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Three-dimensional volumetric analyses of temporal bone pneumatization from early childhood to early adulthood in a South African population

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Background: *A debate exists on whether the size of temporal bone pneumatization is a cause or consequence of otitis media (a global disease burden). However, a normal middle-ear mucosa is a prerequisite for normal temporal bone pneumatization. This study investigated the size of temporal bone pneumatization with age and the normal distribution of air cell volume in different stages of human growth postnatally.*

Materials and methods: *A three-dimensional computer-based volumetric-rendering technique was performed bilaterally on 248 head/brain and internal acoustic meatus computed tomography images of slice thickness ≤ 0.6 mm consisting of 133 males and 115 females with age range 0–35 years.*

Results: *The average volume of infant (0–2 years) pneumatization was 1920 mm^3 with an expected rapid increase to about 4510 mm^3 in childhood (6–9 years). The result also showed a significant increase ($p < 0.001$) in the volume of air cells up to the young adult stage I (19–25 years), followed by a significant decline in young adult stage II (26–35 years). However, the females were observed to experience an earlier increase than males. Also, population differences were observed as the Black South African population group showed a higher increase in volume with age than the White and Indian South African population groups, though the volumes of the latter increased up to young adult stage II.*

Conclusions: *This study concludes that the pneumatization of a healthy temporal bone is expected to continue a linear increase up until at least adult stage I. Termination of temporal bone pneumatization in an individual before this stage could signify pathologic involvement of the middle ear during childhood.* (Folia Morphol 2024; 83, 1: 146–156)

Keywords: pneumatization, temporal bone, air cells, three-dimensional

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INTRODUCTION

Since the interest of science in the temporal bone and ear dating back to 'Hippocrates' (460 B.C.), studies regarding the development of temporal bone pneumatization or the size of air cells with age remain minimal [1, 15, 45]. Embryologically, the temporal bone pneumatization or air cell system begins between the 22nd and 24th week of intrauterine life, as the mastoid antrum (the only visible cell) begins to develop during this period [15, 45]. During late foetal life or at birth, the mastoid antrum (the large central air cell) is fully developed, either pneumatized or filled with embryonic connective tissue [8, 15]. After birth, temporal bone air cells become readily visible as hollowed-out spaces lined by flattened, non-ciliated squamous epithelium [27, 38, 40]. As postnatal development and growth continue, these air cells exhibit variability in size and extent, communicating with the middle ear via the mastoid antrum and the aditus ad antrum and extending variably to the petrous apex and around the inner ear [24, 39, 45]. However, a gradual reduction in air cells is expected throughout life as the individual continues growing older [48].

Although the prevalence of minimal pneumatization of temporal bones in connection with chronic inflammatory middle-ear disease is well known, controversy about the relationship between temporal bone pneumatization and chronic middle-ear disease still exists [12, 25, 42]. A common infection to the middle ear is otitis media (OM) which still exists as one of the global burdens of diseases and a predisposing factor to hearing loss with increasing prevalence in sub-Saharan Africa with South Africa inclusive [11, 31, 41, 46]. More so, studies in South Africa revealed an 8.2% prevalence rate of OM among children [9, 13, 32]. Recent studies have shown an increased incidence rate of OM among younger and older children, with 31.4% and 16.7% prevalence, respectively [6, 34]. It was also recorded as the major significant risk factor for the high prevalence of hearing loss (up to 19.88%) [20, 28].

Much as genetically determined hypo-cellularity predisposes to acute and chronic otitis, the concrete fact remains that a normal middle-ear mucosa is a prerequisite for normal pneumatization, which may be hampered throughout childhood by inflammation, infection, and poor tubal function [12, 25, 42]. Another substantiated fact is that the onset of middle--ear infection such as OM has been linked to the development of the temporal bone pneumatization and air cell system, which in turn tends to affect the size of the air cells with age [3, 25]. Evidence has demonstrated that a temporal bone pneumatization with larger air cells tends to improve functional results after surgery (e.g. *mastoidectomy*) than one with smaller air cells [25, 30]. Among major theories, the hereditary theory explains the factors determining an individual pneumatization. However, the normal size of air cells and growth rate within a population should not be disregarded since there is an established link between OM and the size of pneumatization. On this account, there is a paucity of information on the normal size of the air cells and growth rate concerning a particular population, especially in sub-Saharan Africa and South Africa.

Several reports have utilized different techniques to measure the size of the temporal bone or mastoid pneumatization quantitatively. These techniques include the water-weight, acoustic and pressurized transducer [2, 30]. Following the development of radiological tools, more accurate and easier methods have been developed and mostly employed in measuring the size of temporal bone pneumatization in area or volume.

Various studies have been identified to utilize different radiological tools in evaluating the size of temporal bone pneumatization with age [4, 7, 12, 15, 18, 21, 27, 35, 37]. These studies, however, have revealed changes in the size of air cells with age and discrepancies in growth rates. These reported discrepancies may be due to different methods or techniques used and the differences in age, sex, and population groups of the study populations, with the highest growth rate reported to be around the third decade of life among the Korean population [27] and age-related changes (beginning from infants; 0–2 years) in the bony organization of pneumatized spaces in various regions of the temporal bone reported in Missouri, Columbia [15].

Although both areas (2D sizes) and volumes (3D sizes) were used to measure the size of air cells in these studies, volumetric analysis, which likely gives the foremost comprehensive insight to appreciate the air cells estimate, was limited to 3 studies [15, 18, 27]. In addition, the slice thickness of computed tomography (CT) images used in those studies ranges between 1 mm to 2.5 mm. Precision in quantifying air cells requires very thin slices of about 0.6 mm and below, which brings about the limitations of these studies.

Table 1. Distribution of patients according to age groupings, sex and population groups

Age groupings [years]	Overall (n = 248)			Black South African (n = 202)			Indian South African (n = 28)			White South African (n = 18)		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
0–2	12	10	22	10	8	18	1	1	2	1	1	2
3–5	11	13	24	8	12	20	2	0	2	1	1	2
6–9	22	15	37	18	12	30	1	3	4	2	1	3
10–14	39	14	53	34	12	46	3	1	4	2	1	3
15–18	10	16	26	9	13	22	1	1	2	0	2	2
19–25	14	22	36	11	19	30	1	2	3	2	1	3
26–35	25	25	50	16	20	36	7	4	11	2	1	3

The present study focuses on the CT images of slice thickness ≤ 0.6 mm for precision in volumetric quantification of air cells utilizing a 3D computer-based volume rendering technique arriving at a more accurate volume as possible to achieve a normal distribution of air cells with age as well as the growth rate in other to ascertain the development of temporal bone pneumatization from early childhood to adulthood. In addition, this study also considered sex, laterality, and population groupings.

MATERIALS AND METHODS

Study design and population

Following ethical approval obtained from the University of KwaZulu-Natal Biomedical Research Ethics Committee (Protocol Ref. No.: BREC/00002263/2020) and ethical clearance obtained from the National Health Research Committee of the Kwazulu-Natal Department of Health (NHRD Ref.: KZ_202102_026), 248 head and neck/ /brain and internal acoustic meatus (IAM) CT images of South African patients (133 males, 115 females) from the radiology departments of public hospitals in Durban and Pietermaritzburg, Kwazulu-Natal, South Africa were retrospectively retrieved, reviewed and analysed bilaterally (giving a total of 496) from January 2011 to August 2021. These CT scans were selected because they meet the inclusion criteria, which are as follows; a) scans of patients between the age range 0–35 years; b) high-resolution multidetector CT images acquired with ≤ 0.6 mm collimation; c) images without observable signs of abnormal pathological processes in the temporal bone or compatible with chronic otitis and/or mastoiditis on CT; d) images of patients with no history of middle ear infection such as OM and any other pathology (by reviewing patients' medical history), and e) absence of bony destruction, fluid, or mass in any of the temporal bone air spaces.

The age range of 0 to 35 years was further conveniently subdivided into seven levels: 0–2 (infant); 3–5 (young child); 6–9 (middle child); 10–14 (early adolescent); 15–18 (middle adolescent); 19–25 (young adult stage I); 26–35 (young adult stage II). Age categorization was similar to that reported by Hill [15]: according to age-related changes in the bony organization of pneumatized spaces in various regions of the temporal bone. The distribution of patients in the age categorization used for this study is presented in Table 1.

The South African population groups included in this study were as follows; Black South African (202; 81.4%), Indian South African (28; 11.3%), and White South Africans (18; 7.3%) (Table 1). (Note: Generally, of the South African population, Black South Africans make up about 79.8%, White South Africans make up about 8.7%, while Asian/Indians make up about 2.5%) [22, 26].

Imaging protocol

The head and neck, and IAM CT images were taken using a multi-detector row computed tomography (MDCT) scanner (GE Revolution Evo 64 slice, 128 configuration, Milwaukee, Wisconsin, USA). The axial view was reconstructed parallel to the orbito-meatal line using a slice thickness of 0.625 mm, detector coverage of 20 mm, and a PITCH of 0.5. The scan was performed using 140 kV and modulated mAs ranging between 280–400 mA with 30% dose reduction and ASIR-V application in a bony algorithm with a window width of > 3000 hU and a window centre of 500 hU.

Calculation of 3D volume of air cells of the temporal bone

Continuous non-overlapping temporal bone CT scans with acquisition parameters of ≤ 0.6 mm slice thickness, 140 kV, and modulated mAs ranging between 280–400 mA were used for this study. The DICOM images stored in the PACS of these hospitals were transferred to a Workstation running IntelliSpace Portal (ISP) Version 11.1 (Philips Image and Information Management software, Nederland).

With a surface rendering algorithm of lowest limit window level of –1,024 hU and uppermost limit window level of –318 hU, the clip and 3D segmentation process were used to achieve 3D reconstruction and the volume of air cells of each temporal bone. The axial image was double-clicked in other to be enlarged. Next, 3D models were created using a smart segmentation process. The IntelliSpace Portal (ISP) Version 11.1 then provided a calculator that automatically calculates the volume of each 3D reconstructed temporal bone pneumatization from the mastoid process to the petrous apex, including the middle ear (Fig. 1).

Inter-observer reliability testing

The accuracy and repeatability of the volume calculation were determined by using 50 randomly selected temporal bone CT scans independently by two authors, and a third observer (Specialist Radiologist) verified the volumetric calculation for inter-observer reliability.

Statistical analysis

The statistical data analysis was conducted in R Statistical computing software of the R Core Team, 2020, version 3.6.3, and presented in the form of descriptive and inferential statistics. The continuous variables were non-normal and were presented in median (interquartile ranges). The median differences were assessed using Wilcoxon for two groups. The median differences across at least three categorical variable levels (in the case of population group) were assessed with the aid of Kruskal-Wallis. In the case of significant median difference, post-hoc tests were conducted using the Dunn test. All the inferential statistical analysis tests were conducted at 5% significance levels.

RESULTS

Data from 496 HRCT temporal bones (right and left side) of 248 patients' scans were presented as the median and interquartile range (IQR). The intraclass correlation was 89% for volumetric calculation for inter-observer reliability testing.

Average volume (mm^3) of temporal bone pneumatization according to laterality, sex, and population group

The average volume of temporal bone pneumatization in this study population was 8300 mm^3 (interquartile range of 4100–12200 mm^3). The result presented in Table 2 showed no significant difference in the average volume of temporal bone pneumatization as regards laterality ($p = 0.719$), sex ($p = 0.363$), and population group ($p = 0.416$) using Ranksum and Kruskal-Wallis tests.

The volume of temporal bone pneumatization with age

From early childhood to adulthood, the average volumes of temporal bone pneumatization of infants (0–2 years), children (3–9 years), adolescents (10–18 years), and adults (19–35 years) were 1920 mm^3, 6005 mm^3, 11750 mm^3, and 11550 mm^3, respectively. In general, the Kruskal-Wallis test showed a significant difference ($p < 0.001$) in the volume of temporal bone pneumatization between age groups (Table 3), with a linear and rapid increase at an average of 2400 mm^3 between age groups up to 19–25 years followed by a decrease (Fig. 2). However, the volume of temporal bone pneumatization was higher on the right side, as shown in Figure 2.

The volume of temporal bone pneumatization with age concerning sex

The Kruskal-Wallis test showed a significant difference ($p < 0.001$) in the volume of temporal bone pneumatization with age groups in males and females. In the distribution of the volume of air cells with age, a decrease in pneumatization was also observed after the age group 19–25 years, but the females showed a more rapid increase in pneumatization of the temporal bone earlier (6–9 years) than males (Table 4). However, pneumatization in males was observed to follow a rapid linear growth between the age groups 10–14 years and 19–25 years (Fig. 3).

The volume of temporal bone pneumatization with age concerning population groups

The Kruskal-Wallis test showed a significant difference ($p < 0.001$) in the volume of temporal bone

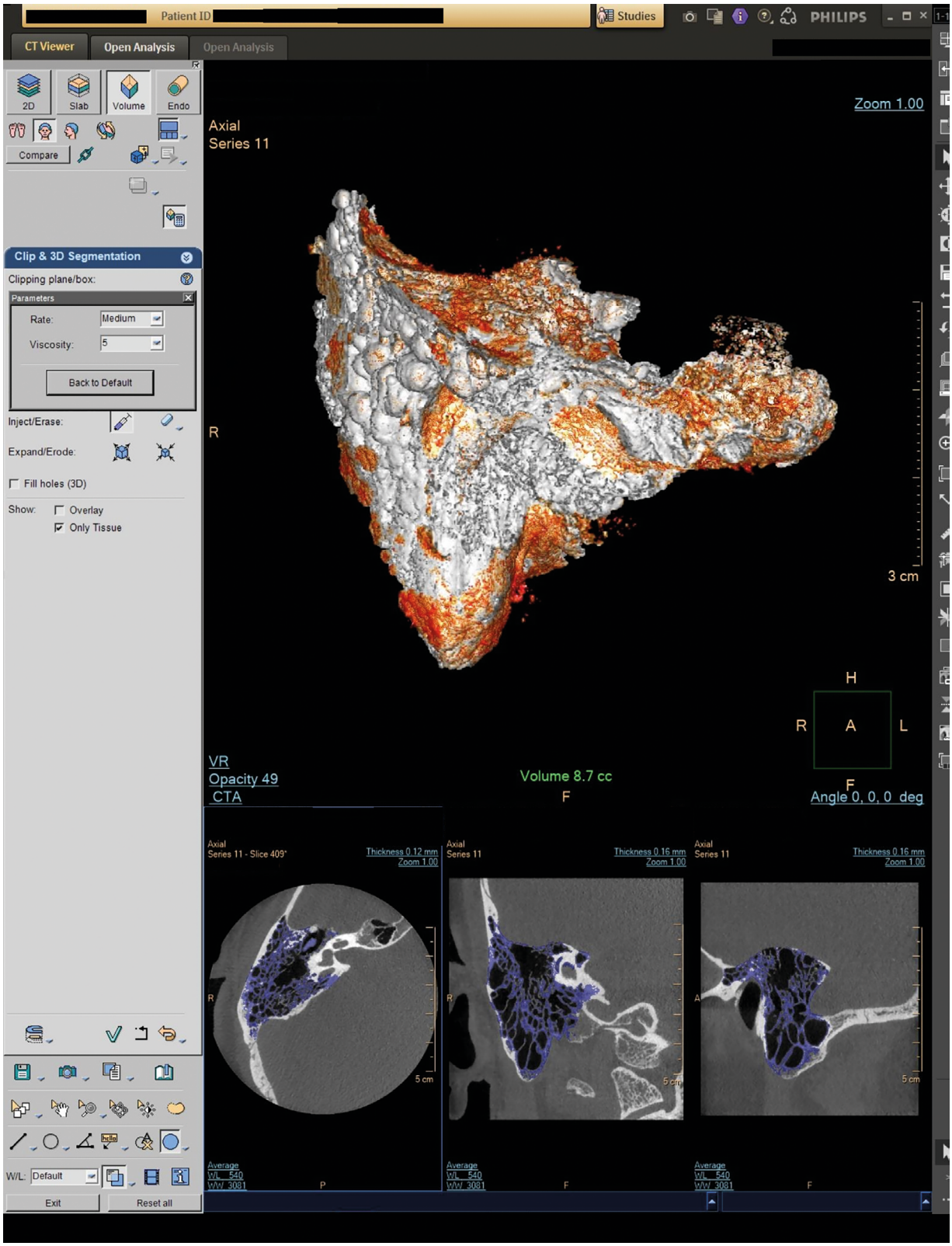

Figure 1. Three-dimensional using computer-based volume rendering reconstruction technique. Pneumatization of the right temporal bone composing the middle ear, petrous, and mastoid air cells with a volume of 8.7 cc (cubic centimetre) (Conversion to cubic millimetres = 8700 mm^3).

Table 2. Average volume (mm^3) of temporal bone pneumatization according to laterality, sex, and population group

Laterality			Sex			Population group			
Left Median (IQR)	Right Median (IQR)	L vs. R	Male Median (IQR)	Female Median (IQR)	M vs. F	SA Black Median (IQR)	Indian Median (IQR)	White Median (IQR)	B vs. I vs. W
7830 mm^3 (3860–12200)	8500 mm^3 (4210–12200)	P = 0.719	8510 mm^3 (4340–12100)	8900 mm^3 (4550–12700)	P = 0.363	7580 mm^3 (4010–12200)	9400 mm^3 (4400–10800)	9900 mm^3 (3060–10900)	P = 0.416

L — left; R — right; M — male; F— female; SA — South African; B — black; I — Indian; W — white; IQR — interquartile range

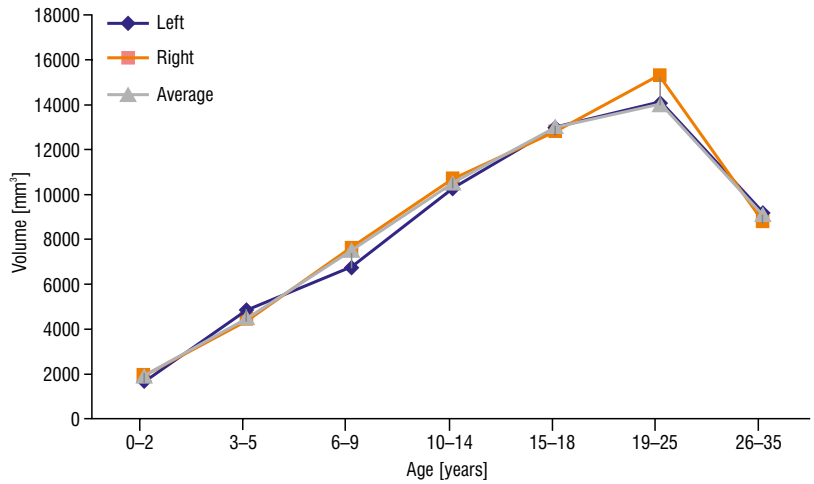

Figure 2. Distribution of volumes of temporal bone pneumatization of left and right sides according to human stages of development.

Table 3. Median volumes (mm^3) and interquartile range of temporal bone pneumatization according to age groups of human stages of development (overall and laterality)

Laterality	Age groups [years]							P-value
	0–2 (n = 22)	3–5 (n = 24)	6–9 (n = 37)	10–14 (n = 53)	15–18 (n = 26)	19–25 (n = 36)	26–35 (n = 50)	
Left [mm^3] Median (IQR)	1680 (1510–2910)	4880 (4990–9190)	6750 (4990–9190)	10300 (7000–11800)	13000 (9360–18600)	14100 (8230–14500)	9840 (3810–14500)	< 0.001*
Right [mm^3] Median (IQR)	1950 (1450–2400)	4330 (3910–5450)	7600 (5300–8790)	10700 (7090–12400)	12800 (8120–15000)	15300 (11100––18900)	8800 (4750–12400)	< 0.001*
Both sides [mm^3] (average) Median (IQR)	1920 (1450–2450)	4510 (4010–5450)	7500 (5080–8840)	10500 (6950–12100)	13000 (9420–18900)	14000 (7970–15000)	9100 (4240––113900)	< 0.001*

IQR — interquartile range

pneumatization with age groups among the Black South African population. Still, it showed no significant difference in the volume of temporal bone pneumatization with age groups among the Indians and Whites with p = 0.053 and p = 0.058, respectively (Table 5). In the distribution of the volume of air cells with age, a rapid linear increase in the volume of air cells was observed among South African Blacks from 0–2 years up to 19–25 years, afterward a decline. However, a slow increase in air cell volume was observed in the Indian and White population from 3–5 years, continuing up to 26–35 years (Fig. 4).

DISCUSSION

The interest in the size of temporal bone pneumatization and its importance arose from the association between mastoid air cells and OM either as a cause or a consequence. Concerning human development

Table 4. Median volume (mm^3) and interquartile range of temporal bone pneumatization of males and females according to age groups of human stages of development

Male								
Age range [years]	0–2 (n = 12)	3–5 (n = 11)	6–9 (n = 22)	10–14 (n = 39)	15–18 (n = 10)	19–25 (n = 14)	26–35 (n = 25)	P-value
Volume [mm^3] Median (IQR)	1940 (1410–2480)	4320 (3550–4880)	5570 (3920–8300)	10600 (6930–12000)	13600 (10800–14100)	16700 (8830–20800)	9700 (5800–16100)	< 0.001*
Female								
Age range [years]	0–2 (n = 10)	3–5 (n = 13)	(6–9 (n = 15)	10–14 (n = 14)	15–18 (n = 16)	19–25 (n = 22)	26–35 (n = 25)	P-value
Volume [mm^3] Median (IQR)	1920 (1510–2450)	5230 (4170–5800)	8100 (6650–9880)	11500 (7300–12500)	13000 (10900–17100)	15000 (7900–15100)	9100 (3880–12300)	< 0.001*

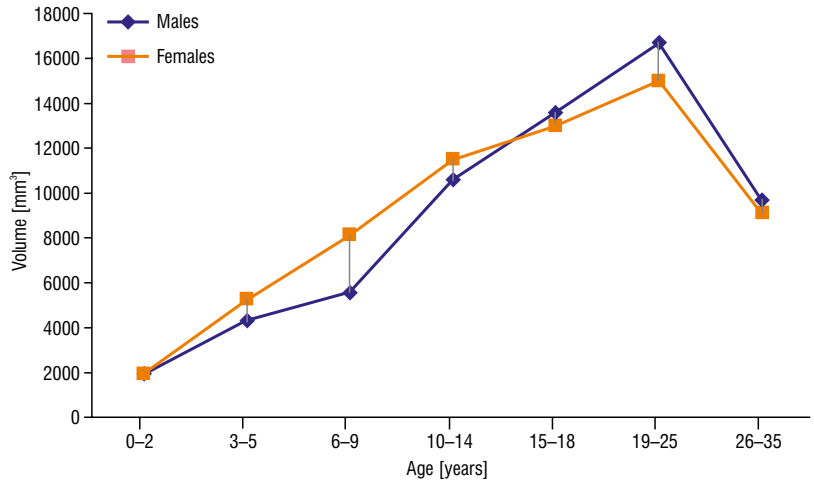

Figure 3. Distribution of volumes of temporal bone pneumatization of males and females according to human stages of development.

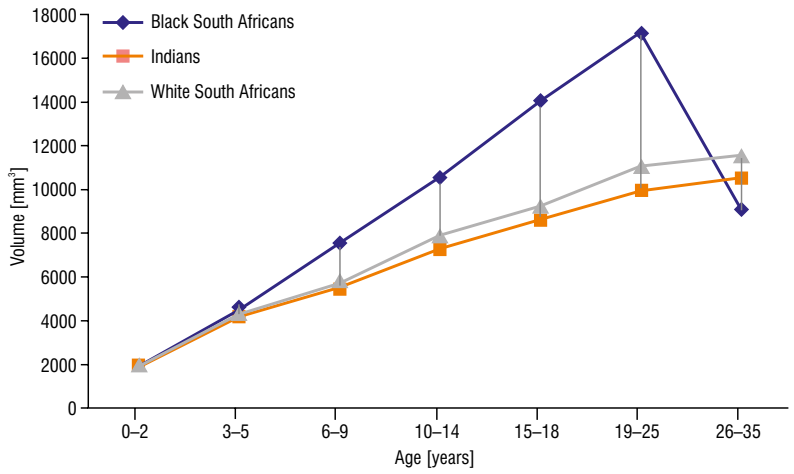

Figure 4. Distribution of volumes of temporal bone pneumatization of Black South Africans, South African Indians, and White South Africans according to human stages of growth.

and growth, Virapongse et al. [45] described changes in the size of temporal bone pneumatization to occur in three stages: "the infantile stage — occurring from birth to two years of age (air cells begin to appear and are readily visible by two years); transitional stage — from two to five years (squamomastoid/mastoid

Table 5. Population group distribution median volume (mm^3) and interquartile range of temporal bone pneumatization according to age groups of human stages of growth

Black South African								
Age range [years]	0–2 (n = 18)	3–5 (n = 20)	6–9 (n = 30)	10–14 (n = 46)	15–18 (n = 22)	19–25 (n = 30)	26–35 (n = 36)	P-value
Volume [mm^3] Median (IQR)	1920 (1450–2450)	4470 (4010–5450)	7500 (5140–8790)	10500 (7010–15000)	14000 (7970–15000)	17100 (9200–19300)	9100 (4130–13700)	< 0.001*
Indian South African								
Age range [years]	0–2 (n = 2)	3–5 (n = 2)	6–9 (n = 4)	10–14 (n = 4)	15–18 (n = 2)	19–25 (n = 3)	26–35 (n = 11)	P-value
Volume [mm^3] Median (IQR)	1920 (1510–2450)	4210 (3100–4400)	5510 (5510–5510)	7270 (5860–9360)	8600 (7100–10200)	9900 (7680–10400)	10500 (8900–11800)	0.053
White South African								
Age range [years]	0–2 (n = 2)	3–5 (n = 2)	6–9 (n = 3)	10–14 (n = 3)	15–18 (n = 2)	19–25 (n = 3)	26–35 (n = 3)	P-value
Volume [mm^3] Median (IQR)	1950 (1510–2480)	4300 (3500–4850)	5700 (4250–5900)	7900 (5910–9600)	9200 (7200–10900)	11000 (7550–11500)	11500 (7840–11500)	0.053

undergoes gradual enlargement with the migration of air cells toward the periphery); and adult stage — age 6 and above (attainment of this stage result in cessation of pneumatization)". Cinamon [10] also supported this description and further identified that air cells continue to increase in size until puberty, while Aladeyelu et al. [1] identified a continuous increase in the size of air cells beyond puberty.

Two theories on pneumatization have been hypothesized: the first is that the size of air cells in temporal bone pneumatization is genetically determined [12]; while the second is that the size of air cells in temporal bone pneumatization is determined by the degree of pathologic involvement of the middle ear during childhood [14, 33, 44]. The second hypothesis validated this study as the degree of pathologic involvement during life may influence the size of mastoid pneumatization with age. Although considering the first theory, there may be a few limitations resulting from interindividual variation. However, to overcome these limitations, a longitudinal study needs to be employed, which would be a dilemma and seem impossible in practice as it would involve tracking all subjects daily for scanning and measurement and could take an entire career of these subjects to measure the size of their air cells. Hence, the second hypothesis appears to be widely used and generally accepted [4, 7, 15, 18, 21, 27, 35, 37, 43].

This study utilized a 3D computer-based volumetric-rendering technique on head/brain and inner ear CT images of slice thicknesses of ≤ 0.6 mm. The average volumes of infants, children, adolescents, and adults' temporal bone pneumatization obtained in this study were quite higher than the previous reports [15, 17–19, 23, 25, 27, 29]. This discrepancy may be due to technical characteristics (e.g. 0.6 mm slice thickness which gives more detailed volumetric information) or population differences. It may also be due to the cranial size and shape of the study population. Hence, the average air cell volumetric size of temporal bone pneumatization in a South African population is higher than in other age-related studies reported in Japanese, Korean, and Colombian populations [15, 18, 27]. The temporal bone pneumatization with average volumes of 1920 mm^3 in paediatrics and 4510 mm^3 in young children indicates that pneumatization of the temporal bone is expected to follow a rapid growth during childhood development. This finding agrees with previous studies, which reported that air cells are readily visible after birth and immediately begin to increase in size and extent [24, 40].

In this study, various developmental stages were subdivided into the infant, young child, middle child, early adolescents, middle adolescents, young adult stage I, and young adult stage II to reflect human postnatal growth stages and understand the possible age when pneumatization ceases. An evident increase in the volume of temporal bone pneumatization relative with age until young adult stage I and reduction in the volume of air cells as well as cessation in pneumatization in young adult stage II observed in this study concurs with the previous study that linked aging-related changes to reduction in air cells [48]. In contrast, this finding contradicts the previous reports

about pneumatization terminating at puberty though these reports utilized planimetric measurements and were only to give information on the area of air cells, not volume [4, 12, 35].

Notably, a significant increase in pneumatization volumes in different age groups in relation to sex was observed in this study. But the females showed a much earlier rapid increase in the volume of temporal bone pneumatization before the onset of puberty (6–9 years) which is similar to the report of Diamant [12] that utilized surface area and Hill [15] that utilized both 2D and 3D methods. This may, however, be linked to early puberty in females [10]. However, the males were observed to have a larger pneumatization at late puberty up to the young adult stage I, which is similar to the previous study by Chatterjee et al. [7] that utilized 2D planimetric measurements of temporal bone pneumatization. This implies that the development of temporal bone pneumatization tends to be more rapid in adolescent females, with the females first attaining adult size before adolescent males.

Furthermore, differences were also observed among population groups within the study population. The present study considered three groups: Black South Africans (indigenous African origin or Native group), White South Africans (European descent), and Indians (Asian descent). Although the paediatric volume was about the same size with a rapid increase in volume during childhood development, the volume of temporal bone pneumatization was observed to increase significantly with age showing a rapid linear growth up to the young adult stage I among the Black South Africans. The significant increase in the volume of pneumatization observed from the young child to young adult stage I conforms with the increase in the volume of paranasal air sinus in the same stages of postnatal growth in a South African population as reported by Rennie et al. [36]. Kim et al. [23] also identified a correlation between pneumatization of mastoid air cells and paranasal air sinus.

However, among the South African White and Indians, the volume of temporal bone pneumatization follows a rapid increase from infant up to the young child (3–5 years), followed by a slow increase up to the young adult stage I; thereafter, a plateau with no significant difference. This could be attributed to the small skull sizes, especially among Indians, because the skull size influences the pneumatization of the temporal bone [5, 7, 16]. In addition, the early study of Arora et al. [4] also identified this attribute while working with the population in the Northern part of the Indian subcontinent and found the size of the temporal bone air cell system to have a value much less than that of the Swedish population in the study of Diamant [12] and assumed that it could be due to the smaller sized cranial bones of Indians. Although, there were no significant differences in the volume of temporal bone pneumatization within age groups among Indians and White. However, the continuous increase in the pneumatization among these two population groups up to young adult stage II conforms with the previous study among the Korean population of Asian descent [27].

Although the two hypothesized theories of pneumatization (genetic and environmental) have described the relationship between temporal bone pneumatization and middle-ear diseases to be "a chicken and egg" tale [14, 44], a small pneumatization of the temporal bone could possibly permit normal ventilation of the ear. However, a small mastoid system predisposes to acute and chronic OM. Consequently, the degree of pathologic involvement of the middle ear during childhood, such as acute and chronic OM, is well known to be a determinant factor in temporal bone pneumatization. The present study has been able to analyse healthy temporal bones in order to know the expected size of normal temporal bone pneumatization at every stage of human growth, ascertaining its growth rate and completion stage in adult life. This study also utilized a method with high accuracy and hope that it will contribute to establishing general references of what is expected to be the size of temporal bone volume and size as regards to age and development, which could help give an understanding of the history of the middle-ear of any patient, most especially during childhood.

CONCLUSIONS

This study investigated the size of temporal bone pneumatization from early childhood to adulthood utilizing a 3D computer-based volumetric rendering technique of normal CT images of slice thickness of ≤ 0.6 mm. A rapid increase in the size of pneumatization was observed during childhood development, with females showing a more rapid increase. In addition, the volume of air cells was observed to increase at an average of 2400 mm^3 at every stage of human postnatal growth, with a higher volume of the right temporal bone up to the young adult stage I before

experiencing a decline. Population group differences were also observed in the distribution of air cells as the volume of temporal bone pneumatization of other population groups aside from Black South Africans increased up to adult stage II. The study concludes that the pneumatization of a healthy temporal bone is expected to continue linear increase up until at least adult stage I (19–25 years). This study hopes that its findings will contribute significantly to achieving a unanimous age landmark expected for the temporal bone pneumatization to be complete among otolaryngologists. Furthermore, it could also be useful in anatomical and forensic sciences for predicting age by evaluating the volume of temporal bone air cells of skulls.

Ethical approval

The design was approved by the Institutional Review Board/Ethics Committee (Biomedical Research Ethics Committee of the University of KwaZulu-Natal with Ref. No.: BREC/00002263/2020) and the National Health Research Committee of the Kwazulu-Natal Department of Health (NHRD Ref.: KZ_202102_026).

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