Identifying the Misshapen Head: Craniosynostosis and Related Disorders

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abstract

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 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
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 CALVARIAL 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, 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 (lambda) 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. 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. The role of cartilage growth disturbance within the cranial base in craniosynostosis is still a matter of debate.

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

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. 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. 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 (FGF), 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, resulting in mineralization and progressive ossification that unites the bones on either side of the suture. Pathogenic variants of fibroblast growth factor receptors (FGFRs) are the most common genetic variants associated with craniosynostosis. 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

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.
flattening (retrusion).\textsuperscript{22–31} Pathogenic variants in \textit{TWIST1} (twist family basic Helix-Loop-Helix transcription factor 1) gene, another transcription factor associated with craniosynostosis,\textsuperscript{32–34} directly affect BMP signaling of skull preosteoblasts, leading to variations in cerebral brain angiogenesis.\textsuperscript{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.\textsuperscript{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.\textsuperscript{38} Generalized IQ is shifted downward with increased learning disabilities, language delays, and behavioral difficulties.\textsuperscript{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\textsuperscript{40–44}; the incidence of intracranial hypertension is higher among older untreated individuals.\textsuperscript{42,44} Elevated ICP correlates with developmental and cognitive outcomes in some studies\textsuperscript{40} but not others.\textsuperscript{39,45,46} Neither has the severity of the deformity correlated with the presence of neurocognitive deficits.\textsuperscript{39} A few studies have suggested that earlier treatment of craniosynostosis may result in better early and late neurocognitive outcomes,\textsuperscript{45,47} but the majority have not found such an association.\textsuperscript{12,48–50} Finally, genes involved in craniosynostosis syndromes have recently been found to be involved in brain development,\textsuperscript{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\textsuperscript{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 suturel synostoses (Fig 2). Multisutural synostosis can be appreciated as the combined effect of fusion involving each of the individual component sutures.

**SCAPHOCEPHALY (SAGITTAL SYNOSTOSIS), DOLICHOCHEPHALY (NICUCEPHALY), AND BATHROCEPHALY**

Sagittal synostosis is the most common form of craniosynostosis, accounting for approximately 40% to 45% of cases\textsuperscript{53–55} and having a prevalence of 2 to 3.2 per 10 000 live births.\textsuperscript{53,56,57} Sagittal synostosis has a distinct male predominance of 2.5 to 3.8:1.\textsuperscript{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
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.
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.
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. 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. 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 and having a prevalence of 0.9 to 2.3 per 10 000 live births. The prevalence of metopic synostosis may have increased over the past decades (without a corresponding increase in other synostoses) for uncertain reasons. Metopic synostosis also has a distinct male preponderance of 1.8 to 2.8:1. 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 suture produces a conical head shape with prominent frontal bossing and sagittal ridging. Reduced age at correction can result in a more extensive remodeling procedure.
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.\(^1\) CT scans readily demonstrate the triangular-shaped anterior fossa with midline thickening of the metopic suture and hypotelorism (Fig 7).

**ANTERIOR PLAGIOCEPHALY (UNICORNAL SYNOSTOSIS)**

Unicoronal synostosis is the third most common form of craniosynostosis, accounting for 12% to 24%\(^5,55\) 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 an attaining 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
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).

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...
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, with a prevalence of approximately 0.5 per 10,000 live births. 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. 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. 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
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.

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).

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 bicornal 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
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.

**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.\textsuperscript{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 \textit{FGFR1} or \textit{FGFR2} genes are responsible for all but Crouzon with acanthosis nigricans, which is caused by pathogenic variants in the \textit{FGFR3} gene.

\textbf{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, turriccephaly, 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,\textsuperscript{69} and vertebral fusion abnormalities (most commonly involving C5-C6) may be present.\textsuperscript{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 \textit{FGFR2} gene is responsible.

\textbf{Pfeiffer Syndrome}

Pfeiffer syndrome is characterized by bicornal 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 \textit{FGFR2} gene is responsible.

Cohen has described 3 types of Pfeiffer syndrome.\textsuperscript{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.

\textbf{Saethre-Chotzen Syndrome}

Saethre-Chotzen syndrome is characterized by bicornal synostosis (with occasional involvement of other sutures) leading to turriccephaly 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 \textit{TWIST} gene is responsible.

\textbf{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 bicornal 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%. 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. 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 r) 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. It is more common (approximately 60% of cases) in male children. 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). 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 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. 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).

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 turriencephaly, orbital retraction, Harlequin orbit, and exophthalmos differentiate DB from bicornal 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).
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 \( \approx 85\% \) 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 radiographs 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
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. 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, 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.

**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. 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.

**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 lambdoidal 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 lambdoidal synostosis produce a short head (brachycephaly) and are differentiated by the presence or absence of associated midface hypoplasia or bilateral retromastoid bulging.

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**TABLE 3 Conditions Causing Microcephaly**

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

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

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: bicornoral 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 bicornal 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.

**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
- CVAI: cranial vault asymmetry index
- FGFR: fibroblast growth factor receptor
- FGR: fibroblast growth factor
- ICP: intercranial pressure

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