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Morphometric variants of the paranasal sinuses in a Mexican population: expected changes according to age and gender

N.G. Jasso-Ramirez et al., Variants of the paranasal sinuses

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ABSTRACT

Background: There are developmental variations in the paranasal sinuses. Our objective is to determine their dimensions and volume stratified by age and sex and define the expected growth pattern.

Materials and methods: A retrospective, observational study was performed including computed tomography (CT) of patients between 1 and 20 years of age. The volumes of the frontal, sphenoid, and maxillary sinuses were obtained.

Results: A total of 210 CT were included with a mean age of 10±6.1 years, 106(50.5%) were female. Groups were categorized in ranges of 5 years. Spearman correlation coefficients between the right and left sides were 0.843, 0.711, 0.916 for the frontal, sphenoid and maxillary sinuses. Post-hoc for the categorical age groups demonstrated statistically significant differences with values of $p < 0.01$, except between age groups 11-15 against ≥ 16 years of age ($p = 0.8$). Gender-related differences were evident with a higher air volume in girls in the 5-10-year-old group, while boys predominated in the rest of the groups.

Conclusions: CT is ideal for pre-surgical sinus assessment. The maximum volume of paranasal sinuses is reached at age 15. There is a clear volumetric difference between age and gender groups. There is a direct relationship between a volume and its contralateral counterpart.

Key words: paranasal sinuses, pediatrics, morphology, age groups, gender

INTRODUCTION

The paranasal sinuses (PNS) are hollow cavities lodged inside the facial bones. The size of the sinuses is variable and depends particularly on the age and gender of the individual (28). Their function is controversial (18). Most believe the PNS support respiratory function and resonance, however, because they constitute the largest viscerocranial cavity, the air space it occupies is the most important anatomical feature (17,19).

Sadler reports the frontal sinus does not develop before age 3, but reaches its maximum development between ages 4-8 years and continues its growth until 14-16 years (29). The ethmoidal sinus has a faster development in the anterior ethmoid region and a complete development around 12 years of age with increased convexity of its lateral and middle walls in the last phases (34). The sphenoid sinus begins to be pneumatized around age 2, progresses anterior-posteriorly around age 5, and completes its development at age 15 in half of the cases, with the other half continuing until age 30 (43). The maxillary sinus initially grows in a transverse pattern (>2 years of age) and then vertically (0-2 years and 7-10 years) reaching the level of the nasal passages, the nasolacrimal duct, and the zygomatic recess at age 12 (33,43). All sinuses are usually asymmetrical to their contralateral pair (29).

Knowledge of the variations in the development of the PNS is a clinically relevant issue (37). Genetic diseases, environmental conditions, and infections can affect its structure and variations (6,10,35,40). Understanding age-related changes in their dimensions and volume can aid in radiographs and CT assessment for the identification of pathology (20,21,35). Examples include hypoplasia (incomplete development) and sinus atelectasis (known as silent sinus syndrome, which is a rare finding in general but found in the majority of patients with orbital floor fracture (38), usually seen on CT as an opacified sinus with retraction of its walls towards light and associated loss of volume (31). For these instances, it is helpful to have normal range values and clinical morphometric parameters in the diagnostic approach of pathologies such as sinusitis or sinus dysmorphism (3). Morphometric parameters are also important in the preoperative evaluation for functional endoscopic sinus surgery (FESS) as this procedure can jeopardize the anatomical variations of vital structures adjacent to the sinuses (3,27).

Currently, nasosinusal endoscopic surgery has become the surgical procedure of choice to resolve chronic and recurrent nasosinusal inflammatory pathologies that do not respond to medical treatment. These minimally invasive techniques allow clear visualization of the sinuses and successful surgical treatment (11,12,42).

Previous studies have calculated PNS volume using dry skulls (1), cadaveric specimens (39), CT images (32,44), and magnetic resonance imaging (MRI) (21). The use of CT scan instead of simple radiography for PNS evaluation was introduced by Zinreich SJ et. al in 1987 (44).

Due to the craniofacial variations between populations, our objective is to establish morphometric parameters stratified by age and gender in our population as a guide for endoscopic surgery and a reference for a specific pathology approach.

MATERIALS AND METHODS

A retrospective, descriptive, observational, and cross-sectional study was performed. PNS morphometrics were obtained from CTs of patients between 0 and 20 years of age, from the database of the Radiology and Imaging Department of the University Hospital. Exclusion criteria included those patients with injury or pathology of the PNS or a history of PNS surgery. CTs with poor technical quality were eliminated.

The images were acquired using a helical tomography (Light Speed Plus CT, GE Medical Systems) with collimation of 0.625 mm, a table speed of 15.0 mm per second, a cutting interval of 1.25 mm parallel to the temporal bone with 50 mA and 120 kV and a 512 x 512 matrix. Volume operations were performed with multiplanar reformatting using Centricity Universal Viewer. The studies were assessed separately by two expert head and neck radiologists.

Bilateral measurements were made for frontal, sphenoid, and maxillary sinuses' volume (Figures 1, Figure 2, Figure 3). Data were registered in a database and stratified by age, gender, and laterality. Age groups were categorized in ranges of 5 years of age. Patients less than one-year-old were included quantifiable as 0 years.

Statistical analysis

The database was analyzed using the SPSS statistical package version 20 program (IBM, Armonk, NY, USA), for Windows 7. Normality tests were applied with Kolmogorov-Smirnoff and for each of the groups, the mean±standard deviation for each measurement parameter was determined independently. The Mann-Whitney U test was used to determine the significance of the differences between men and women for each morphometric parameter. Kruskal-Wallis tests were performed to compare the results of each measurement parameter for the different age groups, interpreting a value of $p \leq 0.05$ as significant. The results are presented in tables 1 and 2.

Ethical considerations

The study was previously reviewed and approved by the University's Ethics and Research Committees, receiving the registration number AH16-00005, making sure it adheres to the Helsinki declaration and national and international standards of research. The authors declare no financial or commercial gain for the realization of this study. Also, the authors declare no conflict of interest. None of the imaging studies were performed for the purposes of this study.

RESULTS

A total of 210 axial head and neck CT scans were included, with similar distribution in gender (104 [49.5%] male, 106 [50.5%] female). The mean age was 10 ± 6.06 years.

The mean volumes and lengths stratified by gender are reported in Table 1 and by age in Table 2. In the post-hoc analysis for non-parametric tests for categorical age groups, all groups were statistically significant with values of $p <0.01$, with the exception of the group aged 11 to 15 years with the group over 16 years of age. Significance among the volume means groups having a value of $p > 0.8$ in all the variables compared between the groups.

DISCUSSION

There has been a continued interest in the sinuses and nasal passages to correlate with the ideal approach for paranasal sinus surgery and surgical approach of associated structures. Computed tomographies are considered the gold standard for the evaluation of PNS due to the invasiveness of an endoscopic approach and its possible complications such as infection, bleeding, perforation, among others (15).

Although a higher time consumption was involved, for this study, manual segmentation was used to create 3D models based on the aerial reconstruction of the PNS, to better identify and delimit each structure. This allows non-invasive visualization, simulation, and precise quantitative measurements of internal body structures. The PNS volumes are the most important index due to the large differences shown between the individuals (15).

Several authors (Table 3) have categorized their population using different age groups. Karakas et al.,(16) divided their population into five-year age groups (total 5 groups) starting at the age of 5 years. Wolf et al.,(43) evaluated the development of the sinuses in 102 cadaverous specimens and divided them into 4 age groups: newborn, 1 to 4 years old, 4 to 8 years old, and 8 to 12 years old. In this study ventrodorsal, cephalocaudal, and mediolateral length measurements were performed, however without differentiating between genders. The group of newborns showed anterior and posterior ethmoid cells almost completely developed in number and a spherical or pyramidal shape for the maxillary sinus. Lorkiewicz-Muszyńska et al., (21) studied their population individually by age and also reported the maxillary sinus was present at birth. They observed the ethmoidal and maxillary region expanding rapidly in the first few years, and similar to our results, they identified frontal and sphenoid sinuses pneumatization. Sadler described, frontal sinuses are always absent at birth, but evident in boys by age 2, and until age 4 in girls (29).

Most studies focus on the maxillary sinuses, lacking data on the sphenoid and frontal sinuses. The sphenoid sinus is considered the most variable cavity in the human body and is of great relevance for optimal surgical access to the pituitary gland (36). In addition, its' pneumatization may provide access to other parts of the skull base (41). We report it present at birth, with a continued volume growth throughout all age groups. The degree and direction of pneumatization play a crucial role in the planning of surgical procedures.

According to Wolf et al.,(43) at 8 years, pneumatization has progressed considerably and the nasal cavity and sinuses have almost completed their development and reached adult proportions. Karakas et al., (16) reported the volume increased in both sexes up until age 25, then progressively decreased thereafter.

In the maxillary sinuses, we report maximum volumes reached at age of 16-20, similar to that reported by Jun et al.,(14) and Lorkiewicz-Muszyńska et al.(21). Like the maxilla, the frontal sinus has also taken a tetrahedral shape and the sphenoid sinus has reached its permanent size, but its shape is still developing. We determine the greatest change in volume was between ages 11 and 15, a contrast to the results of Ariji et al., (2) who reported PNS volumes continued increasing until age 20 and then decreased. Similarly, Karakas et al., (16) found the highest means for PNS volumes in the 21 to 25 year age group in men, and in the 16 to 20 year age group for the maxillary sinuses of women. Masri et al., (23) evaluated maxillary sinus and reported sizes and volume increased from birth until 30 years of age; men also exhibited larger maxillary sinus volume than women in 7-12 ($p<0.01$) and 21-30 ($p<0.01$) age groups. Size sexual dimorphism was evident in most age groups for the maxillary sinus.

Emirzeglou et al.(9) reported the PNS is typically larger in men than in women. Cohen et al., (5) also demonstrated larger sinus volumes for men. The means for adult PNS were 12.75cc, 4.00cc, and 2.92cc for the maxillary, sphenoid and frontal sinuses respectively. These compare much smaller than our mean in a pediatric population with 27.57cc, 8.79cc, and 7.46cc respectively for the same PNS (Table 3).

Laterality dysmorphism was not evident in the vertical, horizontal, and anteroposterior axes of our measurements. However, gender-related differences were evident in the 5 to 10-year-old group, in which girls had higher volumes than boys. Other studies observed no statistically significant correlation between the measured volumes with age, gender, or side (2,7,9,30). In our categorical age groups, boys tended to have higher air volumes, agreeing with Cohen et al.,(5) that the difference noted could not be solely explained by the general difference in skull size between genders, which has also been demonstrated in other studies (8, 24-26). Marino et al., (22) consider the postnatal development of the frontal and sphenoid sinuses as a predisposing factor for greater variation in its development and final volumes.

It’s important to evaluate the characteristics of the PNS, to correlate with rhinosinusitis diseases, and other bone defects (4,6,13). Our study is the first to evaluate morphometrics in a Latino population, resulting in significantly higher volumes than other populations. However, it is limited by the lack of mastoid cells measurement due to the difficulty and inaccuracy when assessment.

CONCLUSIONS

The use of automated 3D volume reconstructions is a precise tool for PNS morphometrics and accurate knowledge of their anatomy. The CT allows not only a full evaluation of the sinuses and the adjacent anatomical structures but also for the planning of the FES.

Our results evidence higher volumes at a younger age, than reported in other populations. There is a clear volumetric difference with respect to categorized age groups and gender. The correlation between a volume and its contralateral counterpart is also demonstrated. Head and neck surgeons must consider the PNS differences in size and shape in pediatric patients, from those found in adults. It is important to understand that each age has a specific anatomical characteristic directly related to the development of the facial part of the skull and teething. The size and the disparity in the location of the floor of the nose and the floor of the maxillary sinus in children predispose them to more complications than expected in adults.

Conflicts of interest

Authors also declare no conflict of interest and certify they have no commercial, proprietary, or financial interest in the products or companies described in the manuscript. The authors did not receive grants or a consultant honorarium to conduct the study, write the manuscript, or otherwise assist in the development of the abovementioned manuscript.

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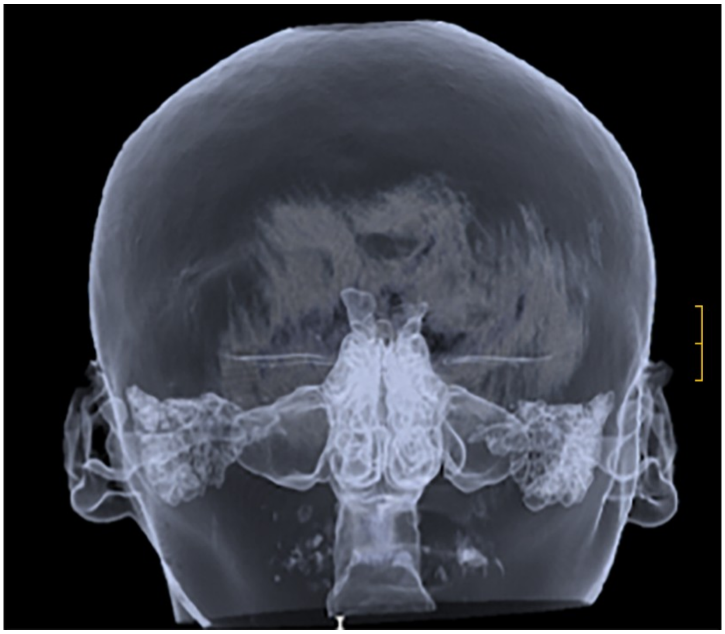

Figure 1. Three-dimensional reconstruction of aerial structures of the skull of a 4 year old patient. Scale with marks for each centimeter.

Figure 2. Three-dimensional reconstruction of paranasal sinuses of a 10 year old patient. A) Lateral view in a sagittal slice; B) Frontal view with a coronal slice; C) Superior view in a transverse slice. Scale with marks for each centimeter.

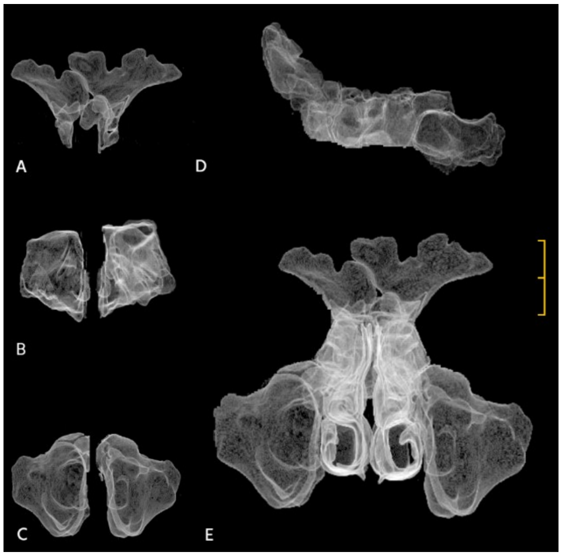

Figure 3. Aerial reconstruction of paranasal sinuses. A)Frontal sinuses; B) Sphenoidal sinuses; C) Maxillary sinuses; D) Lateral view of frontal, ethmoidal cells and sphenoidal sinuses (left to right); E) Anterior view of frontal sinuses, ethmoidal cells, maxillary sinuses, and nasal turbinates. All images correspond to a fully grown young woman of 18 years of age. Scale with marks for each centimeter.

Table 1. Paranasal sinuses morphometrics stratified by laterality and gender

	Variable		Mean	Total (n 210)	P value	Males (n 104)	Females (n 106)	P value
Volume (cm^3)	Frontal	Right	7.460	6.77 ± 6.70	0.0843	7.76 ± 7.49	5.80 ± 5.71	0.096
		Left		8.14 ± 10.82		8.81 ± 10.08	7.50 ± 11.52	0.243
	Sphenoid	Right	8.796	8.38 ± 7.08	0.711	8.52 ± 7.39	8.25 ± 6.8	0.832
		Left		9.21 ± 8.58		9.81 ± 8.41	8.62 ± 8.74	0.181
	Maxillary	Right	27.572	27.24 ± 13.79	0.916	28.73 ± 14.37	25.78 ± 13.11	0.179
		Left		27.90 ± 10.20		28.50 ± 14.62	27.31 ± 13.83	0.716

Values reported according to their parameter ± standard deviation. Statistical difference was obtained using the U Mann-Whitney between genders and a Spearman's correlation coeficient for laterality; * Statistically significant result ($p < 0.05$)

Table 2. Difference between categorical age between the parameters of volume and length of the paranasal sinuses

	Variable		Categorical age			
			<5 (n 60, 28.6%)	6-10 (n 50, 23.8%)	11-15 (n 50, 23.8%)	> 16 (n 50, 23.8%)
Volume (cm^3)	Frontal	Right	0.79 ± 1.41	3.94 ± 3.30	10.18 ± 4.96	13.38 ± 6.75
		Left	1.14 ± 2.26	4.59 ± 4.37	12.22 ± 6.52	16.05 ± 16.68
	Sphenoid	Right	2.65 ± 4.19	6.29 ± 4.69	11.19 ± 6.67	14.54 ± 5.93
		Left	2.84 ± 3.25	7.08 ± 5.84	13.34 ± 10.01	14.87 ± 7.91
	Maxillary	Right	12.33 ± 7.66	23.88 ± 8.27	35.95 ± 9.50	39.80 ± 7.76
		Left	12.74 ± 7.84	23.82 ± 7.07	35.51 ± 9.09	42.57 ± 8.79

Values reported according to their parameter ± standard deviation. Statistical difference was obtained usting the Krustal-Wallis formula; All results were statistically significant ($p <0.001$)

Table 3. Differences in paranasal sinuses volume between populations

Author, Year, Country	Imaging method	Sample size (men, women)	Gender	Age groups	Mean volume cm^3 (men, women)		
					Maxillary	Frontal	Sphenoid
Ariji et al. (2) 1993 Japan	CT	230 (116,114)	116	4-84	4.56	-	-
			114	6-96	4.76	-	-
Barghout et al.[16] 2002 Switzerland	MRI	179 (103,76)		<1	0.14	-	0.01
				2	1.6	-	0.17
				4	4.1	-	0.57
				8	10.1	-	1,77
				12	17.1	-	3.44
				16	25.9	-	5.82
Jun et al.[29] 2005 Korea	CT	173 (84,89)	15 (11, 4)	0 a 10	8.94, 4.23	-	-
			26 (17, 9)	11 a 20	19.45, 9.06	-	-
			22 (8, 14)	21 a 30	2.40, 15.85	-	-
			25 (14, 11)	31 a 40	22.28, 13.97	-	-
			35 (15, 20)	41 a 50	18.39, 11.94	-	-
			17 (8, 9)	51 a 60	19.42, 13.32	-	-
			22 (9, 13)	61 a 70	14.29, 13.69	-	-
			11 (2, 9)	71 a 80	20.26, 12.03	-	-
Karakas et al.[25] 2005 Turkey	CT	91 (47,44)	18 (9, 9)	5-10	6.02, 6.81	1.19, 1.23	2.96, 3.14
			19 (10, 9)	11-15	11.17, 9.8	4.20, 1.75	5.40, 4.85
			17 (8, 8)	16-20	14.64, 14.03	7.57, 3.54	7.50, 5.43
			18 (10, 9)	21-25	15.98, 10.90	8.83, 3.51	9.68, 8.71
			19 (10, 9)	>25	15.50, 11.33	8.41, 3.50	7.88, 1.14
Emirzeoglu et al.[32] 2007 Turkey	CT	77 (39,38)	39	18 – 72	19.8	7.5	7.7
			38		16.0	4.1	6.1
Sahlstrand-Johnson et al.[34] 2011 Sweden	CT	60 (28,32)	20	18-32	14.4	-	-
			20	33-49	16.6	-	-
			20	50-65	15.2	-	-
Masri et al.[31] 2013 Malaysia	CT	144		0-6	1.81, 2.81	-	-
				7-12	10.2, 9.26	-	-
				13-20	17.3, 13.5	-	-
				21-30	19.75, 14.5	-	-
Degermenci et al. [35] 2015 Turkey	CT*	361 (18,180)	100 (50, 50)	<5	3.23, 2.89	-	-
			100 (50, 50)	6 a 10	3.61, 7.18	-	-
			101 (51, 50)	11 a 15	11.03, 10.40	-	-
			60 (30, 30)	>16	14.46, 12.58	-	-
Lorkiewicks-Muszyńska et al. [13]	CT	170	40	0 a 4	1.97, 2.25	-	-
			30	4 a 8	5.48, 4.92	-	-

CT: computed tomography; MRI: magnetic resonance imaging; cm^3: cubic centimeters; *Ellipsoid formula vs. Stereological method