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Why paranasal sinuses?

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Abstract
This essay attempts to address the perennial question 'Why Paranasal Sinuses?'. In doing so it highlights the flaws in many much-favoured but ill-founded theories concerning the role of these sinuses in humans. It is concluded that the question can only be fully answered through a greater understanding of differential growth changes within the craniofacial massif.

Introduction

The role of the paranasal sinuses in the human race, and many mammals in general, remains as much an engima as it did nearly two millennia ago. Indeed, Takahashi (1983) identifies the significance of these air spaces as 'one of the most difficult problems in human evolution'.

In his 'A History of Laryngology and Rhinology', Wright (1914) notes that Vesalius (1542) attributed the earliest knowledge on the existence of the sinuses to Galen (130–201 A.D.). Flottes *et al.*, (1960), however, recognize Leonardo Da Vinci as the true discoverer of the paranasal sinuses. In his 'Two views of the skull' (Windsor 19057), circa 1489, both the frontal sinus and opening of the maxillary sinus are visible (Kemp, 1989).

Fallopius's (1600) observation that the sinuses were not present in neonatal skulls was according to Wright (1914) the first substantial contribution to anatomists' knowledge of paranasal sinus ontogeny. Rui, *et al.* (1960) note that a further step was made when Highmore (1651) advanced the concept of pneumatization of the sinuses, together with a detailed description of the maxillary antrum (antrum of Highmore).

Throughout the remaining centuries much of the literature has focused, with little success, on the functional significance of the paranasal sinuses and the factors determining the diversity of their development.

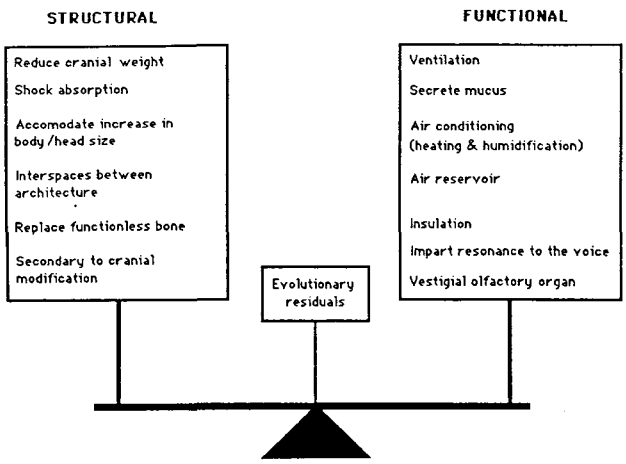


FIG. 1
Proposed roles of the human paranasal sinuses.

Hypothetical roles of the human paranasal sinuses

No conclusive theory has yet been accepted as to the *raison d'être* of the human paranasal sinuses. Some authors have opted for a functional role, be it active or passive, structural or physiological. Others have argued that the paranasal sinuses in higher primates are merely non-functional residuals of a common mammalian ancestor. Many of the theories (Fig. 1) have been applied to the paranasal sinuses as a whole, and this perhaps has led to several seemingly absurd proposed functions. Furthermore, almost all of the theories have been perpetuated over time with very little empirical research. Indeed as Proetz (1953) sadly noted, the function of the sinuses have 'on the whole aroused more speculation than investigation' (p. 7). I will discuss the most often quoted theories more out of a sense of historical context than scientific reality. I believe only the final theory warrants careful consideration.
The theories are as follows:

Impart resonance to the voice: This theory, originally proposed in the seventeenth century (Bartholinus, 1660), argues that the sinuses are important phonatory adjuncts in that they aid resonance. The theory received support from Howell (1917) when he stated that 'the peculiar quality or timbre of the individual voice arises from the accessory sinuses and the bony framework of the face' (p. 646). This he believed due to his observation that the Maori possess 'peculiarly dead voices . . . due to an underdevelopment of their accessory sinuses' (p. 646). Wegner (1955) also supported the theory on the basis that the howling monkeys possess particularly large paranasal sinuses.

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Proetz (1953) discounts the theory by observing that animals with loud voices such as the lion can have small sinuses. Similarly Negus (1958) observes that despite having large sinus cavities the giraffe and rabbit have little voice or shrill irresonant voices. He adds that 'In Man the variable size of the frontal, ethmoidal and sphenoidal cells would cause their effect to be most irregular'. Furthermore, Flottes *et al.* (1960) report that paranasal sinus physical properties make them poor resonators adding that sinus surgery does not modify the voice.

The theory of resonance is now generally regarded as untenable.

Increase the olfactory area: This theory arose when Cloquet (1830) incorrectly stated that the human maxillary sinus was lined with olfactory epithelium. Whilst in certain mammals, such as the carnivores, the presence of paranasal sinuses can indeed be considered to be related to an increase in olfactory area, with increasing powers of scent this is not the case in humans. The mucous membrane of the human paranasal sinuses is lined by non-olfactory epithelium. It is thinner, less vascular and more loosely fixed to bony walls than that of the respiratory region of the nasal cavity (Williams and Warwick, 1980). Indeed, this thin non-olfactory epithelium is one of the reasons why the paranasal sinuses becomes easily diseased—what Negus (1958) calls 'the unfortunate legacy'.

Thermal insulation to vital parts: This theory was originally proposed by Proetz (1953) who likened the paranasal sinuses to 'an air-jacket about the nasal fossae closely resembling the water jacket of a combustion engine' (p. 14). Flottes *et al.* (1960) observed that polar bears would then possess sinuses whereas brown bears would not, since the latter live in warmer climates. Although the validity of this claim is unknown, the fact that Eskimos often possess no frontal sinus (Koertvelyessy, 1972; Tillier, 1975) whilst African negroes possess large frontal sinuses (Brothwell, Molleson and Metreweli, 1968; Wolfowitz, 1974) would seem to indicate the reverse.

It has been suggested that the large frontal sinus in Neanderthal man is an adaption to protect the brain from the cold (Coon, 1962) but as Tillier (1975) points out even if this were so, one cannot necessarily extend the argument to other hominids since the relationship between frontal sinus size and supraorbital size is unique.

Because of the racial variation in sinus morphology thermal insulation as a primary role of the paranasal sinuses is unlikely.

Secrete mucus to moisten the nasal cavity: This theory is also discounted on the basis of histology. First advocated by Haller (1763) it proposes that the sinuses are important for the moistening of the nasal olfactory mucosa. Skillern (1920) and Negus (1958) note, however, that sufficient mucus for this purpose cannot be secreted by the human paranasal sinus lining. In contrast to the nose with its 100,000 submucosal glands, the sinuses have only 50–100 glands (Mygind and Winther, 1987).

It has recently been reported that paranasal sinus mucus is important in that it is 'uncontaminated', since it is relatively unexposed to noxious elements, and therefore dilutes inspired contaminants in nasal mucus in the middle meatus (Ballenger, 1985). If this were so then it must be proved that the orang-utan, lacking a fronto-ethmoidal sinus complex, is disadvantaged when compared to the gorilla which possess a fronto-ethmoidal sinus complex (Cave and Wheeler Haines, 1940). Similarly, in view of human racial variation in sinus morphology, it must also be proved that Eskimos must be disadvantaged when compared to African negroes.

Humidify and warm the inspired air: It has long been known that air exchange takes place in the sinuses during respiration (Braune and Clasen, 1877, Proetz, 1932). Debate has, however, existed as to whether this exchange occurs to enable humidification and warming of inspired air. Eckert-Mobias (1933) observed that the air sinuses develop in large swiftly moving mammals with an active respiration whilst slow moving mammals, especially those living in a humid medium (e.g. the hippopotamus) have either rudimentary or no sinuses. He therefore proposed that the sinuses do play a part in warming and humidifying inspired air. Air pressure studies however show that the degree of exchange is negligible (Proetz, 1932, 1953; Negus, 1958; Flottes *et al.*, 1960). Furthermore as Negus (1958) noted, 'in species which require the greatest degree of warming of air . . . the heating apparatus takes the form of an elaborately branching maxillo-turbinal body' adding that 'it is more profitable to have large maxillo-turbinal bodies, filling the anterior part of the snout, than hollow air spaces'.

It is more than likely that air exchange is merely necessary for ventilation of the sinuses to ensure good health with therefore no proof of a functional significance.

Absorb stress with possible avoidance of concussion: This theory originated from Negus' work on horned ungulates (1958). He noted that the air spaces which extend over the cranial vault and into the horns of ungulates such as the ox and goat are sometimes explained as stress distributors. In other horned ungulates such as the moose, however, the horns are attached directly to the cranium without intervening air spaces. These animals however 'manage to bear the weight and endure the shock of impact without obvious damage' (Negus, 1958).

Rui *et al.* (1960) observed that the sinus complex could be considered as a pyramidal buffer with the base situated anteriorly and the apex at the sphenoid thus forming an architectural structure suited to a protective function of endocranial structures.

Whilst this theory may have some appeal, it must be remembered that some animals with very small sinuses seem to be at no disadvantage. Similarly known racial variations in sinus morphology do significantly weaken the proposal.

Lighten the skull for equipose of the head: This is, as Wright (1914) notes, the most ancient of all the theories (Galen, 130; Vesalius, 1542; Fallopius, 1600).

The first objection came from Braune and Clasen (1877) who claimed that if the sinuses were filled with

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spongy bone the total weight of the head would be increased by only one per cent.

Despite statements that man's musculature is adequate to maintain head poise regardless of the state of the paranasal sinuses (Proetz, 1922; Negus, 1958; Flottes *et al.*, 1960) it was not until 1969 that an electromyographic investigation was made of the activity of human neck muscles in response to loading the anterior aspect of the head. It was concluded that the paranasal sinuses of man are not significant as weight reducers of the skull for maintenance of equipose of the head (Biggs and Blanton, 1970).

Necessary for facial growth/architecture: Proetz (1922) writes, 'in consideration of the rearrangement of the face structure it becomes apparent that the formation of sinuses is necessary for a readjustment to the surrounding parts, and we are not called upon to attribute to these cavities any further functional activity' (p. 1086). Proetz (1922) later expresses his opinion that the 'frontal sinuses develop . . . along with the advancement of the face; the maxillary grows . . . with the growth of the jaw; the sphenoid . . . with the broadening of adjacent parts' (p. 1088). He concludes that the paranasal sinuses are 'the result of a plastic rearrangement of the skull necessitated by the disproportionate growth of the face and cranium and associated structures after they are fully or partly ossified' (p. 1092). It is, however, documented that individuals with a single frontal sinus do not show deficient facial growth (Negus, 1957).

Galperin (1925) and Eckel (1963) attribute the presence of the sinus cavities to strains and stress of the skull created solely by the pressures exerted by the chewing apparatus. Takahashi (1983), however, believes that the shape of the neurocranium and cranial base must also be considered. He states that in the evolution of mammals through primates to humans, the sinuses originally acted as aids to olfaction, but were influenced by the retraction of the maxillo-facial massif and the process of cerebral enlargement. The human paranasal state is thus the result of an increase in the angle between the forehead and frontal cranial base, and decrease in the angle of the cranial base at the sella turcica.

Shea (1985) also believes that overall skull form is important when considering paranasal sinuses. He states, in his analysis of ape and human skull form, that the presence of a fronto-ethmoidal sinus complex is correlated to a basic structural transformation in neurocranial-splanchnocranial orientation. He notes that 'it is the position of the face, rather than its overall form, that is different in the Asian and African apes'. The upward rotation of the palate with respect to the cranial base in the orang-utan, a phenomenon called airorynchy, results in concavity of the midfacial region, relative lack of a supraorbital torus and naso-frontal-ethmoidal 'pinching' with absence of an ethmoidally derived frontal sinus.

The importance of craniofacial architecture in dictating sinus morphology receives further support from Blaney (1986). In his scaling analysis of frontal sinus size in the great apes, he highlights Stahl's (1967) finding that lung volume relative to body mass is one of the few biological relationships that remains constant in that lung volume scales almost isometrically with body weight. If the frontal sinus had a functional role which involves the nasal cavity or lung volume such as warming inspired air, it would be expected that its volume would scale in a similar fashion. This was not the case and he therefore excluded any physiological role. His study further indicated differences in frontal sinus size between the lowland gorilla, mountain gorilla and chimpanzee, after a measure of body size had been taken into account. This he proposed could be related to differences in forces transmitted through the supraorbital region which in turn are influenced by craniofacial morphology.

Conclusion

It is comparatively easy to answer the question 'Why paranasal sinuses' in such mammals as the carnivora. The question, however, is more difficult to answer when one considers primates in general and humans in particular. Goss's (1968) assertion that 'nature does nothing without a purpose, and she found no value for the spongy bone in the head and so left it out' is not a very satisfactory explanation. Similarly the various functional theories proposed, now hold little favour amongst many authors. In attempting to draw conclusions as to the role of paranasal sinuses I believe that the sinuses must be considered separately. Second, in comparing sinus morphology between mammals it is essential to ensure that the pneumatized cavities are homologous and that, for instance, a pneumatized frontal bone in the orang-utan (extension of the maxillary sinus into the frontal bone) should not be immediately compared to the frontal sinus in the human. Third, in any explanation as to the role of the paranasal sinuses, racial (sub-species) variation should be wholly accounted for.

It is becoming apparent that an architectural theory is far more likely in that it is known that craniofacial form has an important bearing on paranasal sinus morphology. Further research has yet to be done on craniofacial form and development before the exact role of the paranasal sinuses in humans can be answered.

It is welcoming that the more recent studies have emphasized the importance of differential growth (allometry) of individual sinuses (Takahashi, 1983; Shea, 1985; Blaney, 1986). With the advent of new imaging techniques much accurate data about paranasal sinuse size and morphology can be collated and further differential growth studies performed.

Takahashi (1983) notes that 'human evolution has progressed from the 'smell-oriented' mammals, to the 'sight-oriented' primates, and to the 'thought-oriented' humans . . . but the fate of the inside of his nose is not so glorious'. One can add that research into the paranasal sinuses in humans is also not so glorious since until recently, rigorous scientific investigation has not taken place. It is unlikely, however, that the controversy over the paranasal sinuses will continue for a further 1800 years.

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