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Development of the maxillary sinus from birth to age 18. Postnatal growth pattern

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ABSTRACT

Objectives: Anatomical and developmental descriptions of the maxillary sinus may be of great clinical importance. An understanding of age-related changes in the dimensions and volume of the normal maxillary sinus may help in the evaluation of radiographs and identification of sinus abnormalities. The aim of the present study was to define growth patterns of maxillary sinuses in children up to the age of 18 years and evaluate the correlation between normal age-related changes in dimensions and volume.
Methods: The research sample consisted of CT scans of 170 patients subdivided into 17 groups based on age. Normal developmental changes were investigated and linear dimensions measured.
Results: The maxillary sinus, present at birth, increases in size until the end of the 18th year.

The growth pattern includes changes in vertical, horizontal and antero-posterior directions.

No bilateral dimorphism was observed, but gender-related differences were found in children over the age of 8 years. The most extensive period of growth occurs during the first 8 years and by the end of the 16th year the maximal values of all diameters and volume are reached.
Conclusions: A CT study of developing maxillary sinuses allowed a precise evaluation of age-related changes in all diameters and volume to be made.

1. Introduction

The paranasal sinuses develop within the bones of the viscerocranium. The maxillary sinus is the first paranasal sinus to form [1]. The development of the maxillary sinus has been documented as early as the 17th week of the prenatal period [2], however it is after birth that the majority of growth occurs.

In newborn children the viscerocranium is relatively undeveloped. It grows simultaneously with other bones and reaches 25% of its final size by the end of the 2 years and up to the 50% by the end of the 8th year of age. It was reported, that the growth of the viscerocranium is most extensive in the vertical direction, slower in the antero-posterior direction, and slowest in the horizontal direction [3]. As the paranasal sinuses are mostly enclosed within the bones of the viscerocranium, the dynamics of the development of the skull should also refer to their growth. Interestingly, Scuderi et al. [1] stated, that at birth, the rudimentary aerated maxillary sinus is 6–8 cm^3 in volume with its maximal dimension in the antero-posterior direction.

Bone expansion during the formation of the paranasal sinuses although continuous, is not uniform and can take place at different times and at different speeds within the developmental process. Therefore, the shape and size of the paranasal sinuses are probably the most variable of all the anatomical structures of the body. Due to extended aeration, the walls of the paranasal sinuses may turn into thin bony laminae. Undoubtedly the shape and size of the maxillary sinus is determined but not limited by the boundaries of surrounding bony structures.

A close link between the size of the facial skeleton and the maxillary sinus volume is suggested, even when severe facial pathologies are present [3]. As the shape and size of the maxillary sinus reflect the development of bony structures, it may be

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associated with determining the shape of the middle face, moreover, it is suggested that the maxillary sinus might play a crucial role in the formation of facial contours [4].

Despite many proposed theories, the real function of the maxillary sinuses has not been clarified [5]. The most often believed is that the sinuses support the respiratory function and resonation, but, it cannot be excluded, that they arose as an aid to the skull structure or are residual remnants with yet unknown purpose [6]. According to Kawarai et al. [7] the fact, that the paranasal sinuses constitute the major cavity of the skull indicates that the particularity of the sinus is their air space. Nonetheless, the aeration of the sinuses must play an important role if the maxillary sinus is already filled with air in newborns [8,9]. Therefore it is suggested that the volume of the air cavity is the simplest and most important index for sinus evaluation [7].

The maxillary sinuses are complex anatomical structures with a significant inter-individual variation [10]. The study of Kim et al. [11] on the three-dimensional reconstruction and simulation of maxillary sinus showed that its morphology and size are variable. Also the developmental pattern of the paranasal sinuses varies widely according to the individual and the age [5].

The maxillary sinuses used to be observed on the roentgenograms. They can be identified on X-rays at birth [9]. Due to the development of modern imaging techniques the use of plain X-rays is rare, but should not be neglected. The CT is the modality of choice for evaluation of sinuses due to its ability to optimally display the bone, soft tissue and air [12]. It has been proved that anatomical dimensions of the paranasal sinuses can be measured from CT images [7,13,14]. Moreover, the three-dimensional CT images clearly delineate the development of maxillary sinus. Nonetheless the normal findings must be understood and recognized so that the CT scans may be accurately interpreted [1].

Anatomical and developmental descriptions of the maxillary sinus may be of great clinical importance. The pneumatization of children's sinuses and the pattern of normal development may serve as a reference for evaluating normal or abnormal development of the maxillary sinus. Normal values and clinical indexes can be used in diagnostic, preoperative evaluation [8], and treatment planning [15]. An understanding of age-related changes in the dimensions and volume of the normal maxillary sinus may help in the evaluation of radiographs and identification of sinus abnormalities.

The aim of present study was to (a) evaluate normal age-related changes in dimensions of the maxillary sinuses and their co-relations, (b) evaluate the age-related changes in the volume of maxillary sinuses, (c) determine possible sexual dimorphism and bilateral variations, (d) define growth pattern of maxillary sinuses in children up to the age of 18 years measured on computed tomography (CT) of the head.

2. Materials and methods

2.1. CT scans

The multi slice computed tomography (MSCT) scans of patients (aged 0–18 years) from the database of the electronic system (PACS) of the University Children's Clinic were retrospectively studied. All patients who underwent CT imaging of the skull on suspicion of trauma or neurological disease were examined on the 128-slice CT scanner Somatom Definition AS+ (manufactured by Siemens) at the Department of Pediatric Radiology. As most of the sinuses are present on a CT of the skull, a large number of CT scans could be evaluated. Excluded from the study were specimens suffering neurological diseases or developmental abnormalities, pathologies in the skeletal system, midfacial injuries or fractures within the skull and paranasal sinus disease. Scans showing unilateral pathologies within the maxillary sinuses were not included in the study either. Only images described as being normal by radiologists were included in the study.

The access to a hospital database allowed for precise selection of the research sample according to sex and age. The age and sex were found in the medical records, they are also combined with images in DICOM standard.

Finally, the research sample consisted of the CT scans of 170 patients subdivided into 17 groups based on their age. Patients 0–2 years old (younger than 24 months of age) were grouped as 1, those 2–3 years old (younger than 36 months) as 2, those 3–4 years (younger than 48 months) as 3, etc. Finally, the last group, 17, was formed by the patients of 17–18 years old (younger than 18 years). Within every group, the scans of 10 children (5 males and 5 females) were investigated. A total of 340 maxillary sinuses were examined.

The study protocol was approved by the University Bioethical Committee.

2.2. CT analysis

The normal developmental changes of the maxillary sinuses in children were investigated in detail and linear dimensions were measured. Slice thickness was 0.5 mm as a standard for further 2D and 3D reconstruction. This allowed reconstruction of volumetric data (3D) on an accuracy level of 1 mm. All evaluations were done using Siemens standard Syngo Via workstation (Syngo via Software no VD12A), using standard software for image MPR and 3D evaluation.

Measurements were performed on workstation screen with a constant window setting (WL window level 700–600; WW Window width 4000–3500) for each measurement.

The metric dimensions were taken by an experienced researcher with the use of a digital marker (caliper) with magnification correction with accuracy of 0.5 mm. In order to obtain the maximal accuracy and to avoid errors, all measurements were completed three times. Because the differences between the measurements were less than 1% the mean was calculated and used in statistical analysis.

Assessment of the maxillary sinus in each patient included bilateral measurements in maximum diameter in three planes:

(a) maximal horizontal (transverse) diameter (maximal width) of the maxillary sinus-later called MSW, defined as the longest distance perpendicular from the most prominent point of the medial wall to the most prominent point of the lateral wall as presented on the axial image.
(b) maximal vertical (craniocaudal) diameter (maximal height) of the maxillary sinus – later called MSH, 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.
(c) maximal antero-posterior (sagittal) diameter (maximal length) of the maxillary sinus – later called MSL, 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.

Our objective was to find an accurate method of manually calculating the volume of the maxillary sinus based on it resembling a geometric shape. To establish which shape it most resembled we analyzed the data from anatomy and radiology handbooks and scientific papers. Having concluded that the shape can be either a pyramid, sphere or cube, calculations for the volume of every sinus based on it being each of the three shapes found that the average of the pyramidal and spherical shaped volumes was the most accurate.