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RELATION BETWEEN PARANASAL SINUSES AND SURROUNDING BONE TISSUE

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Abstract

Introduction. The formation and increase in volume of the paranasal sinuses occurs during the growth and development of the facial skull. Pneumatization of the sinuses and bone architectonics can have the variability. Understanding of the midfacial bones architectonics is a key to successes in osteosynthesis, reconstructive, orthognathic surgery, dental and maxillofacial implantation.

The aim. Study the individual features of the normal anatomical structure and architectonics of the midfacial bones and to develop the objective criteria for assessing the relationship between bone elements and airways using methods of computed tomography.

Materials and methods. 30 patients spiral computed tomograms with no signs of pathology were analyzed. Relations between volume and surface of the bony elements and airways, the ratio between the volume of bone and air cavities pneumatization index (PI) were determined.

Results. PI ranged from 0.8 to 1.9 and averaged 1.22 ± 0.29 . Range from 0.9 to 1.5 was considered a normal ratio. Index values exceeding 1.5 indicated a sclerotic type of the midfacial bone structure, and less than 0.9 indicated a pneumatic type.

Conclusions. The anatomical structure, architectonics of the midfacial bones and the degree of their pneumatization are characterized by significant individual variability. For an objective integrated assessment of the bone architectonics of the midfacial area the ratio of the bone volume to the volume of the airways (PI) and the volume of bone to its surface area can be used.

Key words: **Pneumatization index; midfacial bones; paranasal sinuses; architectonics.**

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Introduction

The midfacial area, where the visual, digestive, respiratory, nervous systems interact closely, is of particular interest. The complex functional conditions determine the unique anatomical structure and architectonics of the midface. [4] The midfacial area formed by the following facial bones: the maxilla, zygoma, sphenoid, lacrimal, nasal, ethmoid, and palatine [3]. Connecting together they form complex structures, that contains a three-paired transverse and vertical midface buttresses (areas of increased bone thickness), that support the functional units of the face: the airway, the dental occlusion, the muscle attachments and the eyes [6] and paranasal sinuses (frontal, ethmoid, maxillary, and sphenoid), that minimize bone mass of the skull, act as a crumple zone in severe midface trauma, improve the resonance of the voice, etc. [7, 11]. Growth of paranasal sinuses starts as prenatal and they continue growing toward each direction depending on enlargement of other nasal bones and nasal cavities [8]. According to Lee et al. (2014), pneumatization of the maxillary sinus increases with age, in particular, becomes more intense with the removal of the upper molars [9]. Degree of pneumatization of the paranasal sinuses determines following features of anatomical structure, such as position of neurovascular structures around the sphenoid sinus [7]. Frontal

sinus pneumatization has statistically significant effects on presence of upper and middle concha pneumatization, Haller cells, anterior clinoid process, pterygoid process and greater wing pneumatization, internal carotid artery dehiscence and protrusion and on optic nerve and vidian canal types [10]. Paranasal sinus anatomy has the significant variability in the dimensions, volume and shape of the air cavities and bone structures of the midfacial area. Report of Bertl et al. 2015 indicated the difference in bone quality and quantity between the anterior and posterior regions of the maxilla using micro-CT [5].

The maxillary sinus is the largest of the four paranasal sinuses [12]. Its volume varies from 10-25 cm³ in adults, and average volume is 15 cm³ [13]. It is obvious that the presence of diverse in type of sinus pneumatization will lead to diverse in bone architectonics. To address this problem, many authors proposed various classifications of the maxillary architectonics, based on the determination of bone wall thickness, the volume of the bone tissue, residual height of the alveolar ridge [2, 13-15].

The main disadvantage of these classifications, is that most of them were developed for the needs of dental implantation, and concentrated mainly on the alveolar ridge and adjacent areas and partially on the maxillary sinus. They did not take into consideration the structure of other midfacial bones, paranasal sinuses, and nasal cavity which is very important for the surgeries outside the alveolar process. Firm understanding of the anatomy of the mid-face is a necessity when reconstructing defects, decision making for many surgical interventions such as Le Fort I osteotomy, open sinus lift, facial and jaw bone fracture fixation and mini-screw insertion in orthodontics [1, 2].

The Aim. The aim of this research was to study the individual features of the normal anatomical structure and architectonics of the midfacial bones, to develop the objective criteria for assessing the relationship between bone elements and airways using methods of multispiral computed tomography and 3D reconstruction of the CT images.

Materials and methods

The study was based on the analysis of 30 spiral computed tomograms of people aged from 15 to 75 years with no signs of pathology of the midfacial bones and paranasal sinuses. CT scans were performed on Philips Ingenuity CT 128 (slice thickness 0,67 mm). Tomographic sections were based on a standardized protocol of CT scans of the facial skull. Licensed software RealGuide 5.0 (3DIEMME, Italy) was used for processing of the CT images. To create a three-dimensional virtual model of the midfacial bones, special tools of RealGuide 5.0 (3DIEMME, Italy) software were used. Segmentation of the images was initiated from creation of a "mask" in the range corresponding to the radiological density of

bone tissue from 250 to 3071 Hounsfield units (HU). Then, tools for adjustments and modification of the "mask" were used to separate the bone structures of the facial skull (from the level of glabella to the level of the alveolar process of the upper jaw in the frontal plane and from the most protruding point of the alveolar process of the upper jaw to the farthest point of the Lamina medialis of the processus pterygoideus ossis sphenoidalis in the sagittal plane, Fig. 1).

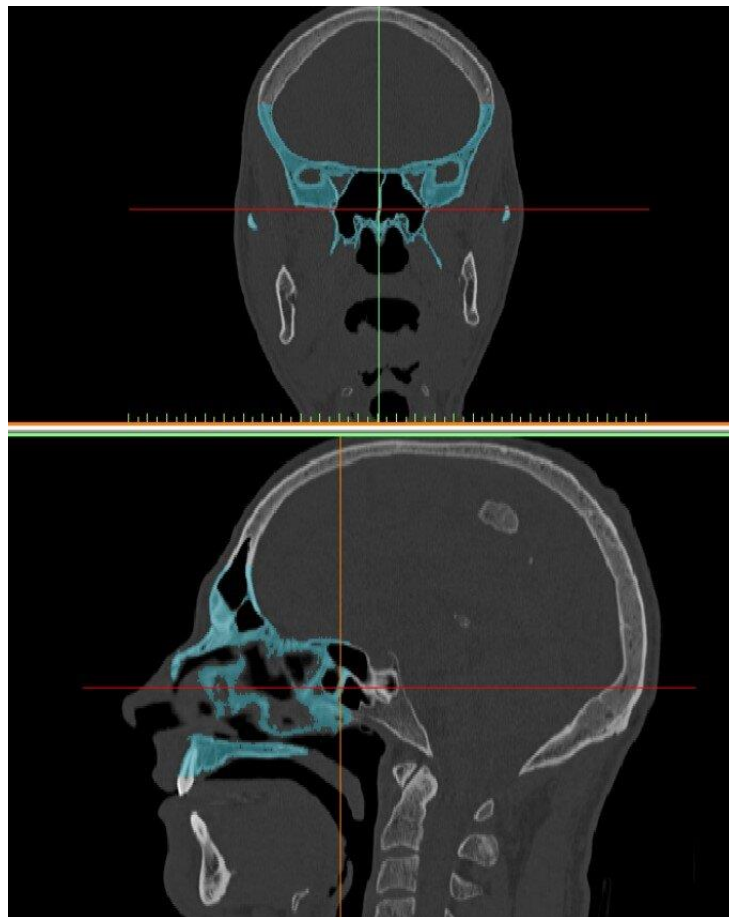


Figure 1. Segmentation of bone structures of the midfacial area within the predetermined range

Since some patients had dentition defects of different sizes and localizations, the model did not include the crown parts of the existing teeth. After editing the "mask", a 3D model of the midfacial bones was generated (Fig. 2).

Using the same algorithm, a model of the upper respiratory tract inside the midfacial area was created. For this purpose, image segmentation was performed within the range of X-ray density from -452 to -1024 HU. The components of the model included the nasal cavity,

maxillary sinuses, ethmoidal labyrinth, part of the frontal and sphenoid sinuses and partially the nasopharyngeal cavity (Fig. 3).



Figure 2. 3D model of the midfacial bones

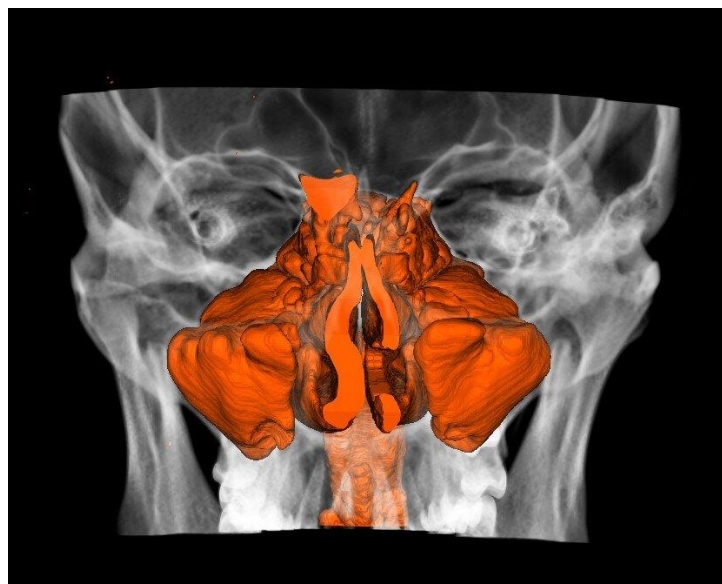


Figure 3. Air cavities of the midfacial area

The type of the face was determined using the Izard morphological facial index [16] (Fig. 4). The facial angle and the inclination angle were measured according to Schwartz in the slices corresponding to the mid-sagittal plane (Fig. 5). To assess the architectonics of the midfacial bones in the axial CT scans, maximum thickness of the cortical layer in two zones on the right and left sides of the facial skull was determined. The first measurement was performed in the lateral wall of the maxillary sinus in the area of the zygomatico-alveolar ridge (Fig. 6), the second - in the area of the nasofrontal buttress at the infraorbital foramen

level (Fig. 7). The volume and surface area were determined in all created models of bones and air cavities, and thus the ratio between the volume of bone and air cavities (pneumatization index (PI) of the midfacial area) was calculated; the mean and standard deviation were calculated for each parameter. The presence of statistical correlation between PI, bone thickness and anthropometric indices were determined by test for Pearson's correlation.

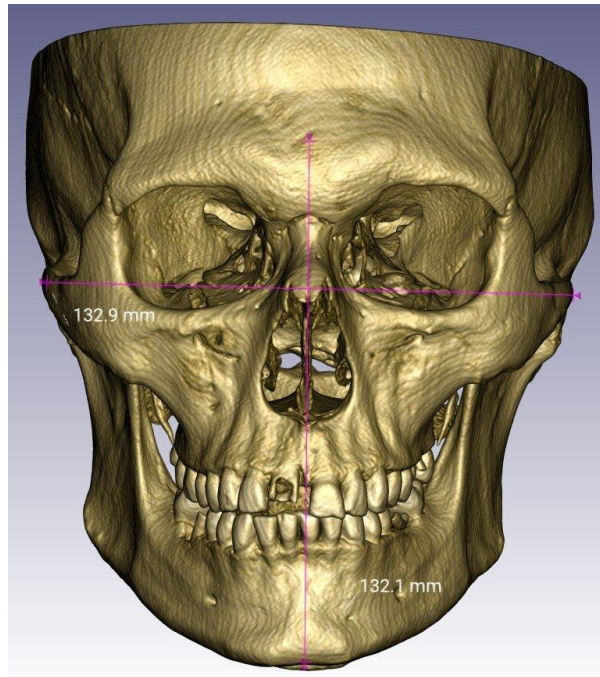


Fig. 4. Determination of Izard facial index on the 3D model of the midfacial bones

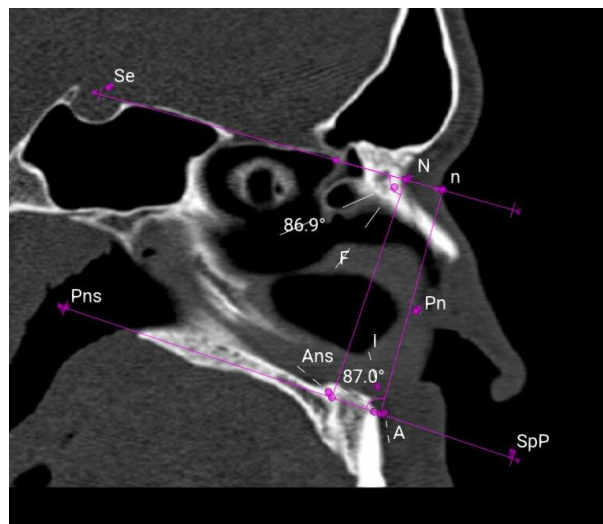


Fig. 5. Sagittal section of the spiral computed tomography with points used for determination of the facial angle and inclination angle

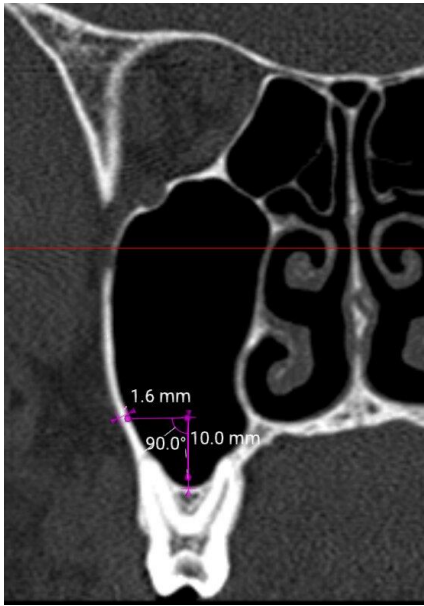


Fig. 6. The area used for measurements of the bone thickness in the projection of the zygomatico-alveolar ridge at a height of 1 cm above the level of the maxillary sinus bottom

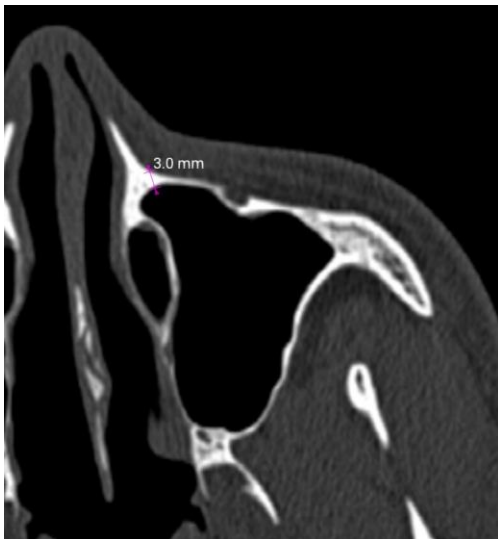


Fig. 7. The area used for measurements of the bone thickness in the projection of the nasofrontal buttress at the level of the infraorbital foramen

Results and discussion

In all CT scans, included to the study, the bone, soft tissue structures and air-filled cavities could be clearly distinguished. Izard morphological facial index ranged from 94 to 113. The mean value of this parameter was 100 ± 5 , which indicated the average width of the face in most of the models. The facial angle was in the range from 72° to 93° , and the average value was $85 \pm 4^\circ$. The inclination angle ranged from 81° to 92° and averaged $87 \pm 2^\circ$, indicating the absence of anomalies and deformations of the facial skull. The volume of the bone tissue of the midface varied from 75 to 175 cm^3 and averaged $112 \pm 25 \text{ cm}^3$. Due to the complex anatomical shape, the bone structures had a large surface area, $727 \pm 120 \text{ cm}^2$ on average. The volume of air cavities inside the bone was $94 \pm 21 \text{ cm}^3$, and their surface area consisted $420 \pm 57 \text{ cm}^2$. The thickness of bone tissue in the area of the nasofrontal buttress

was 1.79 to 5.7 mm (2.85 ± 0.71 mm on average). Thickness of the lateral wall of the maxillary sinus in the projection of the middle part of the zygomatico-alveolar ridge ranged from 1.73 to 5.69 mm, the mean value being 2.83 ± 1.08 mm. PI ranged from 0.8 to 1.9 and averaged 1.22 ± 0.29 . The variations of the index within the standard deviation range were from 0.9 to 1.5, in 80% of the subjects. This range was considered a normal ratio. Index values exceeding 1.5 indicated a sclerotic type of the midfacial bone structure, and less than 0.9 indicated a pneumatic type. An important indicator of bone architectonics was the ratio of bone volume to surface area, which ranged from 1 to 2 mm and averaged 1.54 ± 0.25 mm. The increase in this index was due to the presence of septa, additional cavities and the complexity of the anatomical shape and relief of the anatomical structures. At the same time, no statistically significant correlation was found between this parameter and PI, which indicates the need for simultaneous consideration of both parameters for objective assessment of the bone architectonics of the midface.

Statistical analysis revealed that PI and the ratio of bone volume to surface area had no significant correlations with inclination angle, facial angle, and Izard index. It is obvious that anthropometric measurements, in particular teleradiography data, which are currently used for planning of the orthognathic and reconstructive interventions, do not reflect the architectonics and degree of pneumatization of the midfacial bones. Planning of such operations requires consideration of the available volume of bone tissue, its structural organization and relationships with the air cavities. The significant correlation of average power $r = 0.55$, $p < 0.05$ was found between the PI and the bone tissue thickness in the area of zygomatico-alveolar ridge in the examined subjects. Structural features of this anatomical area play an important role in the installation of fixation elements, performing the osteotomy, sinus lift, dental implantation, which determines the clinical significance of the proposed PI. At the same time, in the areas where the bone structure is less dependent on the structure of the air cavities (nasofrontal buttress), no significant correlations between bone thickness and the PI value were found.

Conclusions

The anatomical structure, architectonics of the midfacial bones and the degree of their pneumatization are characterized by significant individual variability. Calculation of anthropometric data, such as facial angle, inclination angle, Izard index, does not allow an adequate evaluation of the structure, architectonics, degree of pneumatization of the midfacial bones and the level of irregularity of their surfaces. The use of contemporary methods of CT diagnostics and virtual modeling of the anatomical structures allows to determine the surface

area, volume, thickness of bone tissue in different areas with high accuracy. For an objective integrated assessment of the bone architectonics of the midfacial area the ratio of the bone volume to the volume of the airways (PI) and the volume of bone to its surface area can be used.

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