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Assessment of paranasal sinus parameters according to ancient skulls' gender and age by using cone-beam computed tomography

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Background: *The aim of this study was to determine whether paranasal sinus dimensions and volume can be useful to identify gender and age estimation for ancient skulls using cone-beam computed tomography (CBCT) images.*
Materials and methods: *CBCT scans of 32 ancient skulls of approximately 1000 years of age were included in this retrospective study. The gender and age estimation of the skulls were made by an independent anthropologist, which was considered as the gold standard. Paranasal sinuses' dimensions (width and height) and volumes of each sinus were measured from the CBCT data set that was linked to the three-dimensional rendering software (Anatomage, Invivo 5.2). All measurements were performed by an independent observer. Intra-observer analysis was made. Mann-Whitney and Kruskal-Wallis tests were used to compare paranasal sinus parameters in terms of age estimation and gender ($p < 0.05$).*
Results: *The results demonstrated no statistically significant difference between measurements ($p < 0.05$). The measurements were found to be highly reproducible. The mean volumes of frontal and sphenoid sinus were found to be higher in males. The distance from anterior-posterior wall of sphenoid sinus in axial sections is larger in males ($p > 0.05$). The frontal sinus width and volume increased statistically with age above 60 years of age ($p > 0.05$).*
Conclusions: *The paranasal volume and dimensions' measurements from CBCT data can be a promising technique to determine gender and age of ancient skulls because of its lower voxel sizes and higher resolution.* (Folia Morphol 2019; 78, 2: 344–350)

Key words: age estimation, anthropology, gender, paranasal sinus, cone-beam computed tomography

INTRODUCTION

Fingerprints, dental comparison and biological methods such as DNA profiling are essential tools in identification of human beings. However soft tissues can be perished as are in ancient remains, and this makes skeletal examination and anthropological method indispensable in personal identification [8]. By means of unrecognised skeletons epiphysis and metaphysis' evaluation, gender has been estimated from pelvis, skull, and long bones [20].

In gender determination, detection from skeleton, from both pelvis and skull, from pelvis only or the

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Figure 1. Cone beam computed tomography scan of the skull.

pelvis and long bones, from both the skull and long bones, from long bones only exhibits 100%, 98%, 95%, 90–95%, 80–90% precise results, respectively [11, 14].

In age-at-death estimation, the most commonly used indicators are briefly: skeletal maturation, pubic symphysis, sternal end of ribs, auricular surface, acetabulum, suture closure, pathology and cartilage ossification. Other methods include microscopic, molecular and chemical assessments [17].

Bone structures such as paranasal sinuses are typical and specific because of their unique nature and irregular shape. The durable features of these osteological structures make them indispensable for forensic purposes [2]. It has been suggested that the frontal sinus (FS) has the potential to be used for personal identification, age estimation, and sexual dimorphism [25]. Also for sinuses, remaining intact after hard condition and protecting their structure makes them useful for identity purposes. Considering the complex structure of paranasal sinuses, computed tomography (CT) is a gold standard method to assess the exact anatomy of sinuses [16]. Disadvantage of high dose and high cost makes its use to be limited. X-ray and CT analyses have importance for observing some gender identification of facial traits of the skull; furthermore, these radiological modalities are significant in order to estimate the age at death [16]. Medical CT (MDCT) has been shown to yield accurate and reliable assessments for skull evaluations. A cone-beam CT (CBCT), a technique that has been proposed in the last two decades, uses a different type of acquisition than MDCT [4, 10, 19]. Rather than capturing an image as separate slices, as in MDCT, CBCT produces a cone-shaped X-ray beam that makes it possible to capture the image in a single shot. CBCT recently becoming an alternative of MDCT for imaging of the skull base because of reduced radiation dose, higher spatial resolution, smaller voxel sizes along with smaller thickness size on CBCT images compared with MDCT images [15, 27].

The aim of this study was to determine whether paranasal sinus dimensions and volume can be useful to identify gender and age estimation for ancient skulls using CBCT images.

MATERIALS AND METHODS

Thirty-two ancient dry skulls that were unearthed from certain archaeological excavations from Anatolia, Turkey dated approximately back 1000 years ago from period of 800–1000 C.E. were used for this study. The sex and the age estimations of each skull were determined by an independent anthropologist. In this study the symphyseal surfaces of the pubic and the auricular surfaces of the coxa, the aspect of the spongious tissue in humerus and femur, the closure of the cranial sutures and the tooth wear were considered when estimating the age of the adults. For sexual diagnosis, the following complex of characters were considered: general shape of the pelvis, size of the greater sciatic notch, the shape of the sacrum, robustness of the skeleton, development of muscular joints and insertions, cranial relief, forehead shape, robustness and shape of the mandible [3, 6, 14, 24].

There were 18 ancient male skulls with a mean age estimated at 41.4 ± 10.2 years and 14 ancient female skulls with a mean age estimated at 39.6 ± 9.2 years.

Imaging using CBCT

Cone beam CT images were taken with Planmeca ProMax 3D Max CBCT (PlanmecaOy, Helsinki, Finland) (Fig. 1). All CBCT scans of skulls were made according to

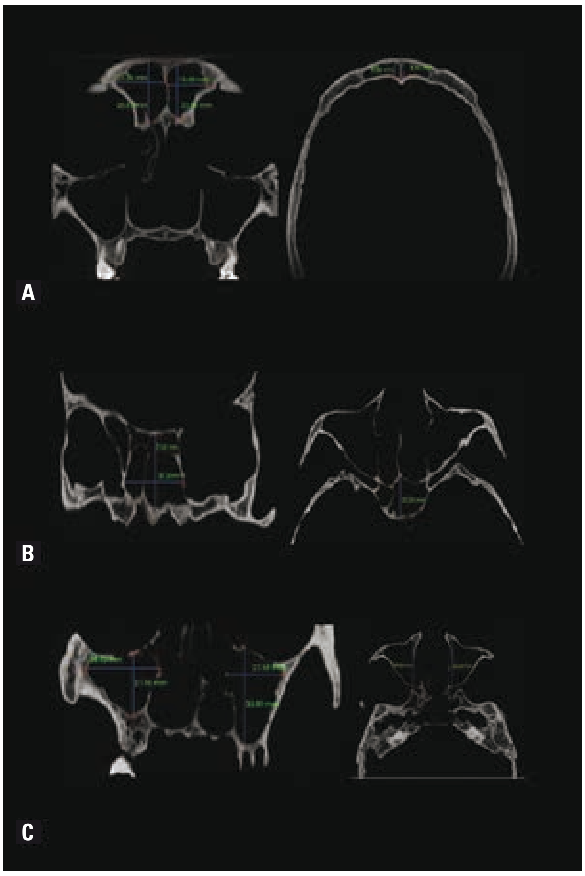

Figure 2. Measurement sites related to paranasal sinuses on the cone beam computed tomography images; **A.** Coronal and axial view of the frontal sinus; **B.** Coronal and axial view of the sphenoid sinus; **C.** Coronal and axial view of the maxillary sinus.

a strict standardised scanning protocol; stabilised with head band and monitored to ensure that they remained motionless throughout the duration of the scan. All constructions and measurements were performed on a 21.3-inch flat-panel colour-active matrix TFT medical display (NEC MultiSync MD215MG, Munchen, Germany) with a resolution of 2048 × 2560 at 75 Hz and 0.17-mm dot pitch operated at 11.9 bits. In the meantime, CBCT images of ancient skulls were also obtained in same protocol using the same CBCT machines.

Image evaluation

Paranasal sinuses dimensions (width and height) and volumes of each sinus were measured from the CBCT data. Coronal and axial images were used for measuring the dimensions. The height and width were measured from coronal images whereas the distance between anterior and posterior (Fig. 2).

Paranasal sinus volumes were calculated using three-dimensional (3D) software. Axial images were exported in a DICOM file format with a 512 × 512

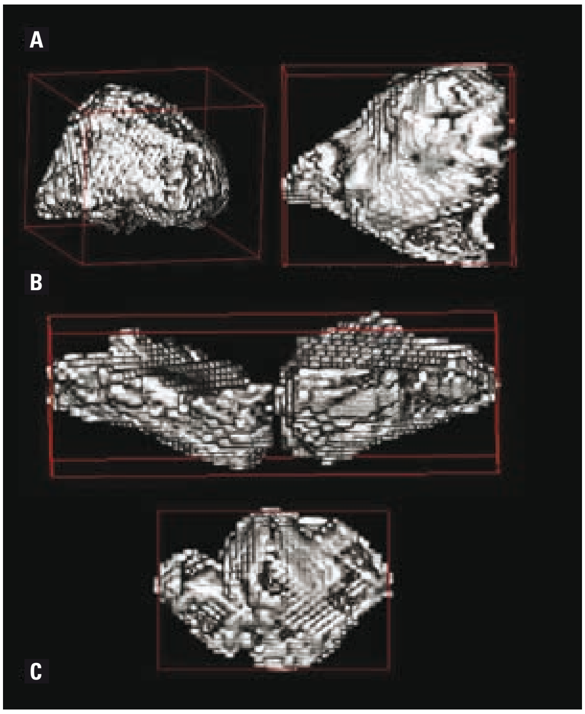

Figure 3. Three-dimensional rendered cone beam computed tomography images showing paranasal sinus volumes; **A.** Maxillary sinus; **B.** Frontal sinus; **C.** Sphenoid sinus.

matrix and were imported to software Invivo 5.1.2® (Anatomage Inc., San Jose, CA, USA) for measurement. The anatomical volumetric measurements were done by means of this software in hand tracing. The software uses an inverse present method the programme reconstructs a 3D model of the sinus from the DICOM image sequence on which the volume was selected by cutting out the complementary areas of the air-filled area in the three dimensions manually, then volume measurement was calculated by the software (Fig. 3).

All constructions and measurements were performed on a 21.3-inch flat-panel colour-active matrix TFT medical display (NEC MultiSync MD215MG, Munchen, Germany) with a resolution of 2048 × × 2560 at 75 Hz and 0.17-mm dot pitch operated at 11.9 bits. The examiner was also permitted to use enhancements and orientation tools such as magnification, brightness, and contrast to improve visualisation.

Statistical analysis

SPSS 17.0.1 (SPSS, Chicago, ILL) software programme used to carry out the statistical analysis. In order to determine intra-observer variability, observer performed the analysis twice with an interval of 2 weeks. To assess intra-observer reliability, the Wilcoxon matched-pairs signed rank test was used for repeat measurements. Mann-Whitney and Kruskal-Wallis tests were used to compare paranasal sinus parameters in terms of age estimation and gender. Age was divided into three groups (21–40, 41–60, 61–80 years). A p value of less than or equal to 0.05 was considered statistically significant.

RESULTS

Repeated CBCT evaluation and measurements indicated no significant intra-examiner difference for the examiner ($p > 0.05$). Overall intra-observer consistency was rated at 92% and 95%. All measurements were found to be highly reproducible for the examiner and no significant difference was obtained from two measurements ($p > 0.05$).

Table 1 shows the descriptive analysis of skulls. The mean FS volume was 2.77 cubic centimetre (cc) (min: 0.55; max: 9.00). The sphenoid sinus volume 3.47 cc (min: 0.95; max: 7.14). The maxillary sinus left and right volumes were found to be 4.72 cc (min: 1.71; max: 10.63) and 5.46 cc (min: 2.23; max: 9.73), respectively. No significant difference was found between left and right for maxillary sinus volume and dimensions ($p < 0.05$). Table 2 shows the measurements according to gender. The mean volumes for frontal and sphenoid sinus were found to be higher in males.

Table 1. The descriptive analysis of skulls

	N	Median (minimum; maximum)	Mean ± standard deviation
Frontal sinus volume	32	2.77 (0.55; 9.00)	3.18 ± 2.27
Maxillary sinus volume (right)	32	4.72 (1.71; 10.63)	5.13 ± 2.21
Maxillary sinus volume (left)	32	5.46 (2.23; 9.73)	5.44 ± 1.92
Sphenoid sinus volume	32	3.47 (0.95; 7.14)	3.46 ± 1.36
Maxillary sinus height (right)	32	28.22 (19.59;40.9)	28.57 ± 4.77
Maxillary sinus width (right)	32	22.18 (14.69; 35.14)	22.99 ± 5.20
Maxillary sinus ant--post distance (right)	32	35.14 (23.62; 43.49)	34.77 ± 4.99
Maxillary sinus height (left)	32	28.51 (17.86; 39.17)	28.41 ± 5.27
Maxillary sinus width (left)	32	23.62 (14.40; 35.71)	23.43 ± 5.44
Maxillary sinus ant--post distance (left)	32	34.85 (24.77; 43.2)	34.62 ± 4.82
Sphenoid sinus height	32	22.75 (14.40; 30.24)	22.86 ± 3.25
Sphenoid sinus width	32	36.00 (19.87; 46.94)	35.07 ± 5.50
Sphenoid sinus ant-post distance	32	22.18 (12.67; 35.71)	22.54 ± 5.52
Frontal sinus height	32	22.04 (9.79; 31.15)	22.56 ± 6.15
Frontal sinus width	32	38.88 (11.04; 64.51)	38.72 ± 13.68
Frontal sinus ant-post distance	32	8.93 (4.32; 14.69)	8.92 ± 2.45

Table 2. Measurements according to gender groups

	Male			Female			Test statistics	
	N	Median (minimum; maximum)	Mean ± standard deviation	N	Median (minimum; maximum)	Mean ± standard deviation	Z	p
Frontal sinus volume	14	2.84 (0.55; 8.01)	3.34 ± 2.18	10	1.86 (1.00; 9.00)	2.98 ± 2.49	0.744	0.483
Maxillary sinus volume (right)	13	4.60 (1.71; 10.63)	5.20 ± 2.74	15	4.87 (2.61; 8.44)	5.06 ± 1.72	0.345	0.751
Maxillary sinus volume (left)	14	5.64 (2.23; 9.73)	5.60 ± 2.09	17	5.46 (2.78; 8.86)	5.30 ± 1.82	0.397	0.710
Sphenoid sinus volume	14	4.09 (1.82; 5.13)	3.24 ± 1.23	17	3.61 (1.45; 7.14)	3.65 ± 1.47	0.635	0.050
Maxillary sinus height (right)	14	29.24 (19.59; 40.9)	29.62 ± 5.24	17	27.65 (21.89; 40.61)	27.70 ± 4.31	1.351	0.186
Maxillary sinus width (right)	14	22.61 (18.14; 34.27)	23.41 ± 4.36	17	20.74 (14.69; 35.14)	22.65 ± 5.91	0.596	0.570
Maxillary sinus ant-post distance (right)	14	34.85 (23.62; 43.49)	34.23 ± 6.04	17	35.14 (27.36; 42.05)	35.22 ± 4.07	0.338	0.739
Maxillary sinus height (left)	14	28.51 (17.86; 37.73)	29.07 ± 5.52	17	26.50 (21.02; 39.17)	27.87 ± 5.15	0.695	0.493
Maxillary sinus width (left)	14	22.61 (14.4; 35.71)	23.64 ± 5.02	17	24.77 (14.69; 33.99)	23.26 ± 5.90	0.139	0.891
Maxillary sinus ant-post distance (left)	14	35.14 (24.77; 43.20)	34.68 ± 5.46	17	34.85 (26.21; 41.78)	34.56 ± 4.39	0.099	0.922
Sphenoid sinus height	14	24.92 (14.4; 30.24)	23.62 ± 3.97	17	22.18 (19.01; 27.08)	22.23 ± 2.47	1.451	0.149
Sphenoid sinus width	14	35.28 (28.22; 40.04)	35.04 ± 3.91	17	36.29 (19.87; 46.94)	35.10 ± 6.65	0.238	0.830
Sphenoid sinus ant-post distance	14	23.33 (16.13; 35.71)	24.73 ± 5.47	17	19.58 (12.67; 29.66)	20.74 ± 5.02	1.985	**0.048**
Frontal sinus height	14	26.07 (10.66; 31.11)	23.62 ± 5.90	16	20.60 (9.79; 31.15)	21.64 ± 6.41	0.894	0.377
Frontal sinus width	14	40.22 (11.04; 61.48)	38.51 ± 14.06	16	38.46 (16.65; 64.51)	38.91 ± 13.79	0.187	0.854
Frontal sinus ant-post distance	14	8.93 (4.32; 10.08)	8.16 ± 1.98	16	9.08 (5.47; 14.69)	9.58 ± 2.69	1.270	0.208

Table 3. Measurements results according to age

	21–40 years			41–60 years			61–80 years			Test statistics	
	N	Median (minimum; maximum)	Mean ± standard deviation	N	Median (minimum; maximum)	Mean ± standard deviation	N	Median (minimum; maximum)	Mean ± standard deviation	χ^2	p
Frontal sinus volume	10	2.77 (0.57; 5.65)	2.50 ± 1.52	9	2.83 (0.55; 8.01)	2.68 ± 2.33	4	5.51 (2.84; 9.00)	5.71 ± 2.54	5.841	0.050
Maxillary sinus volume (right)	12	4.72 (2.61; 7.62)	4.87 ± 1.47	9	4.60 (1.71; 9.34)	4.90 ± 2.43	7	4.08 (2.22; 8.44)	4.81 ± 2.26	0.100	0.951
Maxillary sinus volume (left)	13	5.20 (3.08; 7.68)	5.08 ± 1.40	10	4.87 (2.23; 9.73)	5.05 ± 2.34	8	5.66 (3.24; 8.86)	5.91 ± 1.96	1.389	0.499
Sphenoid sinus volume	13	3.61 (1.45; 4.71)	3.43 ± 1.13	10	2.51 (0.95; 5.13)	2.94 ± 1.35	8	3.67 (2.35; 7.14)	4.08 ± 1.68	2.485	0.289
Maxillary sinus height (right)	13	27.65 (24.48; 34.27)	27.94 ± 3.25	10	27.51 (19.59; 35.71)	27.36 ± 4.40	8	29.24 (21.89; 40.61)	29.05 ± 5.63	0.252	0.882
Maxillary sinus width (right)	13	20.74 (14.69; 25.63)	21.39 ± 3.29	10	23.19 (14.69; 34.27)	23.21 ± 6.43	8	21.75 (17.28; 35.14)	23.69 ± 5.93	0.627	0.731
Maxillary sinus ant--post distance (right)	13	35.14 (27.36; 41.47)	35.03 ± 3.73	10	35.14 (23.62; 42.34)	34.07 ± 6.38	8	32.55 (29.09; 41.19)	34.02 ± 4.68	0.623	0.732
Maxillary sinus height (left)	13	26.50 (21.02; 36.58)	27.91 ± 5.12	10	28.08 (17.86; 37.73)	27.39 ± 5.61	8	28.95 (23.04; 39.17)	29.59 ± 5.66	0.615	0.735
Maxillary sinus width (left)	13	21.60 (14.69; 26.78)	21.65 ± 3.99	10	23.62 (14.40; 35.71)	23.59 ± 6.76	8	22.76 (16.70; 33.99)	24.41 ± 5.62	0.975	0.614
Maxillary sinus ant--post distance (left)	13	36.29 (27.07; 42.05)	35.79 ± 3.80	10	32.40 (24.77; 43.20)	33.67 ± 6.29	8	32.69 (26.21; 40.03)	33.48 ± 4.46	1.893	0.388
Sphenoid sinus height	13	21.89 (14.4; 30.24)	21.78 ± 4.11	10	22.04 (18.43; 25.63)	22.06 ± 2.46	8	25.20 (21.60; 27.08)	24.66±2.20	5.086	0.079
Sphenoid sinus width	13	33.70 (19.87; 40.04)	32.91±6.16	10	37.16 (27.65; 46.94)	36.61 ± 6.13	8	36.72 (33.12; 40.91)	36.94 ± 2.84	2.593	0.273
Sphenoid sinus ant-post distance	13	18.72 (12.67; 31.11)	20.61 ± 6.29	10	22.61 (16.42; 35.71)	23.41 ± 5.23	8	22.90 (16.42; 29.66)	22.9 ± 4.67	2.224	0.329
Frontal sinus height	13	22.18 (9.79; 31.15)	21.88 ± 7.14	10	21.46 (10.66; 31.11)	21.52 ± 6.37	7	27.36 (19.30; 30.82)	24.87 ± 5.04	0.788	0.674
Frontal sinus width	13	38.03 (11.04; 54.94)	34.61 ± 13.19	10	36.98 (19.43; 54.94)	36.63 ± 11.15	7	55.01 (33.12; 64.51)	50.48 ± 12.82	5.591	0.050
Frontal sinus ant-post distance	13	8.64 (4.61; 14.69)	9.16 ± 3.08	10	8.64 (4.32; 10.66)	7.98 ± 2.16	7	9.80 (6.97; 13.25)	9.88 ± 1.83	3.179	0.204

The distance from anterior-posterior wall of sphenoid sinus in axial sections was larger in males compared to females ($p > 0.05$). Table 3 shows the measurement according to age groups. The results showed that the FS width and volume increased statically.

DISCUSSION

Forensic anthropology is a key constituent of an individual's antemortem background from skeletal remains. Gender, race, age and stature constitute the antemortem profile. The durable structure and intact of paranasal sinuses make them useful for forensic anthropology [1, 18].

Michel et al. [18] worked to find out whether it was possible to predict the age and gender of an individual by using FS volume. Sixty-nine anonymised CT scans were studied according to FS volume in mm^3. While sex determination accuracy was found 72.5%, there was no correlation between age and frontal sinus. Male left side FS volume was stated higher without significant difference. In accordance with the literature Michel et al. [18] revealed a significant difference in FS volume between females and males.

Ponde et al. [9] carried out a study on 100 macerated skulls and adjudged that there was a significant difference regarding sex and location of sinus with predominance of the left side in males. Tatlısumak et al. [22] conducted a study on 300 paranasal CT scans and estimated that maximum size of FS was reached between 30 and 40 years of age and that FS volume decreased thereafter. Similarly, in this study, the results showed that the FS width and volume increased statically with ageing.

Uthman et al. [25] found 79.7% accuracy in gender estimation by using frontal sinus CT scans, whereas this ratio increased to 85.9% when they combined skull measurements and FS measurements. In another study done by Uthman et al. [26] maxillary sinus height was the best indicative factor for gender estimation with overall accuracy of 71.6%.

Buckland-Wright [5] was one of the earliest to report sex differences, stating that frontal sinuses in males were approximately twice as large as in females; however, Yoshino et al. [28] evaluated antero-posterior radiographs and found no significant sexual dimorphism through the application of univariate statistics. Cox et al. [7] undertook computer-based assessments of radiograph-traced sinus outlines, but obtained no statistically significant sexual variation.

According to Belaldavar et al. [2], the height and area of left FS were better regressors for sex determination among other individual variables with the ratio 64.6% and 63.2%, respectively. Three systemic factors, that is the craniofacial configuration, the thickness of the frontal bone and growth hormone levels, influence the FS morphology within each population [2].

In a study done by Kanthem et al. [12] the dimensions and volume of maxillary sinuses of right and left side were much larger in males than in females. Sexual dimorphism according to volume was estimated at 85.46% for right side and 78.38% for left side.

Kawarai et al. [13] stated that paranasal sinuses were clearly larger in males than in females after studying in 20 Japanese's 3D CT scans. Amin and Hassan [1] measured maxillary sinuses with multidetector CT and stated that cephalocaudal and size of left maxillary sinus showed significant significance for gender determination. Correct predictive accuracy was 70.8% in males and 62.5% in females. In our study, the mean volumes for frontal and sphenoid sinus were found to be higher in males.

In a study done by Teke et al. [23] width, height and length of maxillary sinus were measured. It was stated that all measurements were higher in males than in females. The mean estimated rate of gender was detected at 69.3%. However, in this study, no significant difference was found between left and right for maxillary sinus volume and dimensions.

The influence of voxel size on image resolution has been widely confirmed in the literature — small voxel sizes generate images with high diagnostic power. Differences have been observed in the quality of images obtained from different devices when the field of view (FOV) or voxel size is changed. Smaller voxel sizes make CBCT better diagnostic tool than conventional radiography and CT scans. When considering the bone, measurements made by CBCT images and comparing them to digital calliper measurements (as a gold standard), Sun et al. [21] indicated (by evaluating bone thickness) that bone measurements obtained with voxel size of 0.25 mm^3 were closer to the results of direct measurement than images of 0.4 mm^3 voxels.

CONCLUSIONS

Gender and age estimation are crucial factors in personal identification. The result of the current study showed that the paranasal sinus can be combined in forensic anthropological studies as well as gender predilection.

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