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RELATIONSHIP OF MASTOID PNEUMATIZATION AND AGE WITH COMPUTED TOMOGRAPHY MEASURED SPHENOID SINUS VOLUME

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SUMMARY – The aim was to measure sphenoid sinus volume on the basis of computed tomography data post processing and to investigate the possible relationship with age, gender and mastoid pneumatization. Sphenoid sinus volume was measured using the semi-automatic post processing algorithm of MSCT DICOM datasets of 66 patients. There were 35 female and 31 male subjects. Median age was 54 (range 17-84) years. Datasets were selected retrospectively from computer archives of our hospital radiology department. Subjects with healthy sphenoid sinuses were included. Relationship of total sphenoid volume with age, gender and mastoid pneumatization was analyzed. Data acquisition was performed using Siemens Somatom Emotion scanner. Measurements were performed using volumetric module of Syngo 2006G software. Virtual endoscopy and three-dimensional volume rendering were also performed. Median sphenoid total volume (left and right together) was 10.12 cm^3. Median volume of the right mastoid was 4.86 cm^3 and 5.31 cm^3 on the left side. We found a significant positive correlation between total sphenoid volume and both left and right mastoid pneumatization (Spearman $\rho=0.528$, $p<0.001$ and $\rho=0.450$, $p<0.001$, respectively). Sphenoid volume was positively correlated with age, but without statistical significance ($\rho=0.186$; $p=0.136$). Sphenoid volumes were larger in males than in females, but mastoid air cells showed no gender difference. In conclusion, volumetric measurements of paranasal sinuses may be accurately performed on the basis of MSCT data post processing. Sphenoid volume was positively correlated with mastoid pneumatization and age. Virtual endoscopy and 3D volume rendering may accurately display anatomic structures of sphenoid sinuses.

Key words: *High resolution computed tomography; Sphenoid sinus; Volume measurements; Mastoid pneumatization; Virtual endoscopy; Three-dimensional volume rendering*

Introduction

Paranasal sinuses and mastoid air cells are the best distinguished forms for aeration purpose in humans[1]. Some studies report that the volume of air cavities in paranasal sinuses is the simplest and most important value employed in the assessment of paranasal sinus[2]. Gradual pneumatization of solid tissue is the mechanism of development of both structures. There are various reasons for the existence of aeration systems in humans and animals[1]. These reasons include weight decrease, phonation resonance increase, warming and humidifying of inspired air, and moderation of air flow during respiration[1,3].

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Fetal sphenoid sinus can be identified during the second trimester. It becomes apparent from the posterior part of the nasal capsule. The greatest growth of the sphenoid sinus usually occurs in the third year of life. Standard size of the sphenoid sinus in adults is 20 mm in height, 23 mm in depth, and 17 mm in width[4]. Mastoid pneumatization stops around puberty, as growth of all air cells in the temporal bone ends[5,6].

Various studies have estimated 95% sensitivity of computed tomography (CT) and magnetic resonance imaging (MRI) in the diagnosis of inflammatory diseases of the sphenoid sinus[7].

Recent advances in computer technology, medical imaging and CT data post processing software offer clinicians many valuable tools useful in diagnostics, as well as for scientific analysis and measurement of 3D anatomic structures[8]. Three-dimensional volume rendering (3DVR)[8] and virtual endoscopy[9] are widely applied for such purposes. Many studies have examined the volume of paranasal sinuses and mastoid air cells[10-12].

No agreement has yet been reached on the choice of optimal method for volumetric measurement of paranasal sinuses and mastoid air cells, although these cavities are located very close and undergo similar developmental processes. Also, the relationship between pneumatization of these cavities has not been fully clarified. To date, volumetric measurement has been mainly done by indirect methods such as cross-sectional area summation or using secondary parameters that represent volume[11], which may pose a limitation in obtaining accurate results. With the standard use of CT and MRI, 3D volume measurement of structures began to be used for the purposes of volumetric analysis, which is recommended as a reliable method for clinical application in measuring the volume of paranasal cavities and mastoid cells[11-13].

In this study, the relationship between volume of sphenoid sinuses and mastoid air cells was studied utilizing volumetric software and image reconstruction to construct a 3D model. Correlation of the volume of sphenoid sinuses and mastoid air cells with age was also assessed. Sphenoid sinus ostia and cavities were examined by virtual endoscopy and 3DVR in order to demonstrate absence of possible sinus pathology. The aim of this study was to conduct a pilot study to estimate the possibilities of sphenoid sinus volume measurement on the basis of CT data post processing and to investigate the possible relationship of sphenoid volume with age, gender and mastoid pneumatization in a sample recruited from the Croatian population.

Materials and Methods

Setting

This retrospective study was performed at Department of Radiology and Department of Otorhinolaryngology in a general hospital in Croatia. Study design and subject inclusion process, as well as procedures required to maintain subject anonymity were authorized by the institutional Ethics Board.

Study sample and selection criteria

A total of 66 subjects of both genders, aged 17-84 years, who underwent high-resolution computed tomography (HRCT) scans of paranasal sinuses and temporal bones during the last three years were selected. There were 31 males and 35 females. Study subjects were free from any manifestations of acute pathologic changes in the sinonasal tract or mastoid cavity. We selected patients aged >16 years, therefore we assumed that paranasal sinus growth was ended. Patients with evidence for acute sinusitis or mastoiditis, or a history of head trauma were excluded from the study. Documentation of patients that participated in the study was examined in order to screen for the presence of the aforementioned comorbidities.

Data acquisition and storage

Continuous non-overlapping sections of HRCT scans were used, with 0.6-1.2 mm slice thickness. A Siemens Somatom Emotion (Siemens Medical Systems, Erlangen, Germany) scanner was used. The imaging data were stored in a computer database in a Digital Imaging and Communication in Medicine (DICOM) format at Department of Radiology. A Dual Xeon processor (Intel, Santa Clara, California, USA) workstation running Syngo 2006G post processing software (Siemens Medical Systems, Erlangen, Germany) was used to create 3D reconstructed models of sinus cavities. Using a surface rendering algorithm, the window selection threshold was set in the range of -1024 to -200 Hounsfield units (HU). Three-dimensional information obtained from HRCT data was used for volume measurements and to explore and evaluate nasal cavity and paranasal sinuses by simulated virtual endoscopy and 3DVR.

Volume measurement

Total volume of sphenoid sinuses and mastoid air cells was semi automatically computed in 3D reconstructions (Figs. 1 and 2). Total sphenoid sinus volumes were calculated as a sum of the left and right cavity volume. Volumes of temporal bone mastoid air cell pneumatization were measured in the same manner. Two ENT specialists outlined the region of interest on each axial slice by pointing device (computer mouse) (Fig. 3), whereas volumetric software from Syngo post processing package integrated those surfaces in a 3D model and calculated sphenoid sinus and mastoid volume (Fig. 4). Interobserver difference was not statistically significant.

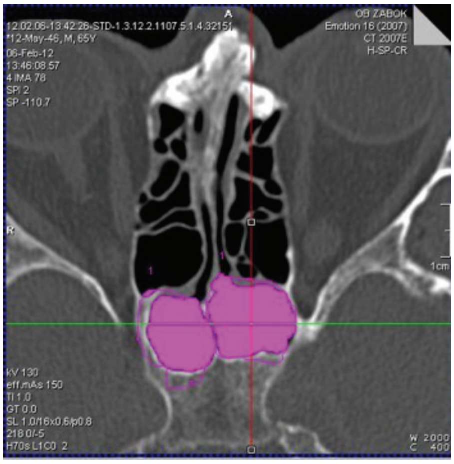

Fig. 1. Axial slice of the computed tomography scan of ethmoid sinus.

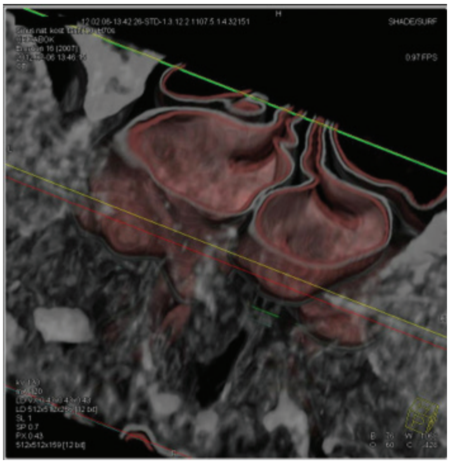

Fig. 2. 3D volume rendering result in the same patient. Clipping planes were applied. Both sphenoid sinus ostia and sphenoethmoid recesses were depicted, as well as their relationship to the surrounding anatomic structures.

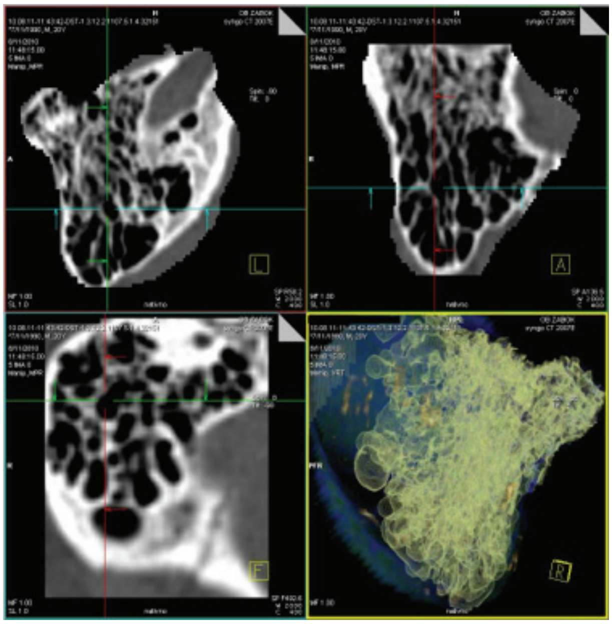

Fig. 3. Volume of interest was selected and confined by using manually driven clipping planes. Volume of interest that contains pneumatized cells of the right mastoid in a 20-year-old man was selected.

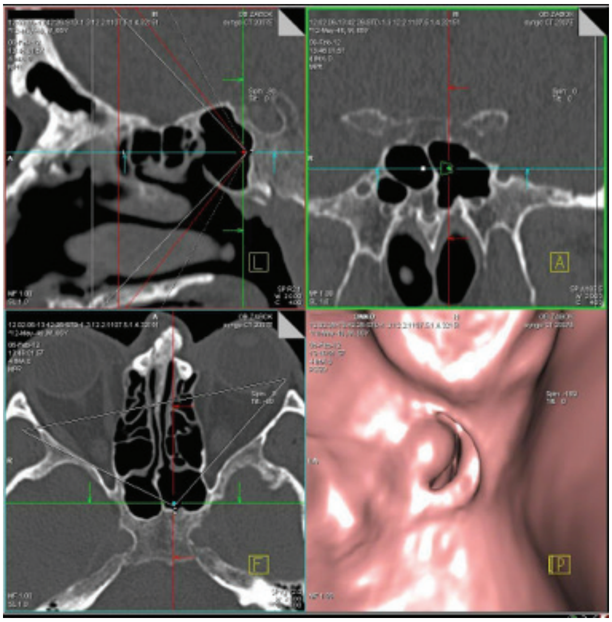

Fig. 4. Virtual endoscopy: virtual endocamera was situated within the left sphenoid sinus and directed towards the sinus ostium. Its location and orientation was visible within three coordinate planes. 3D reconstructed camera view in the fourth window showed anterior wall of the sphenoid and its opening towards the sphenoethmoid recess. Sinus was healthy and there was no obstruction of sinus ostia.

Statistical analysis

Continuous values were expressed as median and range since the assumption of normality was not met. Normality was estimated by Kolmogorov-Smirnov test. Categorical values were expressed as count and percentage. Mann-Whitney U test was used to test for statistical significance between independent sample continuous variable values, Wilcoxon test for paired sample continuous variable values, and Spearman's ρ was calculated to test for correlation between continuous variables. Statistical analysis was performed using SPSS 15.0 software (SPSS Inc., Chicago, USA). The values of $p<0.05$ were considered statistically significant.

Results

Median age of study subjects was 54 (range 17-84) years. There were 35 female and 31 male subjects. All of the subjects were Caucasian. Median volume of the right mastoid was 4.86 cm^3, whereas on the left side it was 5.31 cm^3. There was no significant difference between the left and right mastoid volume (Wilcoxon p=0.556).

We found mild to moderate but statistically significant negative correlation of pneumatization volume with age for both left (ρ=-0.379; p=0.002) and right (ρ=-0.391; p=0.001) mastoid. For both genders, the correlation with age was also significant and negative ($p<0.05$). Median sphenoid total volume was 10.12 cm^3. We found significant positive correlation between sphenoid volume and both left and right mastoid pneumatization (right side ρ=0.528; $p<0.001$ and left side ρ=0.450; $p<0.001$). Sphenoid volume was not significantly correlated with age (ρ=0.186; p=0.136). Negative correlation was found for both right and left mastoid pneumatization with age (ρ=-0.391; p=0.001 and ρ=-0.379; p=0.002).

No significant differences were observed between the left and right mastoid air cell volumes ($p<0.05$) (Fig. 5). No statistically significant difference in mastoid air cell volume was found between genders on either right (p=0.93) or left (p=0.464) side (Fig. 6). The sphenoid sinus systems of male subjects were larger than those of females ($p<0.05$) (Fig. 7).

Discussion

The volumes measured in our study subjects were similar to those obtained by Karakas and Kavakli, who found that the volume of paranasal sinuses and mastoid air cells increased in older subjects, and women had a lower mean volume[11]. We also found that there was a positive correlation between pneumatization of mastoid air cells and that of sphenoid sinus, as described by Kim *et al.*[10]. The

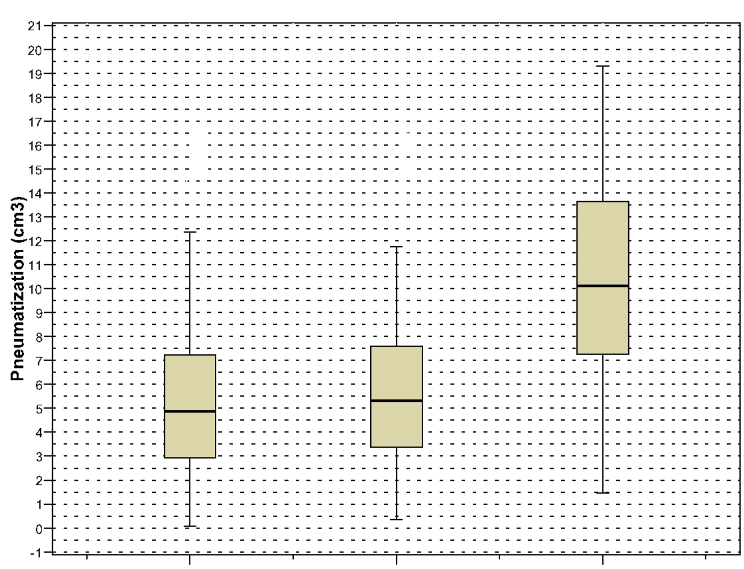

Fig. 5. Total sphenoid volume and median volumes of pneumatized air spaces (cm^3) of the right and left mastoid are presented in the form of box and whisker plots (median, 25th and 75th quartile, range).

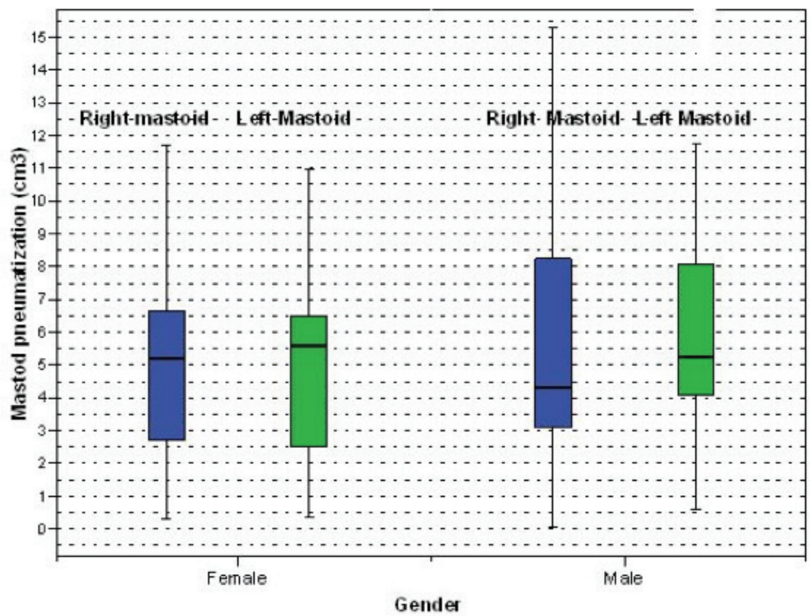

Fig. 6. Mastoid pneumatization of both sides according to gender is shown in the form of box and whisker plots (median, 25th and 75th quartile, range).

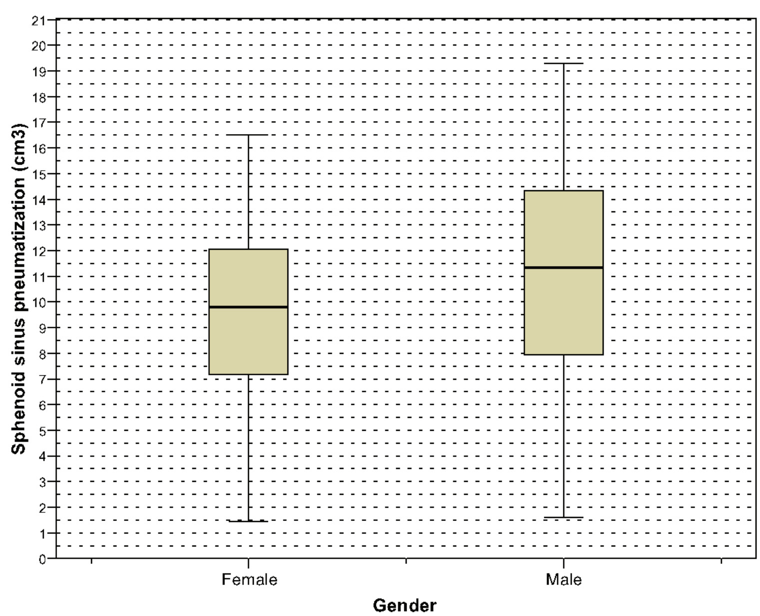

Fig. 7. Median total sphenoid volume according to gender is shown in the form of box and whisker plots (median, 25th and 75th quartile, range).

mastoid air cell volumes measured in our study were somewhat lower than those found by Molvaer *et al.*[14], who report a mean volume of 6.5 cm^3 (range 2-22 cm^3) in their sample. Total sphenoid volume in our sample (10.12 cm^3) was lower than that found by Emirzeoglu *et al.* (13.6±0.7 cm^3)[15].

The pneumatization theory suggests that pneumatized cavities are caused by opportunistic expansion of the epithelium into the available space. Dimensions and form of air cavities arise from two opposing forces. One is the epithelial propensity of opportunistic expansion, and the other is the exigency for a structurally sound and efficacious bone construction. Accumulation of bone confirms that during growth, some integral components such as buttresses are indispensable to defend from exterior pressure. Pneumatization of the air cavities depends on the model of epithelial propagation. Many differences among various species come from permanent conflict between osseous accumulation and propagation of the epithelium because numerous different exterior physical impulses cause the interspecific variety of form and conduct[16]. This clarifies differences within the same species in individuals with different behavior patterns or daily activities. Pneumatization of mastoid and paranasal spaces can be stimulated by the presence of positive air pressure in the epipharynx which affects the eustachian tube opening[10,17]. The cause for the existence of these air systems is loss of the spongiosa in the maxillary, sphenoid and frontal sinuses, as well as mastoid bone. The entire volume of nasal cavity influences airflow within it and has an effect on the quantity of positive air pressure on the mucosa of the epipharynx and nasal space. Until today, different methods of calculating air space volume have been used[10]. According to Colhun *et al.*, mastoid cell volume can be precisely measured on cadavers[18]. However, the failure of the cadaver study results from the fact that the soft tissue volume of the cavities measured in the cadavers is already decomposed[10]. Another method for estimating the size of the mastoid cavities and middle ear is the acoustic method[18], which specifically measures the volume of enclosed air[10]. High resolution multi-slice computed tomography (HRCT) is superior to other methods for evaluation of cavity volume[10]. HRCT has many advantages for measuring volumes and dimensions of 3D structures. Compared to other methods, it is cheaper and demands less operator effort to produce accurate results[10]. CT is a noninvasive method that enables multiple evaluations on the same subject and monitoring changes on sinonasal bones[10].

We used a method that includes volume- and surface-rendering algorithms. Surface rendering or so-called threshold rendering can be used especially in surgical planning to reduce the probability of error and in medical education[8]. It specifically renders the surface of an object and discards its interior. Because of that, it is very precise in describing anatomic features. However, because of its intricacies it is susceptible to noise which might distort the rendered image. For precise volume evaluation, it is important to choose the right window thresholds. Excessive adjustment of upper threshold leads to inclusion of mucosa in mastoid cells and overvaluation of mastoid cell volume. Contrary, too low adjustment of the upper threshold leads to non-recognition of small cells and undervaluation of mastoid cell volume. We used a lower threshold of -1024 HU and an upper threshold of -200 HU in order to display only pneumatized cavities. This is the most favorable and simple measurement technique of pneumatized construction because of its properties regarding HU thresholds in CT images.

Karakas and Kavakli[11] advised a connection between paranasal sinuses and mastoid cavities by adding the cross-sectional area in axial CT images at different section thicknesses. They conclude that the volume of paranasal sinuses and mastoid cavities becomes larger with age, but no significant correlation in their volume difference was found. Concerning the volume, only the sphenoid sinus had a correlation with mastoid cavities. This may be explained by the proximity of the openings of these structures into the nasal cavity, which may provide similar effect as the changes that appear during growth. The development of the sphenoid sinus and mastoid cavities is much slower in comparison to maxillary sinus[10], allowing more possibilities for separate or concurrent pathology to happen. It was also observed that the mastoid cell volume and size of temporal bone were smaller on the side affected by infections or other pathologic events[3].

When comparing our results with the authors mentioned above, differences among various populations should be taken into account. First of all, there are considerable differences in cranial (including sinus shape and volume) features among various races, and since there is virtually no racial variability in the Croatian population (as our results show, all subjects of were Caucasians), only research with similar subject populations should be compared to ours. Some other factors such as body surface area, cranial circumference and body mass index should also be measured (which may also vary among various populations, not only among different countries and continents but also within one country, e.g., anthropologic features of the Croatian people can be very different between northern and southern parts of the country). Those measurements may be used in conjunction with measured sinus volume to create indexed values (such as sinus volume *per* centimeter of cranial circumference at temporal lamina level), which would then make it possible to directly compare indexed values without introducing bias caused by anthropologic differences.

In our present work, we demonstrated the use of 3D reconstruction of HRCT images to analyze the correlation among pneumatization of the sphenoid sinus, mastoid cavities, gender and age. ENT clinicians may find these results helpful for the diagnosis and treatment planning. Preoperative assessment of sphenoid sinus volume is of major clinical significance in patients scheduled for hypophyseal surgery, as sphenoid sinus has to be traversed to approach the sella turcica. Preoperative sinus volume measurement may also be used in the assessment of upper airway dead space. Although measured volumes are negligible compared to upper airway volume in healthy subjects, in patients with reduced upper airway volume (such as those suffering from obstructive sleep apnea) these spaces may become clinically significant, especially in patients that are difficult to intubate and are at a higher risk of early desaturation.

Conclusion

Multi-slice computed tomography data post processing may be used to calculate volumetric measurements of paranasal sinuses. In the study population, the volume of sphenoid sinus was positively correlated with the level of mastoid pneumatization and age. Virtual endoscopy and 3DVR may accurately display anatomic structures of sphenoid sinuses and may offer valuable additional data for patient management planning. We found Syngo 3D platform for postprocessing CT data easy to use and our 3DVR generated images and fly-through were of good quality with acceptable frame rate.

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Sažetak

POVEZANOST PNEUMATIZACIE MASTOIDNIH SINUSA I DOBI S VOLUMENOM SFENOIDNIH SINUSA IZMJERENIM KOMPJUTORIZIRANOM TOMOGRAFIJOM

R. Gulić, A. Šribar i *D. Vagić*

Cilj je bio izračunati volumen sfenoidnih sinusa temeljem naknadno obrađenih podataka CT-a i istražiti moguću povezanost s dobi, spolom i mastoidnom pneumatizacijom. Volumen sfenoidnih sinusa je izmjeren koristeći poluautomatski naknadno obrađeni algoritam MSCT DICOM podataka 66 bolesnika. Bilo je 35 ženskih i 31 muških ispitanika. Medijan dobi je bio 54 (raspon 17-84) godine. Podaci su retrospektivno odabrani iz računalne arhive radiološkog odjela naše bolnice. Uključeni su ispitanici sa zdravim sfenoidnim sinusima. Analiziran je odnos ukupnog sfenoidnog volumena s dobi, spolom i mastoidnom pneumatizacijom. Podaci su dobiveni pomoću Siemens Somatom Emotion skenera. Mjerenja su učinjena koristeći volumetrijski modularni program Syngo 2006G. Izvedena je također virtualna endoskopija i trodimenzionalno prikazivanje volumena. Medijan ukupnog volumena sfenoida (lijevi i desni zajedno) je bio 10,12 cm^3. Medijan volumena desnog mastoida je iznosio 4,86 cm^3 i 5,31 cm^3 s lijeve strane. Našli smo značajno pozitivnu korelaciju između ukupnog volumena sfenoida i obje, lijeve i desne mastoidne pneumatizacije (Spearman rho=0,528, p<0,001, odnosno rho=0,450, p<0,001). Volumen sfenoida je bio u pozitivnoj korelaciji s dobi, ali bez statističke značajnosti (rho=0,186; p=0,136). Volumeni sfenoida su bili veći kod muškaraca nego kod žena, ali mastoidne celule nisu pokazale razlike među spolovima. U zaključku, volumetrijsko mjerenje paranazalnih sinusa može biti točno izvedeno temeljem naknadno obrađenih MSCT podataka. Volumen sfenoida je u pozitivnoj korelaciji s pneumatizacijom mastoida i dobi. Virtualna endoskopija i 3D prikazivanje volumena može točno prikazati anatomske strukture sfenoidnih sinusa.

Ključne riječi: *Visoka rezolucijska kompjutorska tomografija; Sfenoidni sinus; Mjerenje volumena; Mastoidna pneumatizacija; Virtualna endoskopija; Trodimenzionalni prikaz volumena*