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Development of the maxillary sinus in infants and children

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ABSTRACT

Objective: To examine the age related volume change of the maxillary sinus in children by measuring the change of the height, weight, and depth using computed tomography (CT).
Methods: Children <18 years of age who underwent a CT Scan of the sinuses for reasons other than sinus related issues were included in the study.
Results: 139 patients were included (68 females and 71 Males) and the mean age of the patients was 9.6 ± 5.4 years. The cohort was divided into three groups based on their ages − Age <6 years (n = 45), age between 6 and 12 years (n = 44) and age > 12 years (n = 50). Patients in each age group demonstrated an increase in their Maxillary sinus height ($p<0.001$). Patients < 6years of age and between 6 and 12 years of age had a significant increase in their maxillary sinus width and depth ($p < 0.001$). The maxillary sinus width, depth and volume did not increase significantly after the age of 12 years in these patients.
Conclusion: We demonstrated periods of significant size increase of the maxillary sinuses as determined by different dimensions in children at various ages. The height of the maxillary sinus has steady growth from birth to at least the age of 18 years. The width and depth increase up to 12 years of age.

1. Introduction

The maxillary sinuses are complex anatomical structures with significant inter-individual variations. The developmental pattern of the maxillary sinuses also varies widely with age [4] [8]. It has been reported that the development of the maxillary sinus begins in the prenatal period but the majority of growth occurs after birth. The development of maxillary sinuses can occur at different rates and in different dimensions and therefore the shape and size of the sinuses may be the most variable of all the anatomical structures of the body.

A keen understanding of the normal development and physiology of the maxillary sinuses is key for the physician who treats abnormal sinus pathology. Moreover, an understanding of age-related changes in the dimensions and volume of the normal maxillary sinus may help in the understanding and development of sinus abnormalities. Few studies have reported age related changes in size. Some anatomic studies have proposed scales that may be used to determine growth rate but most of these scales are grouped into two axes - width and length [12]. Other studies have speculated on how the size of the sinuses relates to different pathologic conditions such as chronic sinusitis, cleft palate, nasal obstruction and allergic rhinitis. Little information is available on the development of maxillary sinuses in healthy children.

The current study examines the age related volume change of the maxillary sinus in children by measuring the change in the height, weight, and depth using computed tomography (CT). The differing measurements of each dimension at various ages and the way in which these differences contribute to the overall volume change of the sinus are determined. Differences based on gender, ethnicity and laterality are also explored.

2. Materials and methods

2.1. Study design and subjects

This study was conducted at Ann & Robert H. Lurie Children's hospital of Chicago, a tertiary care hospital located in Chicago, USA

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and was approved by its institutional review board. Children less than 18 years of age who underwent a Computed Tomography (CT) Scan of the sinuses from January 2011 through December 2013 for reasons other than sinus related issues were included in the study. Indications for obtaining the CT scan included evaluation of persistent headache, new onset seizures, and other neurological disease. Details of the CT scan and other demographic factors were obtained from patient medical records. Patients with a known history of developmental abnormalities, craniofacial syndromes, mid-facial injuries or fractures, chronic pulmonary diseases, pathologies in the skeletal system, neuromuscular diseases, or those who were at special risk (wards of the state, those with mental handicaps, were incarcerated, with facial injuries or fractures within the skull and paranasal sinus disease) were excluded. Each CT scan was analyzed by a pediatric radiologist and by a pediatric otolaryngologist. In addition, the pertinent data were extracted from the patient's chart that included the age, gender, ethnicity and the indications to scan to be performed.

2.2. CT scans

The sinus CT scans of the patients less than18 years of age were reviewed. Patients were divided into 3 groups based on their age: 0–5.99 years old, 6–11.99 years old, and 12–18 years old. The length, width and depth of the maxillary sinuses were measured. All measurements were performed using the measure tool available on the CT viewing software (iConnect access). The measurement technique of the maxillary sinuses in our study population are similar to the previously reported by Kim et al. [5], who performed the sinus measurements of cadaveric maxillary sinuses. To avoid observer variation and to obtain the maximum accuracy, all measurements were taken three times and the mean of those three values were entered into an excel document.

Maximum horizontal diameter of the maxillary sinus was called maxillary sinus width. The Maximum vertical diameter of the maxillary sinus defined as the longest distance from the lowest point of the inferior wall to the highest point of the superior wall as presented on the sagittal image was considered as maxillary sinus height. The maximum antero-posterior diameter of the maxillary sinus was called as maxillary sinus length was defined as the longest distance from the most anterior point of the anterior wall to the most posterior point of the posterior wall on the axial image. The volume of the maxillary sinus was calculated using the formulae: Length x width x height.

2.3. Statistical analysis

Descriptive statistics include mean and standard deviation of sinus measurements. Categorical data is reported as frequencies and percentages. Age groups were determined by distribution, clinical relevance and to better understand the growth periods of children sinuses: pre-school, grade school, and beyond grade school. To determine demographic differences, piecewise mixed effects models were run for each age group and each sinus. Models include age as a continuous fixed effect and patient id as a random effect to control for variability within each subject's left and right sinus. Table 1 reports piecewise mixed models by sinus measurement and age group. Figures graphically depict the linear relationship of age and sinus measurement by age group. Statistical significance was defined as p-value <0.05 and data were analyzed in SAS 9.3 (SAS Institute Inc., Cary, North Carolina).

3. Results

Total of 139 patients met inclusion criteria and all were included in the final analysis. Sixty-eight (48.6%) were female and 71 (50.7%) were Male. The mean age of the patients was 9.6 ± 5.4 years. The patients were divided into three groups based on their ages: Age<6years (n = 45), age between 6 and 12 years (n = 44) and age>12 years (n = 50). We did not observe any significant difference between gender ($p = 0.25$), race or ethnicity ($p = 0.06$).

Table 1
Piecewise mixed effects models for each sinus measurement by age groups.

Model	Intercept	Estimate	95% LCI	95% UCI	*p-Value*
Height					
Ages <6	1.015	0.210 (±0.061)	0.086	0.333	*0.001*
Ages 6–12	1.555	0.127 (±0.022)	0.082	0.173	*<0.0001*
Ages > 12	1.325	0.144 (±0.041)	0.062	0.226	*0.001*
Width					
Ages < 6	0.799	0.24 (+0.052)	0.135	0.345	*<0.0001*
Ages 6–12	1.641	0.068 (±0.027)	0.013	0.123	*0.02*
Ages > 12	2.224	0.019 (±0.029)	−0.038	0.077	*0.50*
Depth					
Ages < 6	1.395	0.322 (±0.072)	0.176	0.467	*<0.0001*
Ages 6–12	2.42	0.091 (±0.025)	0.041	0.142	*0.001*
Ages > 12	3.692	0.001 (±0.029)	−0.058	0.06	*0.97*
Volume					
Ages < 6	−0.31	2.245 (±0.434)	1.367	3.123	*<0.0001*
Ages 6–12	3.28	1.908 (±0.419)	1.063	2.752	*<0.0001*
Ages > 12	10.273	1.544 (±0.853)	−0.175	3.263	*0.08*

LCI, Lower confidence Interval; UCI, Upper confidence Interval.

3.1. Maxillary sinus height

In patients less than 6 years of age the mean height of the left maxillary sinus was 1.76 ± 0.48 and of the right Maxillary sinus was 1.78 ± 0.50 ($p = 0.85$). In patients between 6 and 12 years of age, the mean height of the left maxillary sinus was 2.7 ± 0.38 and of the right Maxillary sinus was 2.7 ± 0.43 ($p = 1.00$). In patients greater than12 years of age the mean height of the left maxillary sinus was 3.58 ± 0.62 and of the right Maxillary sinus was 3.56 ± 0.65 ($p = 0.87$). There was no significant difference between the left and right maxillary height between any age group. The subsequent data analysis uses the dimensions of both left and right measurements. Patients in each age group had significant ($p<0.001$) increase in their Maxillary sinus height (Table 1). There was a continuous and steady increase in the height of the maxillary sinus from birth to the age of 18years in these children (Fig. 1).

3.2. Maxillary sinus width

In patients who were less than 6 years of age the mean width of the left maxillary sinus was 1.60 ± 0.51 and of the right Maxillary sinus was 1.65 ± 0.53 ($p = 0.65$). In patients between 6 and 12 years of age, the mean width of the left maxillary sinus was 2.27 ± 0.43 and of the right maxillary sinus was 2.25 ± 0.37 ($p = 0.82$). In patients greater than12 years of age the mean width of the left maxillary sinus was 2.49 ± 0.46 and of the right maxillary sinus was 2.46 ± 0.48 ($p = 0.75$). There was no significant difference between the left and right maxillary width between any age group. Patients <6years of age had a significant increase in their maxillary sinus width (Table 1). Patients between 6 and 12 years of age also had a significant increase in the width of maxillary sinus but the increase was less robust than the patients less than 6 years of age. The results demonstrated that the maxillary sinus width did not increase significantly after the age of 12 years. (Fig. 2).

3.3. Maxillary sinus depth

In patients less than 6 years of age the mean depth of the left