DOI 10.26724/2079-8334-2025-3-93-68-73
UDC 616.216.1-06-07

V.M. Zaporozhchenko, I.M. Tkachenko, A.V. Dvornyk, O.V. Gurzhiy, Y.Y. Vodoriz
Poltava State Medical University, Poltava

DEVELOPMENT OF A METHODOLOGY FOR STUDYING INDICATORS RELATED TO THE MEASUREMENT OF MAXILLARY SINUS THICKNESS, VOLUME USING LINEAR CALCULATIONS, AND DENSITY OF ITS COMPACT LAMINA BASED ON THE ANALYSIS OF A COMPUTED TOMOGRAPHY SCAN

e-mail: v.zaporozhchenko@pdmu.edu.ua

Odontogenic maxillary sinusitis is a frequent complication of dental procedures, contributing to 25–40 % of chronic maxillary sinusitis cases and leading to a 10–20 % reduction in sinus volume. This necessitates precise morphometric evaluation. Using a NewTom GIANO HR scanner (voxel 0.1–0.2 mm), tomograms of 10 volunteers (aged 20–40) were analyzed. Linear measurements were taken with Ez3D tools; volume was calculated via ellipsoid and spherical models. The ellipsoid model proved more accurate (error 4–7 %) than the spherical one (8–12 %). The average sinus volume was 14.85 cm³. Cortical lamina density (HU) strongly correlated with its thickness ($r > 0.9$). The method is quick (≤5 min/patient), cost-effective, and suitable for routine clinical use. Correlation analysis supports its use in treatment planning, helping differentiate between surgical and conservative approaches. Further research should compare manual and automated CT analyses and assess mucosal thickness impact on sinus dynamics.

Key words: maxillary sinus volume, linear measurements, density index, odontogenic maxillary sinusitis, cortical plate, cone beam computed tomography.

В.М. Запорожченко, І.М. Ткаченко, А.В. Дворник, О.В. Гуржій, Я.Ю. Водоріз

РОЗРОБКА МЕТОДИКИ ДОСЛІДЖЕННЯ ПОКАЗНИКІВ, ЩО СТОСУЮТЬСЯ ВИМІРУ ТОВЩИНИ ТА ОБ'ЄМУ ГАЙМОРОВОЇ ПАЗУХИ, З ВИКОРИСТАННЯМ ЛІНІЙНИХ РОЗРАХУНКІВ ТА ЩІЛЬНОСТІ ЇЇ КОМПАКТНОЇ ПЛАСТИНКИ НА ОСНОВІ АНАЛІЗУ КОМП'ЮТЕРНОЇ ТОМОГРАМИ

Одонтогенний гайморит є частим ускладненням стоматологічних процедур, що становить 25–40 % випадків хронічного гаймориту і призводить до зменшення об'єму пазухи на 10–20 %. Це вимагає точної морфометричної оцінки. За допомогою сканера NewTom GIANO HR (воксел 0,1–0,2 мм) було проаналізовано томограми 10 добровольців (віком 20–40 років). Лінійні вимірювання проводилися за допомогою інструментів Ez3D; об'єм розраховувався за допомогою еліпсоїдних і сферичних моделей. Еліпсоїдна модель виявилася точнішою (похибка 4–7 %), ніж сферична (8–12 %). Середній об'єм пазухи становив 14,85 см³. Щільність кортикальної пластинки (HU) сильно корелювала з її товщиною ($r > 0,9$). Метод є швидким (≤5 хв/пацієнт), економічно ефективним і придатним для рутинного клінічного використання. Кореляційний аналіз підтверджує його використання в плануванні лікування, допомагаючи розрізняти хірургічні та консервативні підходи. Подальші дослідження повинні порівняти ручний та автоматизований аналіз КТ та оцінити вплив товщини слизової оболонки на динаміку синусів.

Ключові слова: об'єм гайморової пазухи, лінійні вимірювання, індекс щільності, одонтогенний гайморит, кортикальна пластинка, конусно-променева комп'ютерна томографія.

The work is a fragment of the research project "Substantiation of the choice of methods of treatment of organ diseases of the oral cavity depending on their morphological and functional characteristics", state registration No. 0124U004553.

The maxillary sinus is the largest paranasal sinus and plays a key role in facial skeleton formation, vocal resonance, thermoregulation of inhaled air, and reduction of skull weight. Its close anatomical relationship with the teeth of the upper jaw predisposes to odontogenic complications, among which odontogenic maxillary sinusitis (OGS) is of particular clinical importance. OGS most often results from infection spreading from periodontal tissues or root canals, or as a complication of dental interventions such as tooth extraction and implantation [5]. According to numerous studies, approximately 25–40 % of chronic maxillary sinusitis cases are odontogenic in origin. In contrast to rhinogenic sinusitis, OGS is frequently unilateral and may be accompanied by inflammatory mucosal remodeling and impaired pneumatization of the sinus [12].

Accurate diagnosis of OGS requires evaluation of morphometric parameters, primarily sinus volume and mucosal thickness. Cone-beam computed tomography (CBCT) and multislice computed tomography (MSCT) have become essential diagnostic tools, allowing detailed visualization of anatomical changes. Automated software-based algorithms for volume calculation have been proposed, but they are often time-consuming and require specialized programs, limiting their routine clinical application. Linear measurements of sinus dimensions (height, width, length) allow for rapid and reliable estimation of volume using mathematical models such as the sphere or ellipsoid formula [7]. This approach is particularly relevant in dental practice, where timely assessment of sinus anatomy is critical for planning implantation, sinus floor elevation, and treatment of sinusitis.

Previous studies have demonstrated that chronic OGS may lead to a reduction in sinus volume by 10–20 %, largely due to mucosal thickening and proliferation [4]. Early detection of such changes enables prediction of disease progression, adaptation of treatment strategies, and prevention of complications. Literature data also highlight diagnostic uncertainty in determining whether management should be prioritized by the dentist or otorhinolaryngologist, as periapical pathology is associated with maxillary sinus changes in more than 50 % of cases [5, 12]. Most often, the first and second maxillary molars are implicated, and CBCT has been shown to be particularly effective in identifying both sinus changes and their odontogenic causes [2].

The morphology of the maxillary sinus can be approximated by simple geometric forms. Although automated segmentation provides accurate volumetric values, studies such as Przystańska et al. [4] demonstrated that manually calculated sinus volumes strongly correlate with software-based methods. This underscores the clinical utility of simplified, reproducible approaches based on CBCT-derived linear measurements. Average sinus volumes in healthy individuals have been reported to range between 14.8 and 16.1 cm³ [7, 11], while deviations from these values may indicate pathological remodeling. Importantly, CBCT outperforms conventional radiographs in evaluating sinus anatomy and associated periodontal or periapical pathology [6].

Given the high prevalence of OGS and its impact on sinus function, there is a need for fast, clinically applicable, and reliable methods of volumetric assessment. Linear CBCT-based measurements combined with mathematical models (sphere or ellipsoid) provide an efficient solution, avoiding the limitations of automated algorithms while ensuring diagnostic accuracy.

The purpose of the study was to improve the methodology for researching indicators related to the measurement of maxillary sinus volume using linear calculations and the density and thickness of its compact lamina based on the analysis of a computed tomography scan to improve the diagnosis and treatment of odontogenic maxillary sinusitis in the clinical practice of doctors.

Materials and methods. The study was conducted in accordance with bioethical standards. Participants were provided with all necessary information about the purpose, process and possible risks of the study. All participants voluntarily provided informed consent, confirming their understanding and willingness to participate. Data confidentiality was ensured at all stages of the study. To determine the size of the maxillary sinuses, maxillary sinus tomograms belonging to 10 patients aged 20–40 years with an orthognathic bite were analyzed. All CBCT studies were obtained using a NewTom GIANO HR scanner with a voxel range of 0.1–0.2. Linear measurements were obtained using Ez3D software measurement tools.

Table with average maxillary sinus volumes obtained in the study by Giacomini et al [7]. The study was conducted during 2024–2025 at the Poltava State Medical University (Poltava, Ukraine).

The inclusion criteria comprised patients aged 20–60 years with orthognathic bite, no craniofacial deformities, no history of maxillofacial trauma or sinus surgery, absence of systemic diseases affecting bone metabolism, and availability of high-quality CBCT scans (voxel size 0.1–0.2 mm). Exclusion criteria included non-odontogenic rhinosinusitis, previous sinus surgery, severe periodontal or periapical pathology, congenital anomalies, and CBCT images of insufficient quality with artifacts.

Average Volumes of the Maxillary Sinus.

Reported values for the mean maxillary sinus volume in healthy individuals range from 14.8 to 16.1 cm³, depending on the imaging method and evaluation technique. Automated CT analysis yielded 15.2 cm³ (Giacomini et al., 2018), CBCT-based studies reported 14.8 cm³ (Pérez Sayańs et al., 2020) and 16.1 cm³ with manual segmentation (Ceren Aktuna Belgin et al., 2019), while standard CT with the Cavalieri principle showed 15.7 cm³ (Elamin et al., 2019). These findings suggest a consistent volumetric range irrespective of methodological differences [7].

All patients underwent computed tomography (CT) of the facial skeleton to determine the volume of the maxillary sinus. The volume of the sinus was measured using linear measurements and the ellipsoidal volume formula based on CT images.

The method of maxillary sinus volume measurement

was based on the ellipsoid model, which reduces the error compared to the sphere model because it takes into account variations in the size of the sinus in different planes.

Calculation of sinus volume (V) is calculated using the ellipsoid formula:

$V = 4/3 \times \pi \times (2H) \times (2W) \times (2D)$.

This formula gives an approximate volume of the sinus, which can be refined using correction factors that take into account individual anatomical features.

Determination of mucosal volume.

Mucosal volume (V_m) is calculated as the difference between the total volume of the sinus (V) and the volume of free space (V_p), which is determined by the same linear parameters, but taking into account the thickness of the mucosa:

$V_m = V – V_p$.

To update the data obtained for its use in the selection of treatment methods, we determined the cortical lamina density index and its thickness in the area of the periapical tissues of the causative tooth that caused odontogenic maxillary sinusitis. We measured the density and thickness of the cortical plate using a ruler that is present in the EZ3D program.

The correlation of this indicator was carried out with the Hounsfield index, based on the air density index -1000 HU. Measurements on a computed tomography scan were performed outside the structures of the human body.

Results of the study and their discussion. Accurate morphometric assessment of the maxillary sinus is essential for optimizing diagnosis and treatment planning in odontogenic maxillary sinusitis. Standardization of measurement methodology not only improves reproducibility but also ensures that subtle anatomical variations are captured, which is particularly relevant in patients undergoing dental implantation or sinus floor elevation procedures. Establishing a systematic approach that integrates linear dimensions with density analysis provides a clinically valuable framework for differentiating between conservative and surgical treatment strategies. When developing the methodology for determining the volume of the maxillary sinus, we calculated the ratio of air density to the Hounsfield index.

On 10 control tomograms, the air density index was -990, -989, -993, -991, -989, -993, -992, -995, -988, -989 (Fig. 1A). Thus, the ratio of the density index to the Hounsfield index is 0.990.

$I_d / I_h = 0.990$,

where: I_d – density index, I_h – Hounsfield index.

The second stage of the proposed methodology is to establish the study points for the correct calculation of linear dimensions in relation to the width, height and length of the object under study (Fig. 1B). To obtain linear parameters and correctly estimate the volume of the sinus, the following steps are necessary:

1. Determine three main parameters that are set at the extreme points of the bone formation: Height (a): the distance from the bottom of the sinus to its upper border. Width (b): The largest transverse dimension of the sinus. Length (c): anterior-posterior dimension of the sinus.

– Method of determination maxillary sinus height (Fig. 1C):

The height is determined on coronal (frontal) CT sections. – Anthropometric landmarks: – Lower border: The lowest point of the sinus floor adjacent to the alveolar ridge of the maxilla (in the area where the roots of the sixth molars are located). – Upper border: The highest point of the sinus ceiling, forming part of the orbital wall, i.e. the area adjacent to the lower border of the orbit.

Method of determination maxillary sinus width (Fig. 1D):

The width is measured on axial CT sections or can be confirmed on coronal images.

Anthropometric landmarks:

Medial border: The innermost border of the sinus, the point that borders the lateral wall of the nasal cavity. Lateral border: The point farthest from the nasal cavity, defined as the outer wall of the maxillary sinus.

Method of determination maxillary sinus length (Fig. 1E):

The length is determined on the axial section of the CT scan.

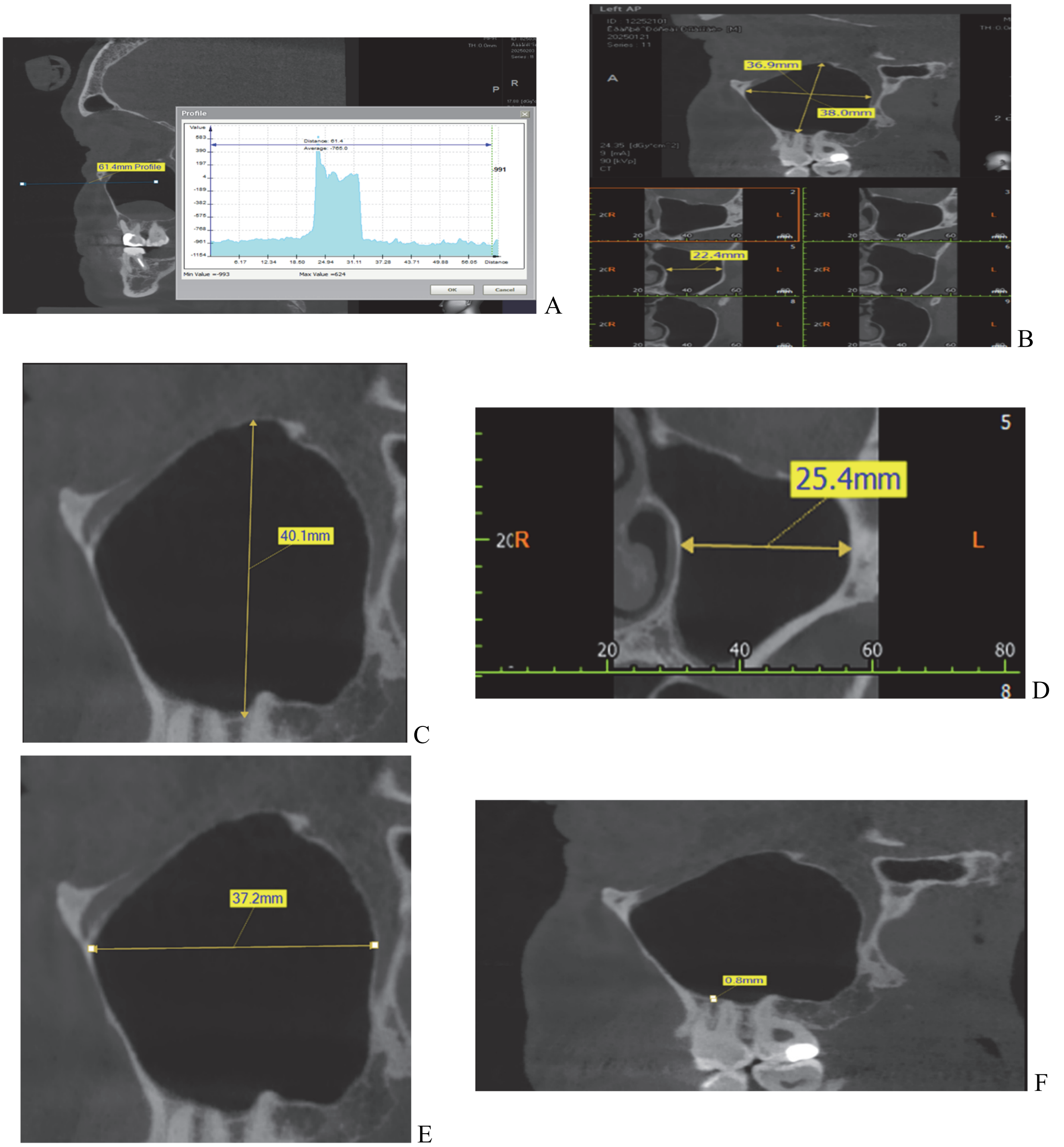
Anthropometric landmarks: Anterior border: The most anterior point of the sinus. Posterior border: The most distal point of the sinus, determined by the posterior wall boundary point that borders the space adjacent to the infratemporal region.

The next step is to measure the thickness of the maxillary sinus cortical lamina for further correlation of the results (Fig. 1F).

In addition, the density of the cortical plate was assessed relative to the Hounsfield index (Fig. 1G).

As a result of the complex of studies, a summary table of indicators was obtained for further processing (Table 1).

For the statistical processing and analysis of the obtained morphometric data, the open-source analytical software JASP was utilized. This platform was selected due to its capacity to perform both descriptive and inferential statistics, providing transparent output and reproducible results.



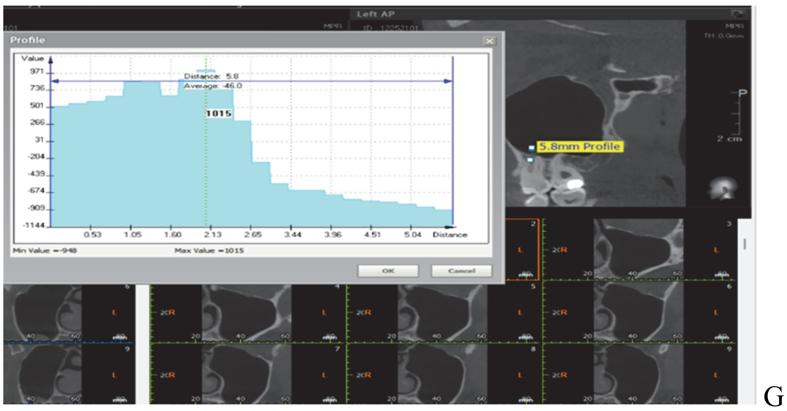


Fig. 1. Visualization of the methodology for measuring and volumetric assessment of the maxillary sinus. A – Air density index (patient's study card No. 2). B – Determination of anatomical landmarks for linear dimensioning. C – Maxillary sinus height. D – Maxillary sinus width. E – Maxillary sinus length (anteroposterior measurement). F – Measurement of the thickness of the cortical plate in the area of the maxillary sinus floor using a ruler in the EZ3D program. G – The density of the cortical lamina was also determined in relation to the Hounsfield index.

Using linear methods of measuring the volume of the maxillary sinus in healthy patients, we found an average value of 14.85 cm^3. Thus, the measurements are accurate, coincide with the measurements of previous authors and confirm the effectiveness of linear calculations, which allows us to recommend the use of this technique in the practice of an otolaryngologist and dentist.

When comparing the thickness and density of the cortical plate, the following correlations of the studied indicators were obtained. After measuring the cortical plate density index and cortical plate thickness in the area of the upper sixth teeth, we established a corresponding relationship between the two indicators – the greater the thickness of the cortical plate, the higher the density index. In the future, we will be able to use these indicators to measure the volume of growth of the maxillary sinus mucosa to the total volume of the sinus as a percentage, and to establish the relationship between these parameters. Based on these measurements, we can choose the best treatment plan for odontogenic maxillary sinusitis. The data obtained were analyzed using correlation and regression analysis to determine the relationship between the degree of mucosal thickening and changes in sinus volume.

Table 1

Results of linear calculations of the study group patients

No.	Gender	Age	Height of the sinuses	Length of the sinuses	Width of the sinuses	Vn	Thickness of c.p	Osteum diameter	Density index of c.p
1	1	26	1.9	1.8	1.1	16.45	0.8	2.0	1015
2	2	20	1.7	1.7	1.4	18.42	0.4	2.5	603
3	2	20	1.6	1.39	1.2	11.25	1.1	3.4	985
4	2	39	1.77	1.5	1.2	13.46	1.0	3.5	1409
5	1	30	1.8	1.65	1.3	16.8	0.9	2.8	1102
6	2	22	1.65	1.5	1.2	12.8	0.5	2.6	851
7	1	35	1.65	1.7	1.4	18.9	1.0	3.2	1318
8	2	28	1.7	1.6	1.2	14.0	0.6	2.7	1031
9	2	40	1.8	1.5	1.3	15.1	0.8	3.0	1120
10	1	32	1.75	1.55	1.25	14.6	0.7	2.9	1000

The sphere model: showed an average error of 8–12 %, which makes it less suitable for clinical use due to oversimplification the anatomical shape of the sinus. Ellipsoid model: had an error of 4–7 %, which makes it a more accurate alternative to linear methods. Automated CT methods: the smallest error is 3–5 %, but they require special software and considerable time for data processing.

Thus, the ellipsoid model is the best option in the absence of access to automated analysis, where the following indicators should be taken into account:

1. Tissue density in the maxillary sinus is assessed using the Hounsfield Units (HU) scale: Air has an indicator of (-1000 HU); Healthy mucous membrane – (10–30 HU); Inflammatory changes (edema, purulent content) can reach (60–100 HU); Bone structures have (300–1000 HU) [10].

This indicator helps to distinguish between healthy and thickened mucosa, as well as to determine the presence of pathological processes.

The cortical plate of the maxilla is an important anatomical landmark that affects the pneumatization of the maxillary sinus. Normally, its thickness is 1.5–3 mm, but in chronic inflammatory processes it can change. This should be taken into account when assessing changes in sinus volume [3].

When using linear methods of calculating the volume, the error can be 5–10 %, which is associated with anatomical variations in the shape of the sinus and possible errors in the measurement of parameters [1, 9]. To minimize errors, it is necessary to use average values from several CT slices, control the correctness of the orientation of the planes when measuring linear dimensions, the permissible error is determined depending on the purpose of the study. For clinical purposes, it should not exceed 10 %, and for scientific research – 5 %.

In contrast to the automated approach proposed by Giacomini et al. (2018), which relies on advanced image processing algorithms and requires specialized software for segmentation, the methodology presented in our study offers a more pragmatic alternative. By employing linear anthropometric landmarks and ellipsoid modeling, our technique does not necessitate additional software beyond standard diagnostic platforms, making it feasible for direct use in clinical practice. The mean maxillary sinus volume obtained in our sample was 14.85 cm³ (ranging from 12.8 cm³ to 16.7 cm³), which is in agreement with reference values reported in previous literature. These findings confirm the reliability of the proposed methodology for volumetric assessment. Although automated tools may provide slightly higher precision in research settings, the simplicity, accessibility, and reproducibility of our approach ensure that accurate volumetric estimations can be obtained rapidly, thereby enhancing its clinical applicability for routine diagnostic and treatment planning purposes, particularly in implantology and sinus floor elevation procedures.

Conclusion

Linear measurements allow to quickly and effectively assess changes in maxillary sinus volume in odontogenic maxillary sinusitis. The use of computed tomography methods in combination with linear calculations is a promising tool for the diagnosis and treatment planning of OG.

The use of the ellipsoid model is more accurate compared to the spherical model. Additional consideration of the Hounsfield index and cortical lamina thickness can improve the quality of diagnosis.

The obtained results confirm that our proposed model for measuring maxillary sinus volume is competitive and comfortable for use in the clinical work of otolaryngologists and dentists. After all, it allows for reliable, correct measurements quickly enough and does not require additional costs for automated software. The use of linear measurements for volume estimation proved to be highly effective and comparable to automated methods, which is confirmed by previous studies.

It is advisable to conduct a further comparative study of the effectiveness of linear measurements of maxillary sinus volume using the ellipsoid model with the results of automated CT programs in different clinical settings. Additional studies are needed on the effect of varying degrees of mucosal thickening (in particular, more than 10 mm) on the volume of the sinus and the possible need for surgical intervention. It is advisable to study the correlation between the thickness of the maxillary cortical plate and the incidence of complications during dental implantation to improve preoperative planning.

References

1. Faustova MO, Ananieva MM, Basarab YO, Dobrobolska OV, Vovk IM, Loban' GA. Bacterial factors of cariogenicity: literature review. Wiad Lek. 2018;71(2 Pt 2):378-82 [in Ukrainian].
2. Kovach IV, Zub HE, Lokes KP. Vykorystannia rehresiinykh liniinykh modelei dlia vyznachennia vplyvu viku na vymiriuvani anatonichni vidstani pry likuvanni perelomiv nyzhnoi shchelepy u ditei. 2024, 4 (90): 68-73. doi: 10.26724/2079-8334-2024-4-90-68-73, [in Ukrainian].
3. Alqahtani H, Basuhail S, Alsulaimani F, Zawawi K, Barayan M, Turki G, et al. The relationship between maxillary sinus volume and various cephalometric characteristics in orthodontics. Contemp Clin Dent. 2023;14(3):191-200. doi:10.4103/ccd.ccd_548_22.
4. Belgin C, Çolak M, Adiguzel O, Akkuş Z, Orhan K. Three-dimensional evaluation of maxillary sinus volume in different age and sex groups using CBCT. Eur Arch Otorhinolaryngol. 2019;276:1493-99. doi:10.1007/s00405-019-05383-y.
5. Craig JR, Poetker DM, Aksoy U, Allevi F, Biglioli F, Bruce Y Cha, et al. Diagnosing odontogenic sinusitis: an international multidisciplinary consensus statement. Int Forum Allergy Rhinol. 2021;11(8):1235-48. doi:10.1002/alr.22777.
6. Elamin A, Acar T, Kajoak S, Idris S, Malik B, Ayad C. Volumetric measurement of the maxillary sinuses in normal Sudanese using computed tomography: a retrospective study. J Clin Diagn Res. 2021;15(5):AC11–AC15. doi:10.7860/JCDR/2021/48095.14894.
7. Giacomini G, Pavan ALM, Altemani JMC, Duarte SB, Fortaleza CMCB, Miranda JRA, et al. Computed tomography-based volumetric tool for standardized measurement of the maxillary sinus. PLoS One. 2018;13(1):e0190770. doi:10.1371/journal.pone.0190770.
8. Hettiarachchi PVKS, Gunathilake PMPC, Jayasinghe RM, Fonseka MC, Bandara RMWR, Nanayakkara CD, et al. Linear and volumetric analysis of maxillary sinus pneumatization in a Sri Lankan population using cone beam computed tomography. Biomed Res Int. 2021;2021:6659085. doi:10.1155/2021/6659085.
9. Przystańska A, Kulczyk T, Rewekant A, Sroka A, Jończyk-Potoczna K, Lorkiewicz-Muszyńska D, et al. Introducing a simple method of maxillary sinus volume assessment based on linear dimensions. Ann Anat. 2018;215:47-51. doi:10.1016/j.aanat.2017.09.010.
10. Sayáns P, Quintanilla J, Petronacci C, Peñaranda J, Jornet L, García F, et al. Volumetric study of the maxillary sinus in patients with sinus pathology. PLoS One. 2020;15(11):e0234915. doi:10.1371/journal.pone.0234915.
11. Simuntis R, Tušas P, Kubilius R, Leketas M, Šiupšinskienė N, Vaitkus S. Association between maxillary posterior teeth periapical odontogenic lesions and maxillary sinus mucosal thickening: a 3D volumetric computed tomography analysis. Sinusitis. 2020;4(1):1. doi:10.3390/sinusitis4010003.
12. Wang KL, Nichols BG, Poetker DM, Loehrl TA. Odontogenic sinusitis: a case series studying diagnosis and management. Int Forum Allergy Rhinol. 2015;5(7):597-601. doi:10.1002/alr.21504.

Стаття надійшла 8.08.2024 р.