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Growth of the maxillary sinus in children and adolescents: A longitudinal study

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ABSTRACT

Maxillary sinus volumetric and surface area data and growth models from longitudinal samples of children and adolescents are presented. Cone-beam radiographic CT scans from two small retrospective longitudinal samples, one from the Baylor College of Dentistry, Dallas, TX ($N = 17$, 12 females, 5 males, 10.9–17.4 years) and one from a group private orthodontic practice in Nevada ($N = 15$, 9 females, 6 males, 6.4–13.4 years) were used to collect maxillary sinus volumes and surface areas from each individual imaged at two times separated by variable intervals. Volume and surface area values were collected in Analyze® (Mayo Clinic) and growth models were produced in MLwiN®, a multi-level modeling program. There is a large degree of inter-individual variation. Surface area and surface-area-to-volume ratio (SA:V) changes are particularly variable. Growth models suggest linear growth in both volume and surface area, without growth spurts.

Introduction

There is a surprising lack of studies focused on growth of the sinuses in children, and very few of these are longitudinal studies. In addition to the cost and necessary time investment involved in longitudinal research, healthy children are rarely subjected to repeated medical imaging that yields high-quality scans available for studies of normal growth and development. One prominent exception is during the course of orthodontic treatment.

The pioneering study of Maresh (1940) reported observations and measurements of children evaluated as a part of a longitudinal growth study conducted in Denver. At the time of his report, Maresh had data spanning 14 years for 100 children. He discussed growth in size of the maxillary sinus, but part of the enduring value of his paper is its emphasis on the variation evident in maxillary sinus growth. He concluded that "longitudinal studies of the growth of the sinuses in individual children appear to illustrate better than measurements the futility of trying to establish a single 'norm' representing either the size or the shape of the sinuses at any given age" (1940:77). Coefficients of variation calculated (by author SLS) for maxillary sinus volumes reported by Darsey et al. (2012) for a group of orthodontic patients exceed 30. Although partly due to age differences and possibly sex differences, this represents a considerable amount of variation in a small sample of orthodontic patients whose average age (13.8 years) is beyond the maximum growth period of childhood.

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Researchers have not consistently found significant maxillary sinus size differences by side or sex, with some studies reporting differences and others not (see below and Supporting Information). One interesting study that points to a possible functionally related difference is that of Oktay (1992), who found that females with an Angle Class II malocclusion had larger maxillary sinuses than did males and other females without this type of malocclusion. In this study, the sinuses of males and females did not differ in size, on average.

Barghouth et al. (2002) examined MRI scans with the goal of determining the normal volumetric growth of the paranasal sinuses. For the maxillary sinus, 153 scans from 94 boys and 59 girls (<17 years) were measured. Volumes were calculated using a simplified ellipsoid formula, and growth curves were modeled using quantile regression. They found no significant differences between volumes of right and left sinuses or between those of males and females across all ages, although they did report some right–left differences for maxillary sinus length. Adibelli et al. (2011) also used MRI scans (N = 1452 patients) to examine paranasal sinus development from birth to 18 years. A maxillary sinus volume index was calculated using a simplified ellipsoid volume formula; the authors admitted volumes might be affected by the shape irregularities of some of the sinuses. Park et al. (2010) conducted a volumetric paranasal sinus study of 260 Asians, including 10 individuals at each age from birth to 25 years. Importantly, they measured actual volumes rather than using a simplifying equation to estimate sinus volume; volumes were automatically calculated by a computer program from 3D sinus reconstructions. They reported two active periods of maxillary sinus pneumatization, one between birth and 2 years of age and the second between 7 and 12 years, with slow development thereafter between the ages of 14 and 18 years. However, they also described maxillary sinus growth as "monomodal."

Many previous volumetric studies of sinuses in living patients have estimated volumes using some form of simplifying equation (Adibelli et al., 2011; Barghouth et al., 2002; Ikeda et al., 1998) rather than measuring the volume of sinuses of complex shapes more directly (Kim et al., 1997; Park et al., 2010). While adequate for estimation purposes, such simplifications assume a regular sinus shape shared by all individuals. Related to this assumption, other shape features are not commonly considered, in part due to difficulty in quantifying them with previously available technology.

Until recently, three dimensional studies of sinus volumes were confined to those employing conventional CT scans or MRI. A recent imaging advance, cone-beam CT, limits radiation exposure to levels acceptable for repeat scanning during orthodontic treatment planning and evaluation. These treatment scans also allow enhanced visualization and three-dimensional analyses of developing sinuses. Anatomical features can be visualized more clearly from cone-beam CT scans than from conventional radiographs, including standard panoramic radiographs (Kilic et al., 2010). In addition to avoiding the superimposition of structures, the CT images are preferable because they do not need to be adjusted for magnification in either the vertical or horizontal direction. Cone-beam CT scans result in less radiation exposure than do conventional CT scans, but the ADA and FDA still recommend their use only when clinically necessary (www.fda.gov).

The purpose of this paper is to present the results of a study designed to measure volumes and surface areas of the developing maxillary sinus in two small longitudinal samples of children and adolescents. Surface areas are considered in addition to volumes to provide an indication of shape alteration and variation during growth in addition to an analysis of size. Cone-beam radiographs of orthodontic patients allowed measurements of values prior to treatment and at one later point during treatment for each individual. Volumes and surface areas were calculated directly by a computer algorithm (Mayo Clinic Analyze®) following hand editing of images. Growth models for volume and surface area were generated using a multilevel modeling program, MLwiN®.

Materials and methods

Samples

Two retrospective longitudinal samples were used in this study. The cone-beam CT scans of the first sample were taken with a 3D ICAT® (Imaging Sciences International, Hatfield, PA, USA) and collected at the Texas A&M University Baylor College of Dentistry (BCD sample). The scans of the other sample were taken with either the NewTom 3G® (Aperio Services, Verona, Italy) or the NewTom DVT 9000® (QR SRL, Verona, Italy) and collected from the records of a group Private Practice in Nevada (PP sample). The Texas A&M Health Science Center IRB approved the use of the records for this study.

For each individual, two scans had to be available in order for the individual to be included in the sample; generally these two scans consisted of a pre-treatment scan and a second scan taken at some point during orthodontic treatment. Other than the scans, treatment records were not available; no individual was excluded based on type of treatment. All accepted BCD scans displayed good clarity and included the full sinuses on both sides. Of the 22 available patients reviewed, 17 were accepted (5 omitted: 3, second scan missing; 1, no apparent sinus; 1, bilateral marked reduction in sinus size). The BCD sample includes 12 females and 5 males with an age range of 10.9–17.4 years at time of scanning.

The PP sample proved more problematic. Of the 74 cases reviewed, only 15 were included in the final study. The vast majority of omitted cases were rejected due to the absence in the scans at one or both ages of the full maxillary sinuses. A few were omitted due to suspected abnormality (e.g., abnormally small or absent sinuses). Despite the lower image quality of the PP scans and the necessity of rejecting a high proportion of reviewed cases, the children were mostly younger than those from the BCD sample, and thus this sample provides valuable data. The PP sample includes 9 females and 6 males between the ages of 6.4 and 13.4 years of age at time of scanning.