Pneumatization of the Paranasal Sinuses: Normal Features of Importance to the Accurate Interpretation of CT Scans and MR Images

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CT and MR imaging of the paranasal sinuses in infants and children reveal a spectrum of findings associated with the normal pneumatization process, both inside the sinus cavities and in the adjacent marrow spaces. These normal findings must be understood and recognized so that CT scans and MR images may be accurately interpreted. If such normal developmental radiologic findings are not appreciated, misinterpretation may occur and lead to inappropriate treatment. In this pictorial essay, the normal process of pneumatization for each paranasal sinus group will be described from the first stages of the process to its completion. CT scans and MR images will illustrate the range of normal radiologic findings associated with the developmental process, with emphasis placed on the types of findings that, although normal, create potential interpretive difficulties.

Pneumatization of the Maxillary Sinus

The maxillary sinus is the first paranasal sinus to form. At birth, the rudimentary aerated sinus is 6–8 cm3 in volume, with its maximal dimension in the anteroposterior direction (Figs. 1 and 2A). Although initially medial to the orbit, the lateral margin of the sinus projects under the medial orbital wall by the end of the first year (Fig. 2B). The sinus extends laterally past the infraorbital canal by age 4 years to reach the maxillary bone by age 9 years. Inferior growth usually also reaches the plane of the hard palate by age 9 years, although the timing of these various stages of development is highly variable.

Fig. 1.—Composite drawing in coronal projection shows temporal and morphologic changes that occur from birth to maturity during development of maxillary and frontal sinuses. Maxillary sinus advances from ethmoidal infundibulum (wide arrow) in an inferolateral direction. Pneumatization is complete when permanent teeth erupt, thus allowing sinus floor to extend below level of hard palate (early and late adult growth bands). Frontal sinus develops essentially as a superior extension of anterior ethmoidal sinus into frontal bone.

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variable (Fig. 2C). Subsequent growth comes from pneumatization of the maxillary alveolus after the permanent teeth erupt. This final phase of pneumatization moves the floor of the maxillary sinus 4–5 mm below the level of the floor of the nasal cavity (Fig. 2D). Asymmetry in the size and shape of the sinus is common. Hypoplasia is unilateral in 7% and bilateral in 2% of adults. Partial or complete opacification of the maxillary sinus in the first few years of life is normal [1].

**Pneumatization of the Ethmoidal Sinus**

Ethmoidal air cells are present at birth and continue to grow until late puberty or until the sinus walls reach compact bone (Fig. 3). In the initial postnatal period, the ethmoidal labyrinth is more developed anteriorly. The anterior cells are already aerated, whereas the middle cells are frequently opacified and presumably fluid filled (Fig. 4A). During the first few years of life, opacification of ethmoidal air cells is commonly seen in children [1]. Pneumatization progresses in a posterior direction, enlarging the posterior air cells until the lateral and medial walls of the ethmoidal sinuses are parallel in the anterior to posterior direction (Fig. 4B). The late phases of ethmoidal pneumatization may create convex medial and lateral walls, with the posterior cells both larger and fewer than the anterior cells (Fig. 4C).

When the final phase of pneumatization includes medial and inferior air cell extension, the extramural air cells, referred to as agger nasi, concha bullosa, and Haller’s cells, are formed. Anteroinferior extension of the anterior ethmoi-

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**Fig. 2.—Maxillary sinuses at various stages of development from infancy through early adulthood.**

A, Axial long TR/short TE (3500/30) MR image in a 9-month-old infant shows rudimentary aerated sinuses (asterisks) adjacent to their origin, lateral nasal wall (arrows). These early sinuses are oval, and maximum diameter is in anteroposterior direction. B–D, Coronal CT scans obtained in three patients, 22 months (B), 4 years (C), and 19 years (D) old, show rapid inferolateral expansion of sinus cavities by early childhood and final extent of pneumatization. Maxillary sinuses have extended laterally to reach halfway across inferior orbital rim (arrows) by age 22 months (B). Pneumatization advances inferiorto level of unerupted adult tooth buds (asterisks). By age 4 years (C), maxillary sinuses are at level of hard palate (black arrow). Their lateral walls (white arrows) have advanced two thirds of the way across orbital floor, past infraorbital nerve. Also note bilateral Haller’s cells (H) and the cells’ strategic location superior and lateral to ethmoidal infundibulum (arrowheads). In D, adult maxillary sinuses have reached below level of hard palate (curved arrows) to alveolar ridge (A).

**Fig. 3.—Composite drawing in axial projection shows temporal and morphologic changes from birth to maturity that occur during development of ethmoidal and sphenoideal sinuses.** Lateral walls of ethmoidal sinuses expand laterally, becoming parallel early in childhood and convex by early adulthood. Pneumatization of sphenoidal sinus advances inferolaterally and may even extend into pterygoid plates and anterior clinoid processes. Perpendicular plate of ethmoid bone and vertical sphenoidal septum have been blackened to illustrate fusion of ethmoidal labyrinth and sphenoidal sinus.
Pneumatization of these cells.
The frontal recesses of the ethmoidal sinuses mature in size and configuration. Walls of ethmoidal complex in adult are not parallel (arrows), and posterior ethmoidal air cells (asterisks) are relatively larger and fewer.

Fig. 4.—Axial CT scans of ethmoidal and sphenoidal sinuses at various stages of normal development from infancy through early adulthood. A, At age 3.5 weeks, only anterior ethmoidal cells (long arrow) are aerated, while middle cells (short arrow) are opacified, and posterior cells (arrowhead) remain undeveloped. This opacification of ethmoidal sinus may be normal during the first few years of life. Future marrow conversion and pneumatization of sphenoidal sinus will begin in presphenoid plate (P). B, By age 2 years, lateral walls of ethmoidal labyrinth (arrows) have become parallel. Small pneumatized sphenoidal sinuses (S) and sphenethmoidal recesses (arrowheads) are clearly seen with CT even at this early age. C, At age 19 years, both ethmoidal and sphenoidal sinuses are mature in size and configuration. Walls of ethmoidal complex in adult are not parallel (arrows), and posterior ethmoidal air cells (asterisks) are relatively larger and fewer.

Pneumatization of the ethmoidal complex into the frontal recess creates the agger nasi cells. The prevalence of these cells varies from 15% to 99% of adults, depending on the exact definition of these air cells and the method used to detect them. In our experience, these air cells are detected on virtually all coronal sinus CT scans if the structure is defined as the first air cells seen on the superolateral wall of the nose when coronal images are observed from anterior to posterior (Fig. 5). The agger nasi serve as the anterior floor of the frontal sinus and may form a significant portion of the anterior wall of the frontal recess and drainage pathway from the frontal sinus. When ethmoidal sinusitis affects an agger nasi cell, frontal sinus disease is commonly associated with it because of the proximity of the agger nasi cells to the nasofrontal duct.

Pneumatization progressing interomedially from the middle ethmoidal cells into the middle turbinate creates a commonly encountered normal variant on coronal sinus CT scans called concha bullosa (Fig. 6). This is thought to be an anatomic variation of ethmoidal air cell development rather than the result of a previous pathologic intranasal process.

It has been postulated that concha bullosa can obstruct ventilation and mucociliary clearance of the middle meatus when it is diseased, although some researchers dispute that it is a causative factor in recurrent sinusitis [2, 3]. When the ethmoidal pneumatization process progresses interolaterally into an infraorbital location, Haller's cells are created. Haller's cells are broadly defined as any air cell located below the ethmoid bulla, along the maxillary sinus roof and most inferior portion of the lamina papyracea, including air cells located within the ethmoidal infundibulum (Fig. 2C). Haller's cells can be clinically significant because of their strategic location along the course of the infundibulum. Such factors as the size of these air cells, their proximity to the natural ostia of the maxillary sinus, evidence of inflammation within the cell, and the presence of mucosal contact points from this cell to neighboring structures should be considered in attempting to implicate the Haller's cell as causal in maxillary sinusitis. A completely aerated Haller's cell seen by itself on a sinus CT scan is nothing more than a normal anatomic variant of aeration.

Fig. 5.—Coronal CT scan at level of anterior frontal sinuses shows agger nasi cell on left side (arrow). This extramural air cell, essentially an anteroinferior extension of anterior ethmoidal complex, if diseased, may obstruct frontal sinus drainage because of its intimate relationship with nasofrontal duct.

Fig. 6.—Coronal CT scan shows concha bullosa (asterisk), a common anatomic variant of ethmoidal pneumatization that extends from middle ethmoidal complex (E) into middle turbinate. Whether concha bullosa is a causative factor in recurrent sinusitis remains in dispute.
Pneumatization of the Sphenoidal Sinus

At birth the sphenoid bone contains erythopoietic (red) marrow and is devoid of air (Fig. 4A). Conversion from red to yellow (fatty) marrow is thought to occur first in the presphenoidal plate from the ages of 7 months to 2 years [4] (Fig. 7A). Marrow conversion then extends posteriorly into the basisphenoidal plate. These fatty changes that normally occur before pneumatization should not be misinterpreted for hemorrhage, proteinaceous fluid, or a dermoid cyst.

High-resolution CT may show pneumatization of the sphenoidal sinuses as early as age 2 years (Fig. 4B). Pneumatization progresses in an inferior posterolateral direction. The pneumatized basisphenoidal plate often extends to but not past the sphenoidcystal synchondrosis in the mature sphenoidal sinus (Fig. 7B). The sinus attains its mature size by the age of 14 years (Fig. 8).

The degree of pneumatization of the sphenoidal sinus varies considerably. Aplasia of a sphenoidal sinus is extremely rare. Therefore, a lack of pneumatization of the sphenoidal sinus in patients more than 10 years old should suggest underlying disease. The pterygoid processes are pneumatized in 25–40% of adults.

Aeration of the anterior clinoid process (13%) and medial pterygoid process (44%) is more common than the dorsum sella and posterior clinoid process.

Pneumatization of the Frontal Sinus

The frontal sinus is the last paranasal sinus to develop. It originates as anterosuperior outpouchings from the frontal recess of the nose. The frontal sinus is merely a slowly developing extension of the anterior ethmoidal sinus. At birth, it is undeveloped and nonaerated and contains red marrow. As in the sphenoidal sinus, pneumatization of the frontal sinus follows a marrow transition phase from red to yellow marrow in the first few years of life. After marrow transformation has occurred, pneumatization progresses into the frontal bone (Fig. 7B). The earliest pneumatization occurs at or shortly after age 2 years. By age years, the cranial extent of the frontal sinus reaches half the height of the orbit, extending just above the top of the most anterior ethmoidal air cells. The top of the frontal sinus is at the level of the orbital roof by age 8 years, and the sinuses extend into the vertical portion of the frontal bone by age 10 years.

Fig. 7.—Normal marrow changes that occur before pneumatization of sphenoidal and frontal sinuses.
A. Sagittal T1-weighted (600/11) MR image in an 8-month-old infant shows high T1 signal that represents fatty marrow in presphenoidal plate (wide arrow) and frontal bone inferiorly (narrow arrow). This high T1 signal should not be mistaken for a dermoid cyst, subacute hemorrhage, or proteinaceous fluid. Note lower T1 signal of red marrow in basisphenoidal plate (b) and sphenoidcystal synchondrosis (arrowhead).
B. Sagittal T1-weighted (500/15) MR image of young adult shows arrested pneumatization of sphenoidal sinus (S) at sphenoidcystal synchondrosis (arrowhead). Pneumatization of frontal sinus (asterisk) advances superiorly within fatty marrow of frontal bone.

Fig. 8.—Composite drawing in sagittal projection shows temporal and morphologic changes that occur from birth to maturity during development of sphenoidal sinus. Aplasia of sphenoidal sinus is extremely rare. If pneumatization is not evident by age 10 years, sphenoidal sinus disease should be suspected. F = frontal sinus.

Continued growth occurs throughout childhood; the sinuses achieve their final size after puberty (Fig. 1). Development of the frontal sinus is quite variable. Aplasia is present unilaterally in 15% and bilaterally in 5% of adults.

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REFERENCES