Age-Related Expansion and Reduction in Aeration of the Sphenoid Sinus: Volume Assessment by Helical CT Scanning

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Age-Related Expansion and Reduction in Aeration of the Sphenoid Sinus: Volume Assessment by Helical CT Scanning

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BACKGROUND AND PURPOSE: **Aeration of the sphenoid sinus expands with the development of the sphenoid bone, but scant detailed volumetric data regarding this process, as it evolves from childhood to old age, exist. Using helical CT scanning, we assessed age-related volumetric changes of the sphenoid sinus.**

METHODS: **We used CT data obtained from 214 patients (age range, 1 to 80 years; 111 male and 103 female subjects) with middle or inner ear disease to assess the extent of sphenoid aeration. We also determined volumes of the sphenoid sinuses on 1.0- or 1.5-mm reformatted images by integrating the sinus air (≤ -900 HU) area.**

RESULTS: **Sphenoid sinus aeration began as a doublet in the anterior boundary of the sphenoid bone by the age of 5 years, with patients more than 6 years old exhibiting varying degrees of aeration. The aeration on both sides continued to expand until the third decade of life. The maximum average volume was 8.2 ± 0.5 cm^3. Thereafter, the volume decreased gradually, with the average volume in the seventh decade of life being 71% of the maximum level. The aeration of the peripheral portions of the sphenoid bone, such as the pterygoid process, anterior clinoid process, and dorsum sella, occurred predominantly after closure of the sphenooccipital suture, and showed a tendency to recede during aging.**

CONCLUSION: **Volumetric assessment of the sphenoid sinus by helical CT scanning revealed age-related expansion and reduction in aeration.**

Aeration of the sphenoid bone begins after birth. Several studies have been performed regarding the postnatal development of the sphenoid sinus (1). In general, aeration expands with age, in keeping with the growth of the sphenoid bone. Little is known regarding changes in sinus aeration beyond the teenage years. Using helical CT scanning, we conducted a volumetric analysis of sphenoid aeration in patients ranging in age from 1 to 80 year(s).

Methods

Study Selection

We analyzed helical CT images revealing the sphenoid sinuses of 214 patients (age range, 1 to 80 years; 111 male and 103 female subjects) with middle or inner ear disease (Table), but who were otherwise healthy, as judged from their medical histories. Of these images, we used 161 images of sphenoid sinuses obtained from patients spanning 1 to 80 years of age (85 male and 76 female subjects) for the volume determinations of aeration in the sphenoid bone. The other 53 sinuses contained either soft tissues or had not been imaged completely. We, however, used all of the 214 sinuses for the analysis of the extent of aeration in the body and the peripheral portions of the sinus.

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Helical CT Scanning

The patients were scanned using a HiSpeed Advantage SG CT imaging system (General Electric Medical Systems, Milwaukee, WI). The scanning orientation was parallel to the Frankfurt horizontal line. Scanning was performed with a collimation of 1 or 3 mm, a pitch of 1:1, a 512×512 matrix; a display field of view of 23 cm, 120 kVp, and 100 mA. Obtained data were transferred to an Advantage Windows Workstation (General Electric Medical Systems), where planar and 3D images of the sphenoid sinus were reconstructed. We obtained reformatted axial images of 1.0 or 1.5-cm slice thickness from these data.

Determination of Sphenoid Sinus Volume and Extent of Aeration

Sinus volume was determined as an integral volume of aeration in the sphenoid bone on the reformatted axial images. Aeration was defined as a volume having the CT number equal or less than -900 HU, and was expressed in cubic centimeters. The extent of aeration in the body and the peripheral portions

Distribution of subjects

Age (years)	Male	Female	Total
0–4	3 (3)	8 (6)	11 (9)
5–9	16 (11)	9 (7)	25 (18)
10–14	16 (14)	12 (6)	28 (20)
15–19	10 (8)	12 (10)	22 (18)
20–29	13 (11)	14 (14)	27 (25)
30–39	11 (8)	6 (6)	17 (14)
40–49	10 (8)	16 (8)	26 (16)
50–59	15 (11)	12 (8)	27 (19)
60–	17 (11)	14 (11)	31 (22)
Total	111 (85)	103 (76)	214 (161)

Note.—Number for the volume determinations of aeration in the sphenoid bone.

of the sphenoid bone (ie, the pterygoid process, anterior and posterior clinoid processes, and dorsum sella) was assessed on planar images of the 186 sphenoid sinuses. The extent of aeration in the body of each patient was assessed on a reformatted midsagittal image and in the peripheral portions on reformatted sagittal and coronal images. On reformatted sagittal images, we divided sinuses into four types: type 1, no sinus aeration (Fig 1A); type 2, sinus aeration occupying the anterior one third of the sphenoid body (Fig 1B); type 3, sinus aeration occupying the anterior two thirds of the sphenoid body without extension beyond the dorsum sella (Fig 1C); and type 4, sinus aeration with extension beyond the dorsum sella (Fig 1D). We decided that aeration occurred in the peripheral portions (except for the dorsum sella) when either side of the peripheral portions was aerated.

Statistical Analysis

Differences in the volume of sphenoid aeration between female and male patients in each of the age groups were analyzed using a paired *t*-test. We used the polynomial regression analysis for age-related changes in the sphenoid aeration volume, and fitted obtained data into an equation of third degree. Analyses were performed with StatView 4.0 software (Abacus Concepts, Berkeley, CA).

Results

Patients first manifested aeration of the sphenoid bone near the anterior border of the bone at 1 to 2 years old (Fig 1A). When patients reached 5 years of age, aeration had begun already in all sphenoid bones examined (Fig 2). The aeration continued to expand both posteriorly and superiorly (Fig 1B-C), and occupied almost the full length of the sphenoid bone from the anterior border to the posterior clinoid process by the end of the third decade of life (Fig 1D, Fig 2). After completion of the spheno-occipital synchondrosis, aeration of the sphenoid bone appeared to reduce in area. Sphenoid aeration never extended beyond the spheno-occipital sutures.

Determinations of sphenoid aeration volume supported the concept that the sphenoid aeration expands and then recedes with age; the volume of sphenoid aeration increased until the third decade of life (Fig 3). Thereafter, the volume reduced with age. The sphenoid sinus volume (V cm^3) at a particular age (A = years) could be estimated by the following formula: $V = -2.23 + 0.77A - 0.018A^2 + 0.00012A^3$ ($r = 0.69$). No significant difference in volume between men and women in any age group was demonstrated (Fig 3).

Three-dimensional CT images clearly delineated the development of the sphenoid sinus. Aeration first occurred as a doublet. Bilateral compartments of sphenoid sinuses were not fused, and the sphenoidal septum was observed in most of the patients examined. Three-dimensional images of the sphenoid sinus demonstrated numerous projections developing with age. These projections represented aeration in the peripheral portions of the sphenoid bone, such as in the pterygoid processes, anterior and posterior clinoid processes, and dorsum sella. Figure 4 shows the age-related development of aeration in these peripheral structures.

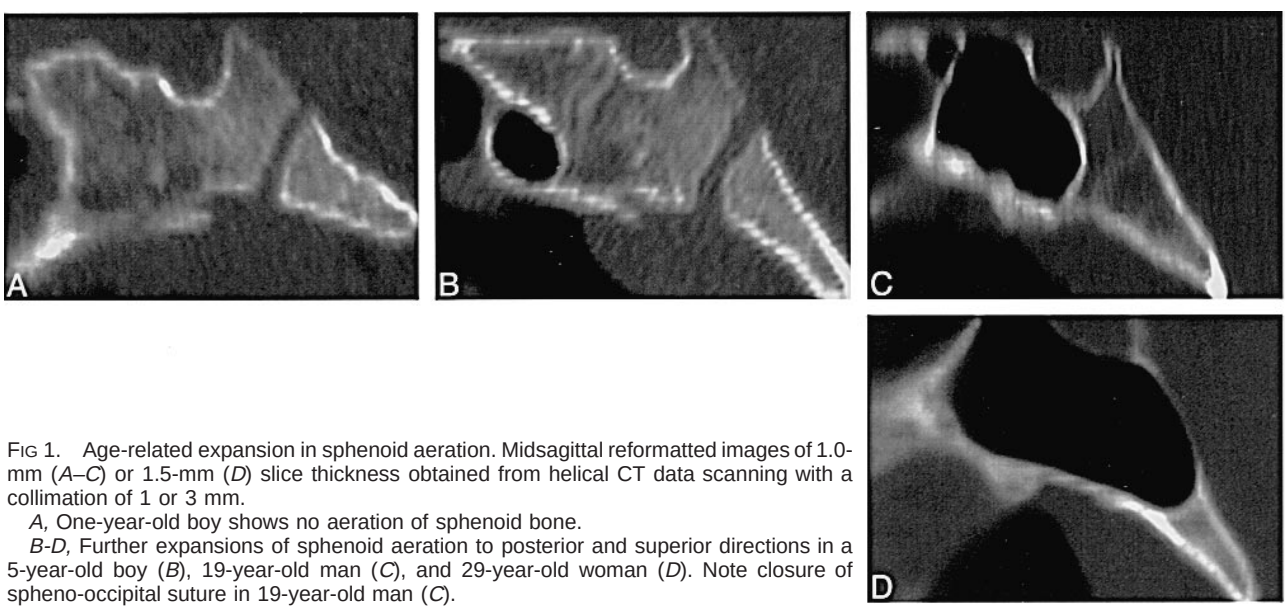
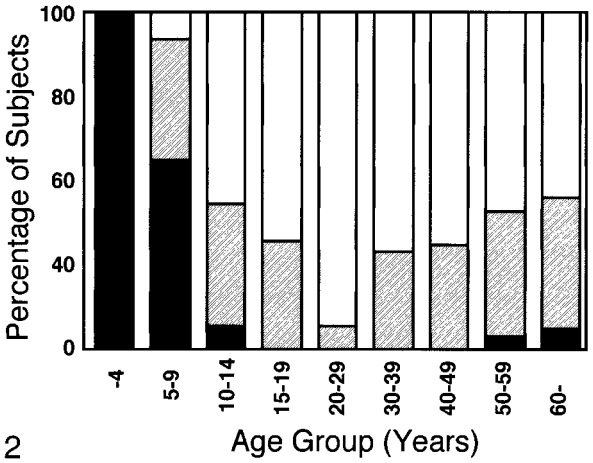


FIG 1. Age-related expansion in sphenoid aeration. Midsagittal reformatted images of 1.0-mm (*A–C*) or 1.5-mm (*D*) slice thickness obtained from helical CT data scanning with a collimation of 1 or 3 mm.

A, One-year-old boy shows no aeration of sphenoid bone.

B-D, Further expansions of sphenoid aeration to posterior and superior directions in a 5-year-old boy (*B*), 19-year-old man (*C*), and 29-year-old woman (*D*). Note closure of spheno-occipital suture in 19-year-old man (*C*).



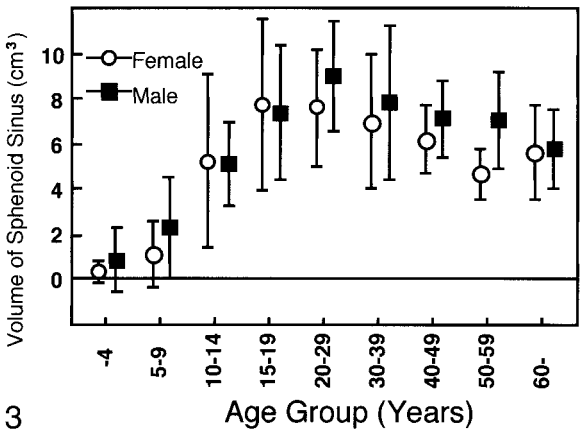


FIG 2. Aeration of sphenoid bone as evidenced by reformatted sagittal images. In this and subsequent figures, patient population was divided into first to seventh or older decades of life. Patients in first and second decades of life were further divided into two groups each. Each of the tandem bars in each age group represents percentage of subjects whose sphenoid aeration is classified into type I (*black bar*), II (*gray bar*), III (*hatched bar*), or IV (*white bar*). See Methods section for classification of sphenoid aeration.

FIG 3. Age-related changes in volume of sphenoid aeration in 76 female and 85 male patients. Data are expressed as means ± SDs.

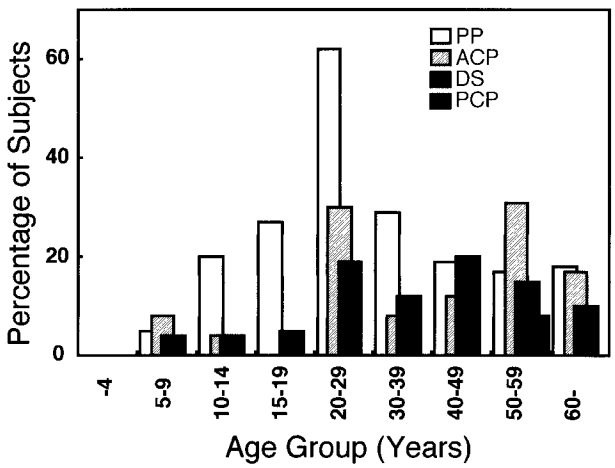


FIG 4. Degrees of aeration of peripheral portions of sphenoid bone. Each bar in each age group represents percentage of subjects whose peripheral portions of sphenoid bone are aerated. PP, pterygoid process; ACP, anterior clinoid process; DS, dorsum sella; PCP, posterior clinoid process.

Discussion

High-resolution helical CT scanning has enabled more detailed volumetric assessment of age-related changes in sphenoid aeration. Our study expanded upon the results of previous investigations to show that 1) aeration of the sphenoid bone begins at the anterior border of the bone as a doublet (Fig 1); 2) aeration did not begin in one half of the study population under 5 years old (Fig 2); 3) aeration was completed in 93% of the study population by the end of the third decade of life (Figs 2 and 3); 4) after the fourth decade of life, the volume of sphenoid aeration starts to decline and, in the seventh decade of life, the volume is two thirds of its maximum level (Figs 2 and 3); 5) aeration of the peripheral portion of the sphenoid bone, such as the pterygoid processes, anterior clinoid process, and dorsum sella, potentially occur after the closure of the spheno-occipital suture (Figs 1 and 4); 6) the bilateral compartments of sphenoid aeration were not fused; and 7) there is no gender-related difference in volume changes in the sphenoid aeration in any age group (Fig 3).

Conversion from red to yellow marrow occurs in the anterior portion of the sphenoid bone during childhood (1). At present, we have no clear explanation for the relationship between aeration and bone marrow conversion of the sphenoid sinus. Aoki et al hypothesized that aeration triggers the conversion of the sphenoid marrow (2). The marrow conversion, however, assessed by MR signal intensity changes from low to intermediate and eventually to high intensities on T1-weighted images, was evident before 1 year of age, when aeration of the sphenoid bone does not occur (3, 4). Furthermore, at least in long tubular bones and the mandible (5, 6), the conversion does not require preceding aeration. Therefore, undefined factors other than aeration might play an important role in conversion of the marrow. Alternatively, changes in the blood supply may be a major factor.

The present study has confirmed that aeration begins as a doublet on both sides of the anterior border of the sphenoid bone, and that the bilateral sinus compartments do not fuse with each other up to the latest stages of sinus development. Thus, the vertical sphenoidal septum persisted throughout the expansion and subsequent reduction in aeration. The image processing procedures for the isolation of sphenoid sinus air confirmed that the bilateral sphenoid sinus compartments do not fuse until the seventh decade of life, because the bilateral compartments were never imaged as a whole. Instead, they always appeared as fragmented parts of aeration. Therefore, sinus aeration on both sides seemed to manifest independently throughout de-

velopment and, at maturation, the volumes of bilateral aeration differed markedly in many cases.

The general consensus is that sphenoid aeration completes its maturation when an individual reaches 12 to 14 years of age (7–9). Nonetheless, we found that aeration continued to expand beyond the teenage years, and did not seem to be completed by the end of the third decade of life. Interestingly, subsequent to complete aeration, the volume of aerated sinus started to decrease, as evidenced by midsagittal CT images (Fig 2) and volumetric analysis (Fig 3). We cannot define the physiologic rationale of the observed changes in volume of sphenoid aeration in late stages of life. Similar changes were observed in maxillary sinus aeration (Y. Ariji and colleagues, unpublished data). Therefore, the event may not be limited to the sphenoid sinus, but may be observable in the other paranasal sinuses and mastoid air cells. Several possible explanations could be raised for the observed decreases with age in the size of the sphenoid aeration in older aged groups. These include loss of vessels supplying the sphenoid bones, with resultant hypoxia in the surrounding bone, and atrophic changes of the lining epithelium of the sinus, which may facilitate bone deposition on the surface of the sinus (10, 11).

Of the 214 patients examined, 25 sphenoid sinuses were associated with soft tissue in the sinus. We excluded these patients from the volume determination. These soft tissues may be extensions of infection from the ethmoid air cells or solitary inflammatory changes (12). Although all patients examined in the present study were symptom-free, associated or isolated diseases of the sphenoid sinus are commonly associated with headache and can cause severe complications such as optic nerve involvement after surgical intervention (12–14). CT examinations revealed that a substantial number of our patients (125 of 214 patients) presented with sclerosing osteitis in their temporal bones. None of these patients, however, exhibited an extension of sclerosis from the temporal bones to the sphenoid bones. Thus, these findings indicated that bone deposition arising from inflammation had not biased the results.

In conclusion, we have presented detailed developmental changes in the volume of sphenoid aeration, which begins as early as 1 year after birth and continues up to 80 years. Helical CT scanning was very informative for this assessment and extended previous findings to show that, after the completion of aeration in the third decade of life, the sphenoid sinus begins to recede from the maximum-volume levels of aeration. The use of axial CT scanning alone has been considered to be limited in screening for sinus diseases (15). In this context, reformatted images obtained by high-resolution helical CT scanning may be beneficial for screening before surgery in patients with sphenoid sinus diseases. The recognition of these changes is helpful for interpreting images and also for understanding the normal process of aeration in the sphenoid sinus.

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