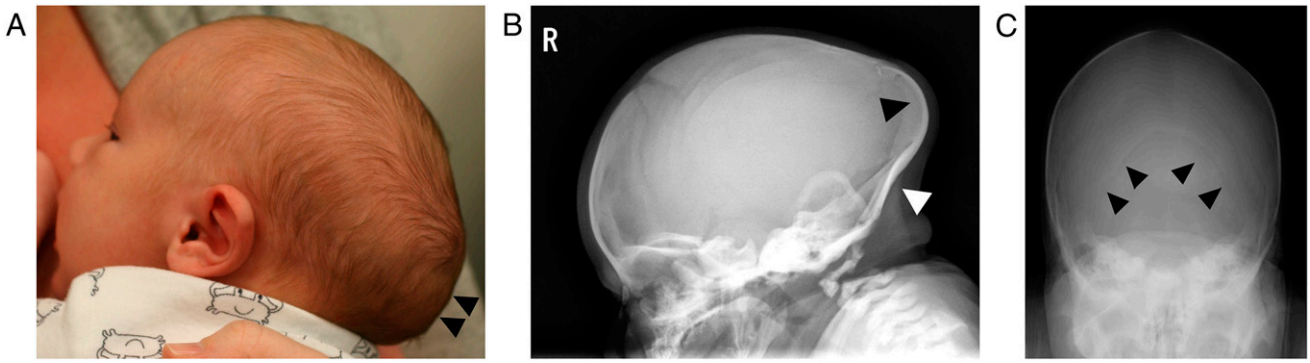

FIGURE 5
Bathrocephaly attributable to persistent mendosal suture. A, Infant with focal prominent occiput (arrowheads). Note the lack of frontal bossing. B, Lateral skull radiograph shows prominent occiput (black arrowhead) and steep angle of the posterior skull (white arrowhead). C, CT scan shows persistent mendosal suture (arrowheads).

sutures, with additional symmetrical growth along the in-line sagittal suture, results in a widened, pear-shaped calvarium behind the coronal suture (Fig 6B).

Some infants may display only a palpable (and sometimes visible) metopic ridge with little or no trigonocephaly; whether this represents a forme fruste of metopic synostosis or another distinct process is unknown. Infants with an isolated metopic ridge and minimal or no trigonocephaly do not require surgical correction.

Plain radiographs may display prominent bony fusion of the metopic suture; however, care must be taken because the metopic suture may normally begin closing as early as 3 months of age and all are closed by 9 months of age.[61] CT scans readily demonstrate the triangular-shaped anterior fossa with midline thickening of the metopic suture and hypotelorism (Fig 7).

ANTERIOR PLAGIOCEPHALY (UNICORONAL SYNOSTOSIS)

Unicoronal synostosis is the third most common form of craniosynostosis, accounting for 12% to 24%[53,55] of nonsyndromic cases and with a prevalence of 0.7 per 10 000 live births.[57] Unlike other forms of synostosis that have a male predominance, unicoronal synostosis has a female preponderance of 1.6 to 3.6:1.[53,57] Unicoronal synostosis produces anterior plagiocephaly in which growth along the ipsilateral coronal suture is reduced and results in a flattening of the ipsilateral forehead (Fig 8). Accelerated growth of the contralateral frontal bone along the perimeter (metopic) and in-line (contralateral frontal) sutures results in compensatory bossing of the contralateral forehead. Some parents and providers may focus on the contralateral compensatory bossing rather than the ipsilateral flattening on the involved side. The metopic suture is bowed toward the side of the flattening. Accelerated growth along the squamosal suture (another perimeter suture) also produces a degree of ipsilateral temporal bossing as well as posterior and inferior ear displacement. The net effect of these changes is a trapezoidal head shape with flattening of the ipsilateral calvarium (both frontally and occipitally) compared to the contralateral side (Fig 8A). This presentation stands in distinct contrast to the parallelogram head shape that accompanies most

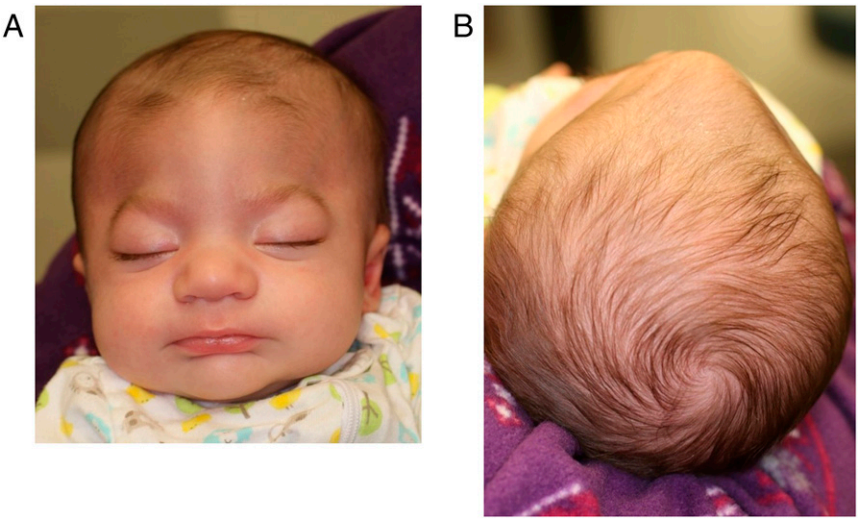

FIGURE 6
Trigonocephaly attributable to metopic synostosis. A, Frontal view of infant showing pronounced midline metopic ridge and bilateral temporal narrowing. B, Vertex view in the same infant shows triangular-shaped forehead.

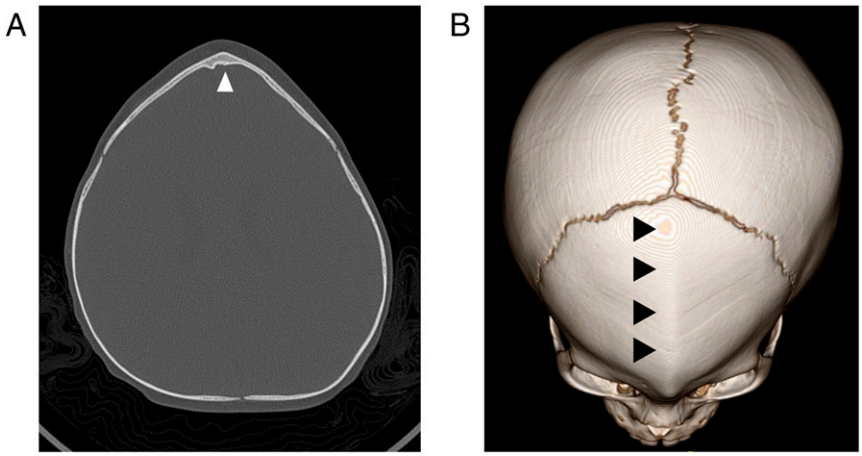

FIGURE 7
Radiologic features of trigonocephaly. A, Axial CT shows triangular-shaped forehead with fused metopic suture (arrowhead) and bitemporal narrowing. B, Three-dimensional CT scan vertex reconstructions show prominent midline metopic ridge with triangular-shaped forehead, bilateral orbital retrusion, and hypotelorism.

cases of occipital deformational plagiocephaly (DP) (see below).

Coronal synostosis additionally involves the sphenozygomatic, frontosphenoidal, and sphenoethmoidal sutures along the frontal skull base, which produces additional secondary morphologic changes involving the orbits and face. Elevation of the lateral sphenoid wing with foreshortening of the zygoma and orbit results in a characteristic elevation of the ipsilateral eyebrow, a seemingly larger palpebral fissure, and/or mild proptosis (Fig 8). The contralateral orbit may be comparatively smaller and is displaced inferiorly and laterally, sometimes leading to a vertical orbital malalignment (dystopia). Diminished growth along the ipsilateral anterior skull base deviates the nasal root toward the involved side and the nasal tip toward the contralateral side (Fig 8B), and the ipsilateral tragus is often displaced anteriorly and inferiorly. In some cases, the entire face appears to be curved with its convexity toward the involved side, leading to a "facial scoliosis" (Fig 8B).

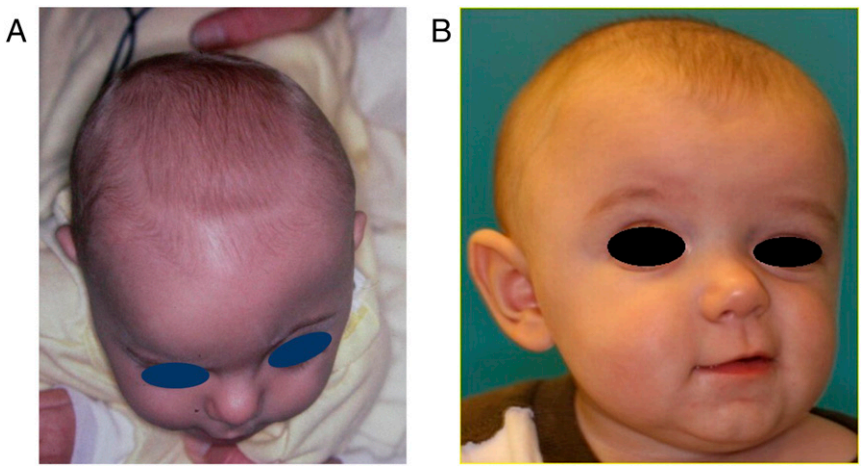

FIGURE 8
Anterior plagiocephaly attributable to unilateral coronal synostosis. A, Vertex view in a child with left coronal synostosis shows flattening of the left forehead and compensatory prominence of the right forehead, upward displacement of the left eyebrow, deviation of the nasal root toward the right and nasal tip toward the left, and trapezoidal head shape. B, Frontal view in another infant with right coronal synostosis shows elevation of the right eyebrow and misshapen orbit, deviation of the nasal root toward the right and nasal tip toward the left, and significant facial scoliosis.

Plain radiographs demonstrate poor visualization of the involved coronal suture. If visible, the ipsilateral suture is deviated anteriorly compared to the contralateral suture; one caveat is that the radiograph must be truly lateral by demonstrating that the ears and/or external ear canals are properly aligned. On the AP view, a characteristic "Harlequin" (or "Mephistophelean") orbit is visible on the involved side and is attributable to elevation of the lesser sphenoid wing (Fig 9A). The nasal bone is also askew, with its upper part deviated toward the involved side.

The findings of unicoronal synostosis are also readily apparent on CT scans. The involved coronal suture is not visible over most or all of its length, whereas the contralateral side is readily apparent on axial images. The ipsilateral flattening and contralateral bossing are also readily evident on axial images. Finally, the sphenoid wing elevation produces a distinct asymmetry to the skull base, with the ipsilateral orbital roof being visible on more superior axial images (and elevated on coronal images) compared to the contralateral orbital roof (Fig 9B). Coronal images also demonstrate the Harlequin orbit to good advantage. Three-dimensional CT reconstructions also demonstrate all of the findings.

The differential diagnosis would include occipital DP and frontosphenoidal synostosis, both discussed below. Hemifacial microsomia is another consideration, although the latter is manifest by primary underdevelopment of the

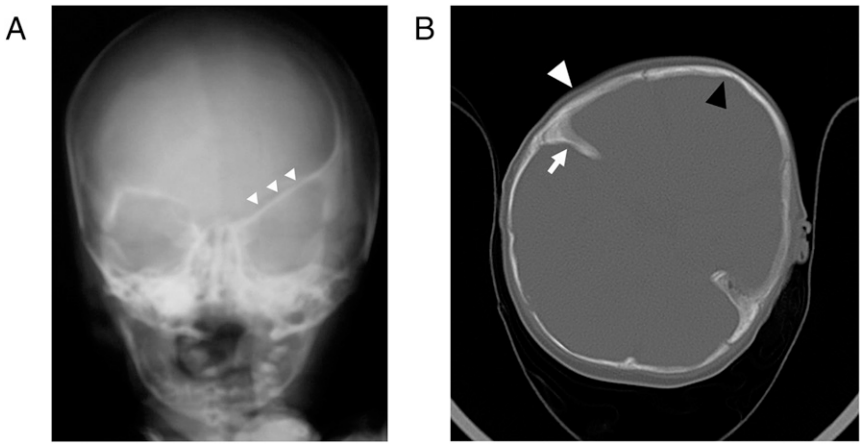

FIGURE 9
Radiologic features of unilateral coronal synostosis. A, A-P radiograph shows elevated ipsilateral sphenoid wing giving rise to the Harlequin eye deformity (arrowheads). The nasal bone is deviated superiorly toward the fused suture. B, Axial CT scan shows trapezoidal head shape with retrusion of the right forehead (white arrowhead), prominence of the left forehead (black arrowhead), and elevation of the sphenoid wing (white arrow).

midface and mandible, with relative sparing of the forehead and orbits; the ear is also malformed, and there are often preauricular skin tags.

ANTERIOR BRACHYCEPHALY (BICORONAL SYNOSTOSIS)

Bicoronal synostosis accounts for about 3% of nonsyndromic and most syndromic synostoses,[53] with a prevalence of approximately 0.5 per 10 000 live births.[57] In bicoronal synostosis, the coronal sutures are palpable on both sides, the entire forehead is flattened, the head is reduced in the anteroposterior dimension (anterior brachycephaly), and the forehead often has a towered appearance (turricephaly). The combination of frontal and maxillary foreshortening results in shallow orbits and produces significant exophthalmos; in addition, the orbits are recessed (retruded) or shallow bilaterally (Fig 10). The nasal bone is short and upturned in many cases.

On radiographs, the anterior fossa and orbits are short and both coronal sutures are radio dense or difficult to see and anteriorly deviated. Bilateral Harlequin orbit deformities are present with elevation of both sphenoid wings. Because both frontal bones are involved, the nasal bone remains midline. CT scans demonstrate brachycephaly, thickening and/or nonvisualization of both coronal sutures, a shallow anterior fossa and orbits, and bilateral sphenoid wing elevation (Fig 11). Coronal images nicely demonstrate bilateral Harlequin orbits as well.

POSTERIOR SYNOSTOTIC PLAGIOCEPHALY (LAMBDOID SYNOSTOSIS)

Lambdoid synostosis is rare; in contemporary series, lambdoid synostosis accounts for only 2% of cases and has a prevalence of 0.1 per 10 000 live births.[55,57] Older studies likely included children with DP and their prevalence rates are, therefore, higher. In one small series, male and female patients were equally represented.[55] True lambdoid synostosis is usually readily differentiated from occipital DP (see below), with which it is most commonly confused. True lambdoid synostosis is most commonly characterized by a flattening of both the ipsilateral occiput and forehead, leading to a trapezoidal or rhomboidal head shape (Fig 12). The contralateral occiput may be prominent by comparison. The lambdoid suture is prominently ridged. The ipsilateral ear is deviated posteriorly (in contrast to DP, in which it is deviated anteriorly), and the mastoid process and associated retromastoid occipital bone are unusually prominent, producing a retroauricular "bulge" (Fig 12). Bilateral involvement produces

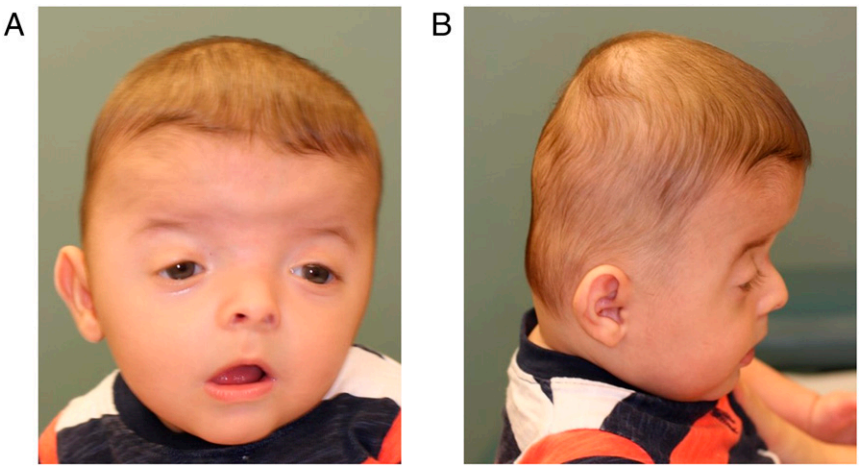

FIGURE 10
Brachycephaly attributable to bicoronal synostosis in a child with Saethre-Chotzen syndrome. A,-Frontal view shows flattened forehead, shallow orbits with bilateral orbital retrusion, a modestly upturned (beaked) nose, bilateral ptosis, and midface hypoplasia. B, Lateral view of the same infant shows flattened and tall (turricephaly) forehead, with shallow orbits and midface hypoplasia.

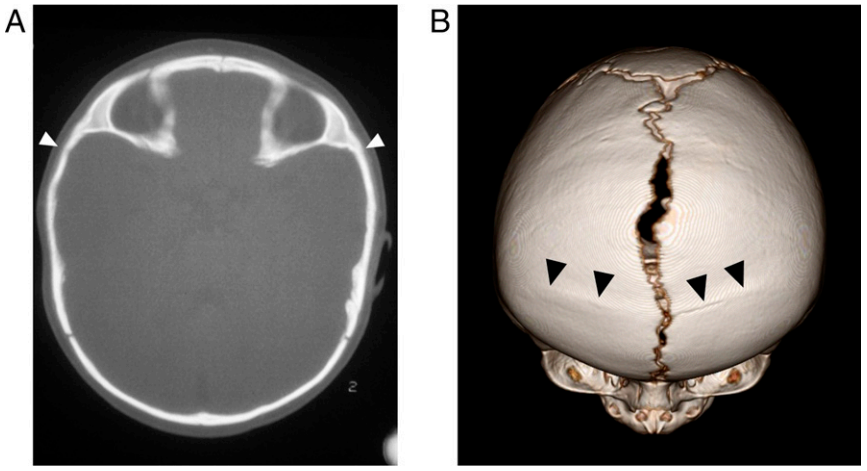

FIGURE 11
Radiologic features of bilateral coronal synostosis. A, Axial CT scan shows shallow anterior fossa and absence of both coronal sutures (arrowheads). B, Three-dimensional CT scan reconstructed vertex view shows shallow anterior fossa, bilateral superior orbital retrusion, and bilaterally fused coronal sutures (arrowheads).

a flattened occiput with ridging of both lambdoid sutures and retromastoid bulge on both sides. The posterior sagittal suture may also be involved, producing an element of scaphocephaly as well as ridging of both lambdoid and posterior sagittal sutures (the "Mercedes-Benz" sign).

Plain radiographs commonly demonstrate significant prominence and hyperostosis or nonvisualization of the involved lambdoid suture(s). CT scans also demonstrate hyperostosis or nonvisualization of the involved lambdoid suture(s). The retromastoid bulge and posterior displacement of the petrous ridge are prominent; the posterior midline and the foramen magnum at the base of the skull are also drawn toward the ipsilateral side (Fig 12C). Three-dimensional CT scans also demonstrate these findings to good advantage (Fig 12D). Treatment involves open posterior cranial vault reconstruction between 5 and 9 months of age or endoscopic repair as early as 2 to 3 months of age, followed by molding helmet treatment for up to 1 year.

FRONTOSPHENOIDAL SYNOSTOSIS

An extremely rare form of synostosis involves the frontosphenoidal suture, located at the anterior skull base and contiguous with the coronal suture and orbital roof.[62,63] Synostosis involving the frontosphenoidal suture produces plagiocephaly with ipsilateral forehead flattening that resembles unilateral coronal synostosis but differs from the latter in that the ipsilateral orbit is deviated inferiorly rather than superiorly, and the nasal root is deviated away from rather than toward the side of the synostosis (Fig 13 A and B). The coronal suture is visible on neuroimaging studies, and there is no Harlequin eye orbital deformity (Fig 13 C and D); CT demonstrates the fusion of the frontosphenoidal suture (Fig 13E). Treatment involves a fronto-orbital reconstruction.[62,63]

SYNDROMIC CRANIOFACIAL MALFORMATIONS

A number of craniosynostosis syndromes have been described phenotypically (Table 2). All of these, most commonly, include elements of bicoronal synostosis and midface hypoplasia. Ophthalmologic manifestations are also common and include shallow orbits, some degree of exorbitism, and extraocular muscle dysfunction with strabismus and resultant amblyopia and poor visual

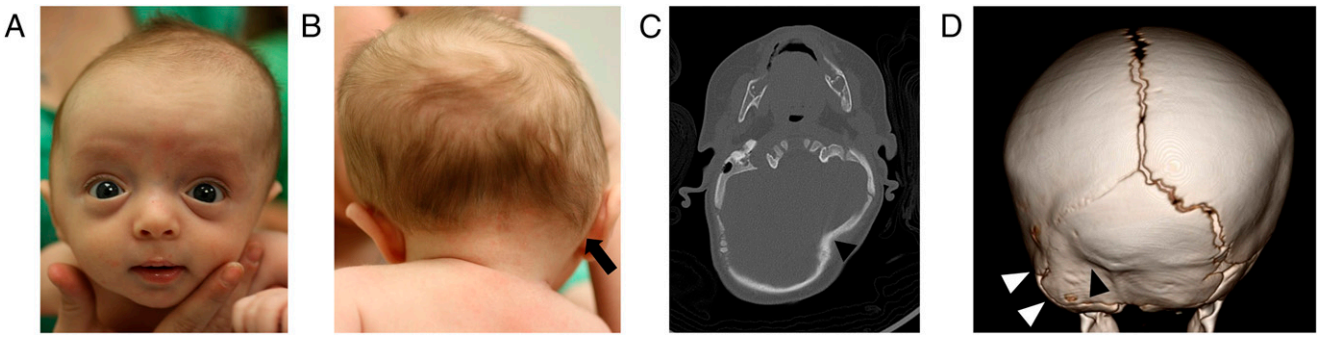

FIGURE 12
Unilateral lambdoid synostosis. A, Anterior view shows asymmetric head with calvarium deviated toward the left. Note the symmetry of orbits. B, Posterior view shows prominent curvature of the occiput toward the left with a retromastoid bulge on the right (arrow) and flattening inferior to the bulge. C, Axial CT scan shows prominent left mastoid bulge and indentation of the occipital skull (arrowhead). D, Three-dimensional CT scan posterior view shows the fused left lambdoid suture, retromastoid bulge (white arrowheads), and indentation of the occipital bone (black arrowhead).

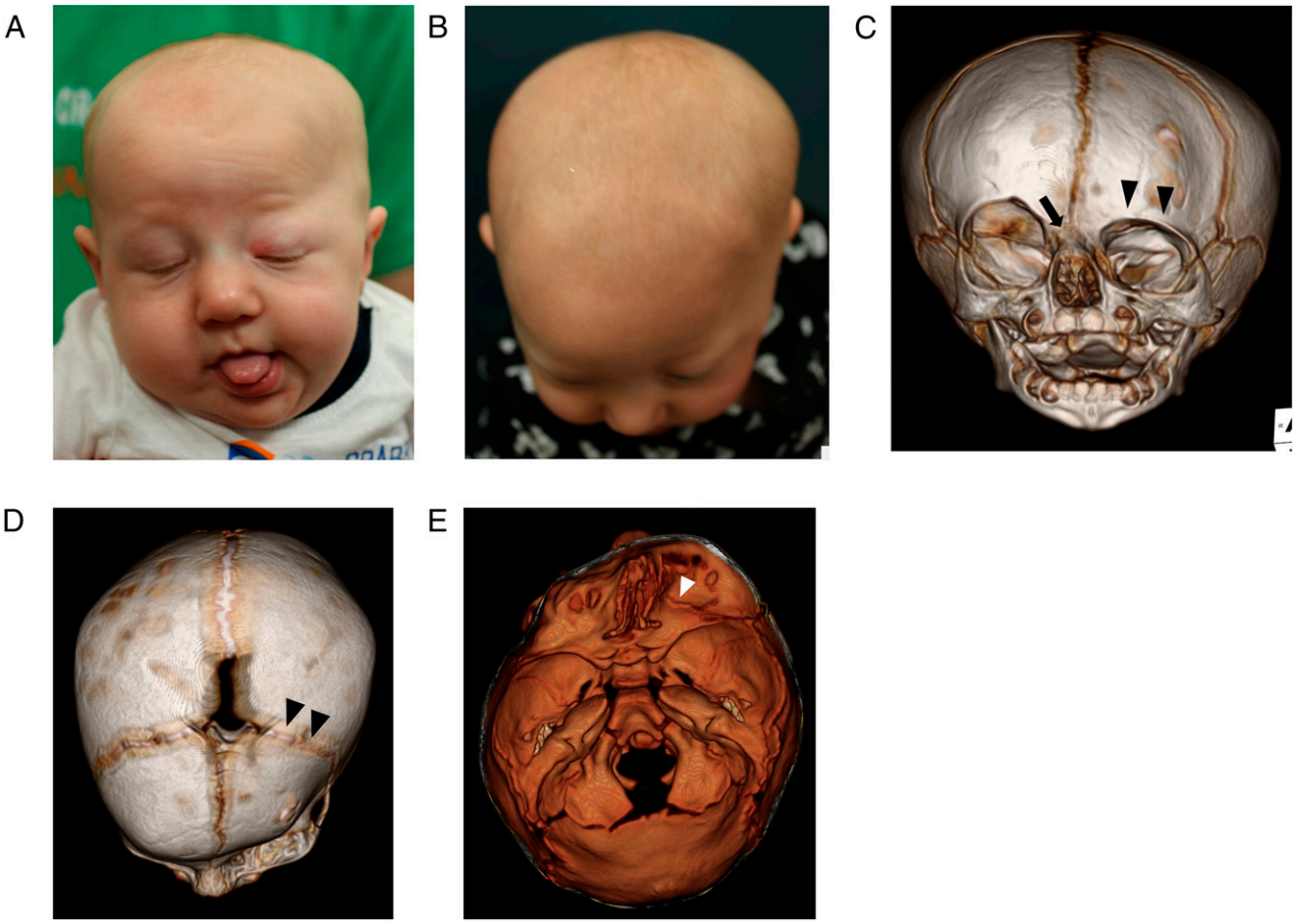

FIGURE 13

Frontosphenoidal synostosis. A, Frontal view of infant with left frontosphenoidal synostosis, with left forehead depression and retrusion and depression of left orbit. B, Vertex view demonstrating left forehead and orbital retrusion. Note in both images the deviation of the nasal root away from, and the nasal tip toward, the involved side, in contrast to coronal synostosis. C, Frontal three-dimensional reconstruction CT scan shows inferiorly displaced ipsilateral eyebrow and orbital roof (arrowheads) and deviation of the nasal root (arrow) toward the contralateral side (in contrast to unicoronal synostosis, see Fig 8). D, Vertex three-dimensional reconstruction CT scan shows left forehead flattening but open coronal suture on that side (arrowheads). E, Three-dimensional reconstruction CT scan with a view of the inside of the skull base with the calvarium digitally subtracted shows flattening of the left orbit. The right frontosphenoidal suture is patent (arrowhead), whereas the left is fused.

acuity.[64,65] More recent genetic testing has revealed significant genotypic overlap, with the same genetic mutation capable of producing distinctly different phenotypes, and a single phenotype resulting from different genetic pathogenic variants. It is beyond the scope of this report to describe all of the various syndromes in detail; brief descriptions of the more common syndromes are provided. The interested reader is referred elsewhere for more detailed information.[66,67]

TABLE 2 Genetics of Craniofacial Syndromes

Syndrome	Transmission	Identified Gene Variants
Crouzon	AD	*FGFR1, FGR2*
Apert	AD	*FGFR2*
Pfeiffer	AD	*FGFR1, FGR2*
Saethre-Chotzen	AD	*TWIST*
Carpenter	AR	*RAB23, MEGF8*
Antley-Bixler	AR and sporadic AD transmission	Uncertain (for AR) and *FGFR2* (for AD)
Muenke	AD	*FGFR3*

AD, autosomal-dominant; AR, autosomal-recessive.

Crouzon Syndrome

Crouzon syndrome is most frequently characterized by bicoronal synostosis leading to a shallow anterior fossa, a high and flat forehead (turricephaly) with reduced anteroposterior cranial measurement (brachycephaly), shallow orbits and prominent globes (exorbitism), midface hypoplasia leading to an underbite and malocclusion, and upturned (or "beaked") nose. Involvement of other sutures may

also occur, and progressive sutural fusion has been described during the first 2 years of life.[68] Craniosynostosis is a variable feature and, rarely, may be absent. Syndactyly is notably absent. Rarely, vertebral fusion, ankylosis (particularly the elbows), and acanthosis nigricans may be present. Cognitive development is often normal, and neurocognitive deficits are uncommon. Crouzon syndrome is transmitted as an autosomal-dominant condition with varying penetrance; pathogenic variants in the *FGFR1* or *FGFR2* genes are responsible for all but Crouzon with acanthosis nigricans, which is caused by pathogenic variants in the *FGFR3* gene.

Apert Syndrome

The craniosynostosis pattern in Apert syndrome is similar to that in Crouzon syndrome, although progressive fusion of additional sutures during the first 2 years occurs more commonly in Apert syndrome. Like in Crouzon syndrome, turricephaly, brachycephaly, exorbitism, beaked nose, and malocclusion are cardinal clinical manifestations in Apert syndrome. Down-slanting palpebral fissures are typical. Palatal abnormalities may be present and include narrowing, bifid uvula, and cleft palate,[69] and vertebral fusion abnormalities (most commonly involving C5-C6) may be present.[70] Structural brain abnormalities may be present, including agenesis of the corpus callosum, gyral malformations, absent or defective septum pellucidum, megalencephaly, and static or progressive ventriculomegaly. Unlike Crouzon syndrome, neurocognitive deficits are more common, with more than one-half having subnormal IQ scores. The most striking extracranial abnormality in Apert syndrome is osseous and/or soft tissue syndactyly involving fingers and/or toes, particularly the second, third, and fourth digits (Fig 14). The digits are short, and broad distal phalanges may also be present. Apert syndrome is transmitted as an autosomal-dominant condition; a mutation in the *FGFR2* gene is responsible.

FIGURE 14
Syndactyly involving the toes in an infant with Apert syndrome.

Pfeiffer Syndrome

Pfeiffer syndrome is characterized by bicoronal synostosis, and the midface is narrow but not generally retruded; there is, therefore, less significant exorbitism and malocclusion. Like Crouzon and Apert syndromes, cranial sutures in Pfeiffer syndrome may progressively fuse over time. The nose is generally small with a low nasal bridge. Partial syndactyly of the second and third fingers and/or toes are cardinal features of Pfeiffer syndrome, and the distal phalanges of the thumb and great toe are often wide. Pfeiffer syndrome is transmitted as an autosomal-dominant condition with variable penetrance; a mutation in the *FGFR2* gene is responsible.

Cohen has described 3 types of Pfeiffer syndrome.[71] Type I is characterized by typical coronal synostosis, midface hypoplasia, and digital malformations with normal neurocognitive development. Types II and III are associated with much more severe involvement, usually involving all of the sutures (and, in type II, producing a cloverleaf skull), with shallow orbits and severe exorbitism sufficient to produce corneal exposure, airway obstruction, partial syndactyly and elbow ankylosis, various visceral abnormalities, and moderate to severe neurocognitive impairment.

Saethre-Chotzen Syndrome

Saethre-Chotzen syndrome is characterized by bicoronal synostosis (with occasional involvement of other sutures) leading to turricephaly and brachycephaly with biparietal foramina but less severe midface hypoplasia and modest exorbitism. Differentiating manifestations include ptosis of the eyelids (Fig 10A), a low anterior hairline, and a prominent nose. Lacrimal duct abnormalities and a characteristic prominent ear crus may be present. Extracranial abnormalities can include partial soft tissue syndactyly, most commonly involving the second and third fingers and third and fourth toes; the digits are often short and the great toes may be broad. Saethre-Chotzen syndrome is transmitted as an autosomal-dominant condition; a mutation in the *TWIST* gene is responsible.

Carpenter Syndrome

Carpenter syndrome is characterized by synostosis most commonly involving both coronal sutures and variably others as well, with shallow supraorbital ridges and flat nasal bridge, midface, and/or mandibular hypoplasia, low-set and malformed ears and a high arched palate. A number of digital malformations may occur including brachydactyly, clinodactyly, and camptodactyly (medial deviation and flexion deformity of the distal phalanges, respectively) and polydactyly involving the toes. Cardiac malformations occur in one-half of affected individuals and include septal defects, tetralogy of Fallot,

transposition of the great vessels, and persistent ductus arteriosus. Carpenter syndrome is transmitted as an autosomal-recessive condition; pathogenic variants in the *RAB23* or *MEGF8* genes are responsible.

Antley-Bixler Syndrome

Antley-Bixler syndrome is characterized by bicoronal synostosis (in 70%) with turricephaly but with frontal bossing, midface hypoplasia with exorbitism, and a flat and depressed nasal bridge. Low-set and dysplastic ears are a consistent feature, and choanal atresia or stenosis is present in 80%. Limited limb mobility and a diminished range of motion involving virtually all joints, phalangeal abnormalities (including long fingers with tapering fingernails), radiohumeral synostosis, and femoral bowing are common features as well. Impaired steroidogenesis and genital abnormalities are associated features. Antley-Bixler syndrome is most commonly related to pathogenic variants in the *POR* gene (with impaired steroidogenesis) and autosomal-recessive transmission and pathogenic variants of the *FGFR2* gene (without impaired steroidogenesis), with autosomal-dominant transmission.

Muenke Syndrome

Muenke syndrome is characterized by fusion of one or both coronal sutures with a broad and shallow supraorbital ridge and prominent forehead (bossing). Hypertelorism and flattened maxillae are variable features. Hearing loss is present in approximately one-third of patients, and macrocephaly is present in approximately 5%.[72] Muenke syndrome is transmitted as an autosomal-dominant condition and is unusual among the syndromic synostoses in that it involves a mutation in the *FGFR3* gene.

SURGICAL MANAGEMENT OF CRANIOSYNOSTOSIS

The evaluation and management of craniosynostosis are beyond the scope of this review, but a few general comments are helpful. Imaging of suspected craniosynostosis most commonly includes either plain skull radiographs or CT scans. In general, plain skull radiographs are of limited value if craniosynostosis is strongly suspected because CT scans will likely be performed by the craniofacial team as part of surgical planning. On the other hand, obtaining a CT scan in children with low suspicion for craniosynostosis is often unnecessary. Cranial ultrasonography is used by some, and studies suggest that it is as effective as plain radiographs or CT scans in identifying a fused suture.[73] However, not all radiologists are equally experienced at identifying fused sutures on ultrasonography, so it is recommended that the provider check with the radiologist first before obtaining this study. Many craniofacial teams prefer that providers refer these children early and postpone imaging until after the child is seen by specialists. For children with occipital DP, the diagnosis is usually obvious by clinical inspection, the absence of significant deformity at birth, and the absence of a retroauricular bulge; questionable cases might require neuroimaging, but these are rare.

The timing of surgery (and, by extension, referral) is another important consideration. Traditional repairs of coronal, metopic, and frontosphenoidal synostosis are generally delayed until 6 to 10 months of age. However, the child with symptomatic increased ICP may require earlier repair. Moreover, sagittal synostosis repairs and endoscopic approaches are performed much earlier, some as early as 8 weeks of age. Delays in referral often lead to more extensive surgical repairs; early referral is, therefore, preferable, even in questionable cases of craniosynostosis.

There are many accepted surgical options for craniosynostosis that are influenced by which suture(s) are involved, the clinical indication, the experience and expertise of the craniofacial surgical team, and, most importantly, the timing of the operation. It is not the intent of this review to recommend any particular operative technique because they all have their merits.

Surgical techniques may include endoscopic suturectomy with helmet therapy, spring-assisted cranioplasty, and subtotal and complete calvarial vault remodeling. Advantages of endoscopic suturectomy include smaller incisions and less operative time and blood loss, but correction should be performed early (during the first few months of life) and followed by up to 12 months of postoperative molding helmet therapy (23 hours a day) to achieve correction comparable to open techniques. Spring-assisted cranioplasty is another surgical adjunct that can be used, in which spring-loaded devices are inserted temporarily to help distract the freed bones.

The advantages of open operative correction include more immediate and complete correction, without the need for extended molding helmet therapy. Disadvantages include a larger incision, longer operative times, greater intraoperative blood loss, and, for coronal and metopic synostosis, the need to remodel the superior orbital rim (which generally requires that the surgery be performed after the infant has reached 6 months of age so the orbital rim is thick enough to hold the surgical screws). A variety of open techniques exist, but surgical timing is important. Open sagittal synostosis repairs are performed much earlier (ideally between 2 and 6 months of

age) than are metopic or coronal synostosis. Sagittal synostosis repair includes a midline or paramedian (so-called π) craniectomy coupled with a variable degree of posterior (parietal and occipital) vault reconstruction with barrel stave osteotomies. Later surgery (generally beyond 6–8 months of age) may require a more extensive total calvarial vault remodeling. Lambdoid suture repair is also, generally, performed early. In contrast, for open coronal or metopic synostosis, in which both cranial and orbital reconstruction are performed, later surgical correction, usually between 6 and 10 months, is preferred so that the orbital rim is thick enough to hold the surgical constructs used to advance and remodel the bone. All open surgical approaches involve a full release of the fused suture and immediate surgical remodeling of the skull; postoperative helmeting is not routinely used after open repair.

The surgical management of midface hypoplasia deserves special mention because it is a frequent component of syndromic synostosis. Severe midface hypoplasia can lead to airway obstruction that requires an immediate intervention, such as a tracheostomy to secure the airway. Definitive midface correction is usually performed when the child is older (6–8 years or more) and is usually accomplished by using distraction osteogenesis, in which the midface is surgically separated from the skull base and distraction plates are applied to the maxillary bones. By using distraction screws that are turned by the patient or family on a daily basis, the midface is slowly advanced forward, and bone grows in the intervening gap, much like an Ilizarov procedure accomplishes for long bones.

OCCIPITAL (DEFORMATIONAL) PLAGIOCEPHALY AND BRACHYCEPHALY

The most common head shape abnormality is deformational (also called positional or nonsynostotic) plagiocephaly (DP) or brachycephaly (DB). The incidence of DP/DB has been estimated at 20% to 50% in 6-month-old children.[74] It is more common (approximately 60% of cases) in male children.[75] DP/DB in 80% of cases presents as an acquired postnatal condition that is most commonly noted during the first 4 to 12 postnatal weeks, although 20% of cases appear to be noted at birth, likely attributable to intrauterine forces (relative fetal restraint, such as primiparity, oligohydramnios, multiple gestation, or bicornuate uterus).[75] Eighty percent of cases are right sided, and the flattening corresponds to the side to which the infant naturally turns the head; this correlates well with observations made by Volpe[76] that normal supine infants look toward the right 80% of the time, toward the left 20%, and almost never look straight up. In addition, 15% to 20% of infants with DP/DB have some degree of neck muscle imbalance or torticollis.[75] It is now apparent that DP/DB is not synostotic but rather is caused by persistent pressure on the skull in the supine infant. The incidence increased significantly after the 1992 "Back to Sleep" campaign, which recommended supine sleep (although the decreased rate of sudden unexpected death in infancy certainly supports the continued endorsement of this strategy).[74]

It is important to differentiate DP/DB from true coronal or lambdoid craniosynostosis. The majority of cases can be readily identified by the history (as described above) and clinical examination. The infant is examined from the front, back, and, most importantly, top of the head. DP/DB is characterized by occipital flattening: unilaterally in DP (Fig 15) and bilaterally in DB. The ipsilateral ear is deviated anteriorly with respect to the contralateral side (which can be most readily identified by placing a finger in each ear and looking down from above the infant's head); the pinna may be rotated outward as well. Finally, there is often some anterior displacement of the ipsilateral forehead. The resulting deformation results in a parallelogram head shape (Fig 15A) in which the entire ipsilateral head appears to have been displaced anteriorly. In contrast, the child with unilateral coronal or lambdoid synostosis will have a trapezoidal-shaped head with ipsilateral flattening of both frontal and occipital calvarium and posterior and inferior deviation of the ipsilateral ear, as discussed above. Patients with DP may have an element of facial scoliosis (Fig 15B). Although the ipsilateral orbit in DP may be slightly misshapen, the Harlequin orbit deformity observed in unicoronal synostosis is not present. Similarly, the bulging retromastoid area in lambdoid synostosis is absent in DP and DB. In DB, the occiput is flattened bilaterally, and the head is, therefore, brachycephalic and widened in the transverse dimension, leading to a round face. However, the absence of turricephaly, orbital retrusion, Harlequin orbit, and exophthalmos differentiate DB from bicoronal synostosis.

Other abnormalities observed in some cases with DP include an element of facial scoliosis. Some have elevation and shortening of the mandible with a "hollow" space in the submandibular region, superficially resembling hemifacial microsomia. This variant seems to be more common among those whose DP is present at birth and/or those with torticollis; it is suggested that perhaps the shoulder may lie within this hollow and restrict neck rotation in utero. Another less common variant of DP is what is referred to as the "Gumby" head shape in which, when viewed from the front, the ipsilateral calvarium is flattened and the vertex slopes upward toward the opposite side (Fig 15B).

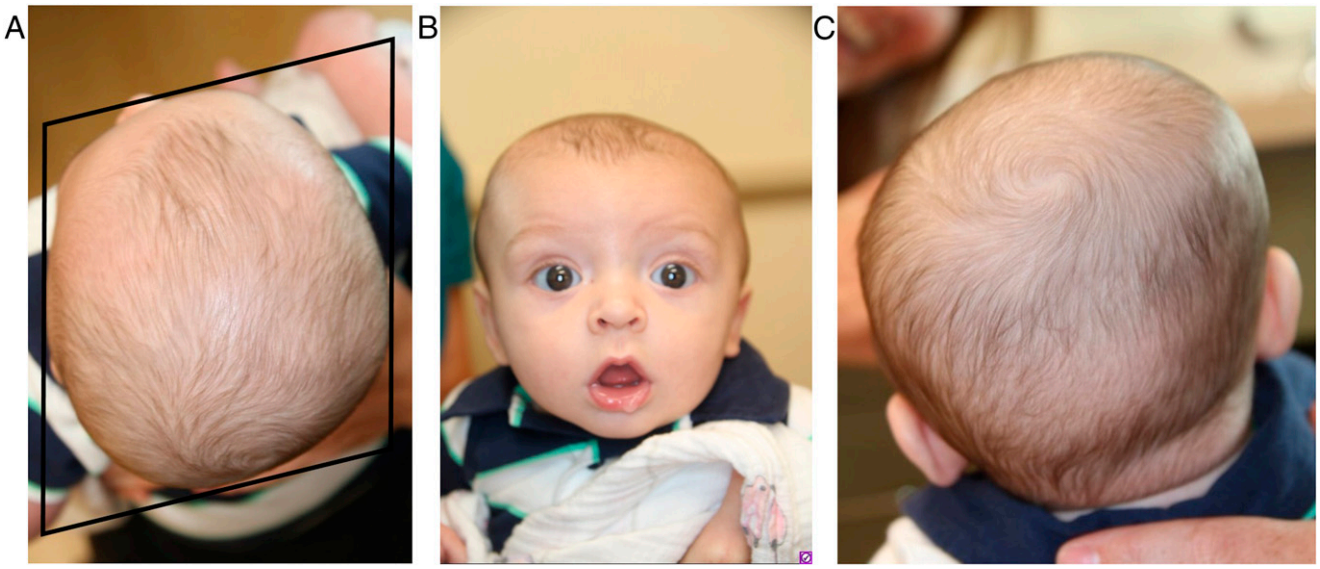

FIGURE 15
Occipital deformational flattening (plagiocephaly and brachycephaly). A, Vertex view of DP shows parallelogram-shaped head with ipsilateral flattening, anterior deviation of the ipsilateral ear, and mildly prominent ipsilateral frontal bossing. B, Frontal view shows the calvarium deviated toward the right but no elevated eyebrow and/or orbit or deviation of the nasal root or tip. Note the upward slanting cranial vault from patient's left to right ("Gumby" deformity). C, Posterior view of DP shows flattened right occiput with parietal boss.

A number of centers quantify the severity of DP and DB, both for the initial assessment and at subsequent follow-up visits, by measuring certain anthropometric indices with cranial calipers. The severity of DP is described by using the cranial vault asymmetry index (CVAI), which describes the difference between the longest and shortest head axes along the diagonal when viewed from above (Fig 16). In general, a CVAI of >3.5 is consistent with DP.[74] The severity of DB is described by using the cranial index (CI), which measures the ratio of head width to head length when viewed from above. A CI of ≥85% is consistent with brachycephaly.[77]

The differential diagnosis of DP includes unilateral coronal and unilateral lambdoid craniosynostosis, both described above. In most cases, the diagnosis of DP or DB is readily apparent on clinical examination, and adjunctive imaging such as plain radiographis or CT scans is unnecessary and would expose the child to ionizing radiation. The use of imaging should be reserved for equivocal cases. Plain radiographs are usually difficult to interpret, except in cases of DB in which the occipital flattening is evident on lateral films. Partial nonvisualization or focal areas of calcification adjacent to the lambdoid suture may be identified on plain radiographs and CT scans but should not be interpreted as lambdoid synostosis. Axial CT scans readily differentiate DP and DB from coronal synostosis, demonstrating the parallelogram head shape, open coronal sutures, and normally formed anterior skull base with normal sphenoid wing and absent Harlequin orbit.

It is not our intent with this report to discuss treatment options for DP and DB. However, the parents of infants with DP or DB should be reassured that since the infant does not have

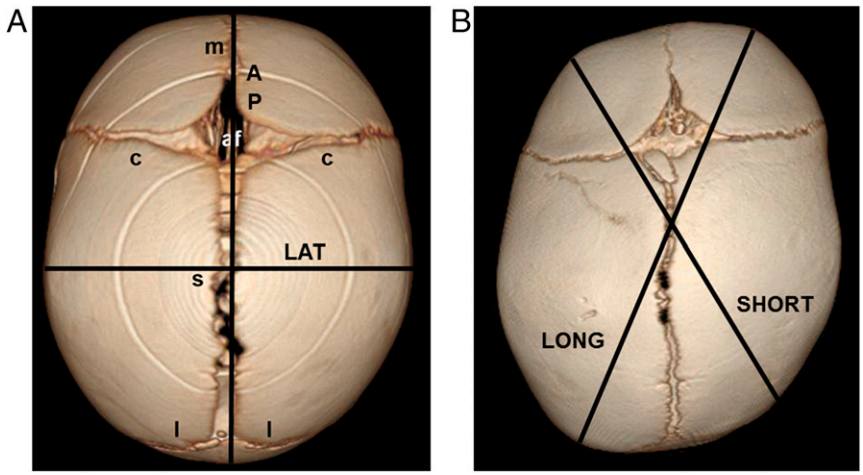

FIGURE 16
Diagram showing the calculation of the (A) CVAI and (B) CI. See text for definitions.

craniosynostosis, surgery is not indicated; they should be counseled that DP and DB are solely aesthetic conditions, with no credible medical evidence suggesting that DP and DB affect brain development or cause any other medical condition. The head shape often improves as the child gains developmental milestones and lies less frequently on the flattened side.[74] Supervised "tummy time" as well as varying head positions while holding the child can help; alternating head positions for sleep can be attempted, but, to reduce the incidence of sudden unexplained death in infancy, it should be emphasized that the infant should sleep alone, on his or her back, and in a crib (the ABCs of safe sleep). A recent study noted a correlation (not necessarily causal) between DP and poorer cognitive outcomes[78]; children with DP should, therefore, be monitored for possible developmental delays. The child with muscular neck imbalance or torticollis may be referred to physical therapy to teach the parents stretching and muscle strengthening exercises to reduce the tension of the sternocleidomastoid muscle and improve the strength of contralateral muscles. Use of a molding helmet may be considered for the infant with a moderate or severe deformity but is not required; a detailed evidence-based review of DP and DB treatment options can be found in a recent publication by the Congress of Neurological Surgeons and is endorsed by the American Academy of Pediatrics.[79–84]

EARLY FONTANELLE CLOSURE AND MICROCEPHALY

Two other common referrals to craniofacial clinics are concerns about early closure of the anterior fontanelle and microcephaly. Although the anterior fontanelle most commonly closes at approximately 12 months of age, there is a wide variation in the timing of fontanelle closure, with the fontanelle closing between 4 and 26 months.[85] Moreover, it is important to note that closure of the fontanelle does not mean that the sutures are closed, nor does it mean that further calvarial growth is not possible. Rather, closure of the fontanelle simply reflects the apposition of the 2 frontal and 2 parietal bones in such a manner that a gap cannot be palpated, although sutures are still present. In fact, even after normal fontanelle closure, significant head growth continues throughout childhood. As long as appropriate head growth is occurring along the normal head growth curve and the head shape is normal, there should not be concern for craniosynostosis. However, other medical conditions can be associated with premature fontanelle closure, including hyperthyroidism, hyperparathyroidism, hypophosphatasia, and rickets.

Microcephaly is defined as a head circumference below the fifth percentile for age. There are numerous causes for microcephaly, some of which are listed in Table 3. Primary microcephaly may be genetic; multiple pathogenic variants with both autosomal-dominant and recessive inheritance patterns have been described. Other conditions are usually identified by history, physical examination, and/or neuroimaging. Important considerations include a family history of microcephaly, the presence or absence of developmental delays or cognitive impairment, and a past history of pre- or postnatal brain injury. Infants with normal developmental milestones, no past history of brain injury, and a normal head shape most often have constitutional microcephaly. Single-suture craniosynostosis virtually never causes significant microcephaly, although multisutural synostosis can. Craniosynostosis is rarely a cause of microcephaly in infants whose head circumferences, although low, are running parallel to the normal curve and who have both a normal head shape and no family history of craniosynostosis.[86]

TABLE 3 Conditions Causing Microcephaly

Primary microcephaly
Chromosomal disorders
Anencephaly
Encephalocele
Holoprosencephaly
Agenesis of the corpus callosum
Neuronal migration disorders
Microcephaly vera
Secondary microcephaly
Intrauterine infections
Intrauterine toxins
Intrauterine vascular insufficiency
Hypoxic-ischemic brain injury
Intracranial hemorrhage
Neonatal infections (meningitis and encephalitis)
Neonatal stroke
Chronic cardiopulmonary or renal disease
Malnutrition
Craniosynostosis

Adapted from Pina-Garza J. *Fenichel's Clinical Pediatric Neurology.* 2nd ed. Amsterdam, Netherlands: Elsevier; 2013:359.

CONCLUSIONS

Single-suture craniosynostosis produces consistent head shape abnormalities that should be readily identifiable by the pediatric health care provider. Sagittal synostosis produces an elongated head (scaphocephaly), and metopic synostosis produces a triangular-shaped forehead (sometimes with hypotelorism). Unilateral coronal and lambdoid synostosis as well as occipital DP all produce an asymmetric head shape (plagiocephaly) but are readily differentiated by the shape of the head (parallelogram versus trapezoid or rhombus), the position of the ears (anterior or posterior), and secondary features such as nasal deviation, orbital asymmetry, or bulging of the retromastoid region. Bilateral coronal and lambdoid synostosis produce a short head (brachycephaly) and are differentiated by the presence or absence of associated midface hypoplasia or bilateral retromastoid bulging.

DP and DB are the most common head shape abnormalities encountered by primary care physicians; they are readily identified by conducting a history and clinical examination and do not usually require adjunctive imaging. Early detection and positional changes (with physical therapy for those with torticollis) suffice for most infants; referral at 5 to 6 months of age is considered for helmet therapy for those who have moderate or severe deformities that have not responded to treatment.[87]

Because both single-suture craniosynostosis and DP/DB can usually be diagnosed on clinical examination, routine imaging for the initial evaluation of infant head shape is not recommended to avoid exposing the child to unnecessary radiation. Instead, timely referral of infants with craniosynostosis and those with moderate or severe DP/DB to an experienced craniofacial team (including both a pediatric neurosurgeon and craniofacial surgeon) will allow sufficient time for the team to help the family cope with the diagnosis, obtain any necessary imaging for surgical planning, discuss treatment options, and plan a timely correction.

Anticipatory guidance for parents of children with craniosynostosis should include monitoring for symptoms of elevated ICP or developmental delays, especially for those with multisutural synostosis, and a discussion about the importance of early and timely referral to specialists. Parents of children with DP or DB should be encouraged to initiate positional changes early and, for those with torticollis, should be taught neck stretching exercises and/or referred to a physical therapist. For those with moderate or severe deformities, consider a referral to craniofacial specialists to discuss molding helmets.

KEY POINTS

- Children with craniosynostosis most commonly present with stereotypically shaped heads, each associated with particular sutural fusions:
- long (scaphocephaly: sagittal);
- short (brachycephaly: bicoronal or bilambdoid);
- anteriorly pointed (trigonocephaly: metopic); and
- asymmetric (plagiocephaly: unilateral coronal or lambdoid).
- DP and DB are the most common head shape abnormalities, recognized by their parallelogram-shaped head, lack of retroauricular bulge, and, in 80%, absence of deformation at birth.
- Syndromic craniosynostosis most commonly manifests with bicoronal synostosis, midface hypoplasia, and shallow orbits with exorbitism and strabismus.
- Surgery is often performed within the first 8 to 10 weeks for sagittal synostosis repairs, endoscopic procedures, and raised ICP. Orbitofrontal advancements for coronal and metopic synostosis are most often performed between 6 and 10 months.
- Early referrals to craniofacial teams are encouraged to allow early identification and repair.

LEAD AUTHORS

Mark S. Dias, MD, FAAP, FAANS
Thomas Samson, MD, FAAP
Elias B. Rizk, MD, FAAP, FAANS
Lance S. Governale, MD, FAAP, FAANS
Joan T. Richtsmeier, PhD

SECTION ON NEUROLOGIC SURGERY EXECUTIVE COMMITTEE, 2018–2019

Philip R. Aldana, MD, FAAP, Chairperson
Douglas L. Brockmeyer, MD, FAAP
Andrew H. Jea, MD, FAAP
John Ragheb, MDGregory W. Albert, MD, MPH, FAAP
Sandi K. Lam, MD, MBA, FAAP, FACS
Ann-Christine Duhaime, MD, FAANS

SECTION ON PLASTIC AND RECONSTRUCTIVE SURGERY EXECUTIVE COMMITTEE, 2018–2019

Jennifer Lynn Rhodes, MD, FAAP, FACS, Chairperson
Stephen B. Baker, MD, DDS, FAAP, FACS, Immediate Past Chairperson
Anand R. Kumar, MD, FAAP, FACS
Jugpal Arneja, MD, FAAP
Karl Bruckman, MD, DDS
Lorelei J. Grunwaldt, MD, FAAP, FACS
Timothy W. King, MD, PhD, FAAP, FACS
Arin K. Greene, MD, MMSc, FAAP
John A. Girotto, MD, FAAP, FACS

ABBREVIATIONS

AP: anterior-posterior
BMP: bone morphogenetic factor
CI: cranial index
CT: computed tomography
CVAI: cranial vault asymmetry index
DB: deformational brachycephaly
DP: deformational plagiocephaly
FGFR: fibroblast growth factor receptor
FGR: fibroblast growth factor
ICP: intercranial pressure

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

REFERENCES

1. Hall BK. Endoskeleton/exo (dermal) skeleton – mesoderm/neural crest: two pair of problems and a shifting paradigm. *J Appl Ichthyol*. 2014;30(4): 608–615
2. Kawasaki K, Richtsmeier JT. Association of the Chondrocranium and Dermatocranium in Early Skull Development. In: Percival CJ, Richtsmeier JT, eds. *Building Bones: Bone Development and Formation in Anthropology. Cambridge Studies in Biological and Evolutionary Anthropology*. Cambridge, United Kingdom: Cambridge University Press; 2017:52–78
3. Flaherty K, Singh N, Richtsmeier JT. Understanding craniosynostosis as a growth disorder. *Wiley Interdiscip Rev Dev Biol*. 2016;5(4):429–459
4. Nagata M, Nuckolls GH, Wang X, et al. The primary site of the acrocephalic feature in Apert Syndrome is a dwarf cranial base with accelerated chondrocytic differentiation due to aberrant activation of the FGFR2 signaling. *Bone*. 2011;48(4):847–856
5. Abramson DL, Janecka IP, Mulliken JB. Abnormalities of the cranial base in synostotic frontal plagiocephaly. *J Craniofac Surg*. 1996;7(6):426–428
6. Burdi AR, Kusnetz AB, Venes JL, Gebarski SS. The natural history and pathogenesis of the cranial coronal ring articulations: implications in understanding the pathogenesis of the Crouzon craniostenotic defects. *Cleft Palate J*. 1986;23(1):28–39
7. Kawasaki K, Richtsmeier JT. Spatial association of the dermatocranium with the chondrocranium in early skull formation. *Am J Phys Anthropol*. 2014; 153(S58):156
8. McBratney-Owen B, Iseki S, Bamforth SD, Olsen BR, Morriss-Kay GM. Development and tissue origins of the mammalian cranial base. *Dev Biol*. 2008;322(1):121–132
9. Jiang X, Iseki S, Maxson RE, Sucov HM, Morriss-Kay GM. Tissue origins and interactions in the mammalian skull vault. *Dev Biol*. 2002;241(1):106–116
10. Opperman LA. Cranial sutures as intramembranous bone growth sites. *Dev Dyn*. 2000;219(4):472–485
11. Beederman M, Farina EM, Reid RR. Molecular basis of cranial suture biology and disease: osteoblastic and osteoclastic perspectives. *Genes Dis*. 2014;1(1):120–125
12. Da Costa AC, Walters I, Savarirayan R, Anderson VA, Wrennall JA, Meara JG. Intellectual outcomes in children and adolescents with syndromic and nonsyndromic craniosynostosis. *Plast Reconstr Surg*. 2006;118(1): 175–181–183
13. Wilkie AOM, Byren JC, Hurst JA, et al. Prevalence and complications of single-gene and chromosomal disorders in craniosynostosis. *Pediatrics*. 2010; 126(2). Available at: www.pediatrics.org/cgi/content/full/126/2/e391
14. Cunningham ML, Seto ML, Ratisoontorn C, Heike CL, Hing AV. Syndromic craniosynostosis: from history to hydrogen bonds. *Orthod Craniofac Res*. 2007;10(2):67–81
15. Heuzé Y, Holmes G, Peter I, Richtsmeier JT, Jabs EW. Closing the gap: genetic and genomic continuum from syndromic to nonsyndromic craniosynostoses. *Curr Genet Med Rep*. 2014;2(3):135–145
16. Orr-Urtreger A, Bedford MT, Burakova T, et al. Developmental localization of the splicing alternatives of fibroblast growth factor receptor-2 (FGFR2). *Dev Biol*. 1993;158(2):475–486
17. Orr-Urtreger A, Givol D, Yayon A, Yarden Y, Lonai P. Developmental expression of two murine fibroblast growth factor receptors, flg and bek. *Development*. 1991;113(4):1419–1434
18. Rice DPC, Rice R, Thesleff I. Fgfr mRNA isoforms in craniofacial bone development. *Bone*. 2003;33(1):14–27
19. Delezoide AL, Benoist-Lasselin C, Legeai-Mallet L, et al. Spatio-temporal expression of FGFR 1, 2 and 3 genes during human embryo-fetal ossification. *Mech Dev*. 1998;77(1):19–30
20. Bansal R, Lakhina V, Remedios R, Tole S. Expression of FGF receptors 1, 2, 3 in the embryonic and postnatal mouse brain compared with Pdgfralpha, Olig2 and Plp/dm20: implications for oligodendrocyte development. *Dev Neurosci*. 2003;25(2–4):83–95
21. Ornitz DM, Marie PJ. FGF signaling pathways in endochondral and intramembranous bone development and human genetic disease. *Genes Dev*. 2002;16(12):1446–1465
22. Wang Y, Sun M, Uhlhorn VL, et al. Activation of p38 MAPK pathway in the skull abnormalities of Apert syndrome Fgfr2(+P253R) mice. *BMC Dev Biol*. 2010;10:22
23. Wang Y, Xiao R, Yang F, et al. Abnormalities in cartilage and bone development in the Apert syndrome FGFR2(+/S252W) mouse. *Development*. 2005;132(15):3537–3548
24. Wang Y, Zhou X, Oberoi K, et al. p38 Inhibition ameliorates skin and skull abnormalities in *Fgfr2* Beare-Stevenson mice. *J Clin Invest*. 2012;122(6): 2153–2164
25. Chen L, Li D, Li C, Engel A, Deng C-X. A Ser252Trp [corrected] substitution in mouse fibroblast growth factor receptor 2 (Fgfr2) results in craniosynostosis. [published correction appears in *Bone*. 2005;37(6):876]. *Bone*. 2003;33(2):169–178
26. Zhou YX, Xu X, Chen L, Li C, Brodie SG, Deng C-X. A Pro250Arg substitution in mouse Fgfr1 causes increased expression of Cbfa1 and premature fusion of calvarial sutures. *Hum Mol Genet*. 2000;9(13):2001–2008
27. Yin L, Du X, Li C, et al. A Pro253Arg mutation in fibroblast growth factor receptor 2 (Fgfr2) causes skeleton malformation mimicking human Apert syndrome by affecting both chondrogenesis and osteogenesis. *Bone*. 2008;42(4):631–643
28. Eswarakumar VP, Horowitz MC, Locklin R, Morriss-Kay GM, Lonai P. A gain-of-function mutation of Fgfr2c demonstrates the roles of this receptor variant in osteogenesis. *Proc Natl Acad Sci U S A*. 2004;101(34):12555–12560
29. Mai S, Wei K, Flenniken A, et al. The missense mutation W290R in Fgfr2 causes developmental defects from aberrant IIIb and IIIc signaling. *Dev Dyn*. 2010;239(6):1888–1900
30. Twigg SRF, Healy C, Babbs C, et al. Skeletal analysis of the Fgfr3(P244R) mouse, a genetic model for the Muenke

craniosynostosis syndrome. *Dev Dyn*. 2009;238(2):331–342

31. Holmes G, O'Rourke C, Motch Perrine SM, et al. Midface and upper airway dysgenesis in FGFR2-related craniosynostosis involves multiple tissue-specific and cell cycle effects. *Development*. 2018;145(19):dev166488
32. Ting M-C, Wu NL, Roybal PG, et al. EphA4 as an effector of Twist1 in the guidance of osteogenic precursor cells during calvarial bone growth and in craniosynostosis. *Development*. 2009; 136(5):855–864
33. Rice DP, Aberg T, Chan Y, et al. Integration of FGF and TWIST in calvarial bone and suture development. *Development*. 2000;127(9):1845–1855
34. Merrill AE, Bochukova EG, Brugger SM, et al. Cell mixing at a neural crest-mesoderm boundary and deficient ephrin-Eph signaling in the pathogenesis of craniosynostosis. *Hum Mol Genet*. 2006;15(8):1319–1328
35. Tischfield MA, Robson CD, Gilette NM, et al. Cerebral vein malformations result from loss of Twist1 expression and BMP signaling from skull progenitor cells and dura. *Dev Cell*. 2017;42(5):445.e5-461.e5
36. Holmes G. The role of vertebrate models in understanding craniosynostosis. *Childs Nerv Syst*. 2012;28(9):1471–1481
37. Martínez-Abadías N, Motch SM, Pankratz TL, et al. Tissue-specific responses to aberrant FGF signaling in complex head phenotypes. *Dev Dyn*. 2013;242(1):80–94
38. Starr JR, Collett BR, Gaither R, et al. Multicenter study of neurodevelopment in 3-year-old children with and without single-suture craniosynostosis. *Arch Pediatr Adolesc Med*. 2012;166(6): 536–542
39. Knight SJ, Anderson VA, Spencer-Smith MM, Da Costa AC. Neurodevelopmental outcomes in infants and children with single-suture craniosynostosis: a systematic review. *Dev Neuropsychol*. 2014;39(3):159–186
40. Renier D. Intracranial Pressure in Craniosynostosis: Pre- and Postoperative Recordings. Correlation with Function Results. In: Persing JA, Edgerton MT, Jane JA, eds. *Scientific Foundations and Surgical Treatment of Craniosynostosis*. Baltimore, MD: Williams & Wilkins; 1989:263–274
41. Gault DT, Renier D, Marchac D, Jones BM. Intracranial pressure and intracranial volume in children with craniosynostosis. *Plast Reconstr Surg*. 1992;90(3):377–381
42. Renier D, Sainte-Rose C, Marchac D, Hirsch JF. Intracranial pressure in craniostenosis. *J Neurosurg*. 1982; 57(3):370–377
43. Blount JP, Louis RG Jr., Tubbs RS, Grant JH. Pansynostosis: a review. *Childs Nerv Syst*. 2007;23(10):1103–1109
44. Judy BF, Swanson JW, Yang W, et al. Intraoperative intracranial pressure monitoring in the pediatric craniosynostosis population. *J Neurosurg Pediatr*. 2018;22(5): 475–480
45. Arnaud E, Renier D, Marchac D. Prognosis for mental function in scaphocephaly. *J Neurosurg*. 1995; 83(3):476–479
46. Gewalli F, da Silva Guimarães-Ferreira JP, Sahlin P, et al. Mental development after modified π procedure: dynamic cranioplasty for sagittal synostosis. *Ann Plast Surg*. 2001;46(4):415–420
47. Patel A, Yang JF, Hashim PW, et al. The impact of age at surgery on long-term neuropsychological outcomes in sagittal craniosynostosis. *Plast Reconstr Surg*. 2014;134(4):608e–617e
48. Toth K, Collett B, Kapp-Simon KA, et al. Memory and response inhibition in young children with single-suture craniosynostosis. *Child Neuropsychol*. 2008;14(4):339–352
49. Starr JR, Kapp-Simon KA, Cloonan YK, et al. Presurgical and postsurgical assessment of the neurodevelopment of infants with single-suture craniosynostosis: comparison with controls. *J Neurosurg*. 2007;107(2 Suppl):103–110
50. Mathijssen I, Arnaud E, Lajeunie E, Marchac D, Renier D. Postoperative cognitive outcome for synostotic frontal plagiocephaly. *J Neurosurg*. 2006;105(1 Suppl):16–20
51. Melville H, Wang Y, Taub PJ, Jabs EW. Genetic basis of potential therapeutic strategies for craniosynostosis. *Am J Med Genet A*. 2010;152A(12): 3007–3015
52. Persing J, Jane JA, Edgerton MT. Surgical Treatment of Craniosynostosis. In: Persing J, Edgerton MT, Jane JA, eds. *Scientific Foundations and Surgical Treatment of Craniosynostosis*. Baltimore, MD: Williams & Wilkins; 1989: 117–238
53. Boulet SL, Rasmussen SA, Honein MA. A population-based study of craniosynostosis in metropolitan Atlanta, 1989-2003. *Am J Med Genet A*. 2008;146A(8):984–991
54. van der Meulen J, van der Hulst R, van Adrichem L, et al. The increase of metopic synostosis: a pan-European observation. *J Craniofac Surg*. 2009; 20(2):283–286
55. Kolar JC. An epidemiological study of nonsyndromal craniosynostoses. *J Craniofac Surg*. 2011;22(1):47–49
56. Lajeunie E, Le Merrer M, Bonaïti-Pellie C, Marchac D, Renier D. Genetic study of scaphocephaly. *Am J Med Genet*. 1996; 62(3):282–285
57. Cornelissen M, Ottelander B, Rizopoulos D, et al. Increase of prevalence of craniosynostosis. *J Craniomaxillofac Surg*. 2016;44(9):1273–1279
58. Gallagher ER, Evans KN, Hing AV, Cunningham ML. Bathrocephaly: a head shape associated with a persistent mendosal suture. *Cleft Palate Craniofac J*. 2013;50(1):104–108
59. Shah MN, Kane AA, Petersen JD, Woo AS, Naidoo SD, Smyth MD. Endoscopically assisted versus open repair of sagittal craniosynostosis: the St. Louis Children's Hospital experience. *J Neurosurg Pediatr*. 2011;8(2):165–170
60. Jimenez DF, Barone CM. Endoscopic technique for sagittal synostosis. *Childs Nerv Syst*. 2012;28(9):1333–1339
61. Vu HL, Panchal J, Parker EE, Levine NS, Francel P. The timing of physiologic closure of the metopic suture: a review of 159 patients using reconstructed 3D CT scans of the craniofacial region. *J Craniofac Surg*. 2001;12(6):527–532
62. Sauerhammer TM, Oh AK, Boyajian M, et al. Isolated frontosphenoidal synostosis: a rare cause of synostotic frontal plagiocephaly. *J Neurosurg Pediatr*. 2014;13(5):553–558

63. Plooij JM, Verhamme Y, Bergé SJ, van Lindert EJ, Borstlap-Engels VMF, Borstlap WA. Unilateral craniosynostosis of the frontosphenoidal suture: a case report and a review of literature. *J Craniomaxillofac Surg*. 2009;37(3):162–166

64. Tay T, Martin F, Rowe N, et al. Prevalence and causes of visual impairment in craniosynostotic syndromes. *Clin Exp Ophthalmol*. 2006;34(5):434–440

65. Khan SH, Nischal KK, Dean F, Hayward RD, Walker J. Visual outcomes and amblyogenic risk factors in craniosynostotic syndromes: a review of 141 cases. *Br J Ophthalmol*. 2003;87(8):999–1003

66. Wilkie AOM, Johnson D, Wall SA. Clinical genetics of craniosynostosis. *Curr Opin Pediatr*. 2017;29(6):622–628

67. Wang JC, Nagy L, Demke JC. Syndromic craniosynostosis. *Facial Plast Surg Clin North Am*. 2016;24(4):531–543

68. Reddy K, Hoffman H, Armstrong D. Delayed and progressive multiple suture craniosynostosis. *Neurosurgery*. 1990;26(3):442–448

69. Kreiborg S, Cohen MM Jr.. The oral manifestations of Apert syndrome. *J Craniofac Genet Dev Biol*. 1992;12(1):41–48

70. Thompson DN, Slaney SF, Hall CM, Shaw D, Jones BM, Hayward RD. Congenital cervical spinal fusion: a study in Apert syndrome. *Pediatr Neurosurg*. 1996;25(1):20–27

71. Cohen MM Jr.. Pfeiffer syndrome update, clinical subtypes, and guidelines for differential diagnosis. *Am J Med Genet*. 1993;45(3):300–307

72. National Center for Advancing Translational Sciences. Muenke syndrome. Available at: https://rarediseases.info.nih.gov/diseases/7097/muenke-syndrome. Accessed September 15, 2018

73. Rozovsky K, Udjus K, Wilson N, Barrowman NJ, Simanovsky N, Miller E. Cranial ultrasound as a first-line imaging examination for craniosynostosis. *Pediatrics*. 2016;137(2):e20152230

74. Roby BB, Finkelstein M, Tibesar RJ, Sidman JD. Prevalence of positional plagiocephaly in teens born after the "Back to Sleep" campaign. *Otolaryngol Head Neck Surg*. 2012;146(5):823–828

75. Robinson S, Proctor M. Diagnosis and management of deformational plagiocephaly. *J Neurosurg Pediatr*. 2009;3(4):284–295

76. Volpe JJ. *Neurology of the Newborn*. Philadelphia, PA: W.B. Saunders Company; 1995

77. Dvoracek LA, Skolnick GB, Nguyen DC, et al. Comparison of traditional versus normative cephalic index in patients with sagittal synostosis: measure of scaphocephaly and post-operative outcome. *Plast Reconstr Surg*. 2015;136(3):541–548

78. Collett BR, Wallace ER, Kartin D, Cunningham ML, Speltz ML. Cognitive outcomes and positional plagiocephaly. *Pediatrics*. 2019;143(2):e20182373

79. Baird LC, Klimo P Jr., Flannery AM, et al. Congress of Neurological Surgeons systematic review and evidence-based guideline for the management of patients with positional plagiocephaly: the role of physical therapy. *Neurosurgery*. 2016;79(5):E630–E631

80. Flannery AM, Tamber MS, Mazzola C, et al. Congress of Neurological Surgeons systematic review and evidence-based guidelines for the management of patients with positional plagiocephaly: executive summary. *Neurosurgery*. 2016;79(5):623–624

81. Klimo P Jr., Lingo PR, Baird LC, et al. Congress of Neurological Surgeons systematic review and evidence-based guideline on the management of patients with positional plagiocephaly: the role of repositioning. *Neurosurgery*. 2016;79(5):E627–E629

82. Mazzola C, Baird LC, Bauer DF, et al. Congress of Neurological Surgeons systematic review and evidence-based guideline for the diagnosis of patients with positional plagiocephaly: the role of imaging. *Neurosurgery*. 2016;79(5):E625–E626

83. Tamber MS, Nikas D, Beier A, et al. Congress of Neurological Surgeons systematic review and evidence-based guideline on the role of cranial molding orthosis (helmet) therapy for patients with positional plagiocephaly. *Neurosurgery*. 2016;79(5):E632–E633

84. Tamber MS, Nikas D, Beier A, et al. Congress of Neurological Surgeons systematic review and evidence-based guideline on the role of cranial molding orthosis (helmet) therapy for patients with positional plagiocephaly. *Neurosurgery*. 2016;79(5):E632–E633

85. Aisenson MR. Closing of the anterior fontanelle. *Pediatrics*. 1950;6(2):223–226

86. Hoffman HJ, Reddy KV. Progressive cranial suture stenosis in craniosynostosis. *Neurosurg Clin N Am*. 1991;2(3):555–564

87. Flannery AM, Tamber MS, Mazzola C, et al Summary: evidence based guidelines for the treatment of pediatric positional plagiocephaly. Available at: https://www.cns.org/Assets/2a42b91b-2146-464e-9b5c-c6a7c01202e2/636985419035000000/summary-with-recommendations-final-12-1-16-pdf Accessed September 15, 2018