

'Pneumatization' and the formation of air sinuses in human development

Brian Freeman
School of Medical Sciences
UNSW

Overview

The so-called paranasal sinuses are all present, although small, before birth; e.g., Broman (1927), citing Kallius (1905), describes the maxillary sinus at birth as being the size of a pea; Schaeffer (1910a) gives its average dorsoventral length at birth as 7 mm. [image] The anlagen of many sinuses can be identified by the third to fourth fetal month (Cummings et al., 2001). Sinuses continue to grow in volume and surface area, most rapidly during puberty. Sinus growth occurs after adult skull growth ceases, e.g., frontal sinus growth continues for up to two years after skull growth stops; sphenoid sinus volume increases until third decade; maxillary sinus may continue to enlarge in old age as maxilla becomes osteoporotic and edentulous. Therefore many sinuses can enlarge even though there may be no obvious change in external skull dimensions. Frequently in adult skulls the walls of the ethmoidal sinuses are paper-thin and often rupture at the medial wall of the orbit. [image]

The middle ear chamber with the mastoid antrum and air cells is a type of sinus that shares common features with the paranasal sinuses. [image]

So-called functional anatomy sheds no light at all on the sinuses, not even the ludicrous view that they exist to form a 'collapsible framework to help protect the brain from frontal blunt trauma' (Cummings et al, 2001). So called sinus functions are mere hypotheses about possible results of early development.

Common developmental features of air cells

Future air spaces (cells), irrespective of size, share the following developmental features.

Position: All arise in locations near the interface of the superior borders of the cartilaginous basicranium and the future desmocranium (membrane bones of the calvaria).

Form: All arise by surface extension (areal growth) of a wedge-shaped limiting tissue into a loosening stroma (bed). The wedging is divergent towards the stroma (convergent to the free surface); thus all sinuses arise from pre-existing furrows (Schaeffer, 1910b). [image] The boundary tissue may be derived from ectoderm in the case of the paranasal sinuses or from a mixture of ectoderm and endoderm as in the case of the middle ear and the mastoid air cells.

All sinuses are therefore lined by a mucosa; in the case of the middle ear, the mucosa covers the bones, ligaments, nerves, tendons and muscles that are

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described (incorrectly) as lying inside the chamber. [image] These elements are no more 'inside' the middle ear than loops of gastro-intestinal tract are inside the abdominopelvic sac; the mucosa of the middle ear is no different to peritoneum. The epithelium lining air sinuses is strongly adherent to the bone and is known as a mucoperiosteum.

Local biodynamics: Sinuses cannot arise in the absence of an actively growing limiting tissue. However epithelial surface growth alone is insufficient to account for the enlargement of a sinus. Such areal growth can occur only if a kind of suction field (common to the formation of all glands) arises in the stroma (bed) of the epithelium (limiting tissue). Thus all sinuses exhibit gland-like epithelial sprouts in their most rapidly growing regions, often at the fundus of the sinus. This is seen clearly in Broman's (1927) reconstruction of the lateral nasal wall of a 53.2 mm fetus with glandular sprouts at the lateral wall of the maxillary sinus. [image Br., Abb. 85, p. 91]

The stroma loosens because it is biomechanically anisotropic, i.e., composed of firmer and weaker parts; the stronger parts consolidate as ligaments (retension fields) and/or osteoid (detraction fields) and the weaker parts loosen (suction fields). The loosening regions lie adjacent to the deep inner tissue of the nasal sac and the tubotympanic recess whereas the consolidating regions usually lie closer to the skin (ectoderm) of the head, which is growing more rapidly in surface area. An interesting common feature of the epithelium of the nasal wall and tubotympanic recess (irrespective whether of ectodermal or endodermal origin) is that its cells, prior to their being given the opportunity to spread out, pass through a phase of restricted surface growth, which results in them becoming temporarily taller.

Thus there is a precise spatial sequence between the innermost epithelial (mucosal) layer, then the loosening layer, then the consolidating layer, then the skin.

The stronger (consolidating) structures, being the perichondrial ligaments of the basicranium and the osseous foci of specific cranial bones (e.g., maxillae; nasal bones) are subject to continuously oscillating growth tractions. Particular examples of this are the increasing displacement between the initial foci of the maxillae due to traction of the connective tissue of the zygomatic arch. [image B&G Fig. 20-11, p. 269] Thus the tiny epithelial anlage of the maxillary sinus appears deep to the focus of chondrification of the nasal capsule; the positional relations are reminiscent of a bell-tent (nasal epithelium) covered by a fly (nasal capsule). A focus of bone arises in the external perichondrium of the cartilaginous nasal capsule, so that there is a precise topography from inside-out of nasal ectoderm, stroma, nasal capsule, external perichondrium, intramembranous maxillary ossification, stroma, skin. Kallius' (1905) illustration of a frontal section through the head of a 15-week fetus (reproduced in Broman, 1927, p. 90) shows this nicely. [image Br., Abb. 84, p. 90]

Subsequently, growth tractions are replaced by frank muscular traction during activity of skeletal muscles of the head, neck, and face, which continues

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throughout puberty. This is particularly well seen in the formation of the mastoid process and its air cells in response to traction in the sternocleidomastoid muscle; initially the pull is due to growth, later it arises from active muscular hardening.

Another factor in the subsequent enlargement of the air sinuses is the division of the skull bones into internal and external plates or laminae (tabula interna, externa). The tabula externa is the locus of musculoskeletal traction, whether due to growth dynamics or mature muscular hardening ('contraction').

Although sinuses are the result of transverse, vertical, and sagittal growth of the head, paired sinuses are always asymmetric because they result from oscillating asymmetric brain growth. Even the sphenoid sinus of the midline, which arises from separate left and right embryonic anlagen that become (partially) confluent (corrosion field), has asymmetrical lateral recesses.

Surface enlargement of the ectoderm of the midface is therefore the major driving force associated with sinus growth. Later this role will be taken over by the piston-like (distusional) growth of chondrocytes of the midface, principally the nasal capsule. [\[image, OBHA, Fig. 5.15, p.132\]](#)

Contents: Prior to birth all future air sinuses are filled by fluid that must eventually become amniotic in nature; this fluid is replaced by air in the perinatal period.

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