Chapter

Morphological Aspects of the Maxillary Sinus

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Abstract

The development of modern surgical methods and techniques for treatment of the diseases of the paranasal sinuses and the edentulous ridge of the maxilla requires detailed knowledge of the anatomy, physiology and pathology of the maxillary sinus. The sinus dimensions and volume, thickness of the mucosa, height of the inferior wall and presence of septa and root prominence are important indicators for the pneumatization of the maxillary sinus and have essential role by performing sino-nasal and dental implant surgery. The preliminary assessment of some morphological aspects of the maxillary sinus is essential for the proper diagnosis and treatment of a number of diseases in maxillofacial region, including treatment of the chronic rhinosinusitis and the edentulous ridges of the distal maxilla.

Keywords: anatomy, maxillary sinus, sinus development, sinus walls, sinus septa, sinus mucosa

1. Introduction

A considerable portion of the pathology of the maxillofacial region affects the maxillary sinus (MS). These include various inflammatory processes (rhinogenic, allergic, odontogenic), systemic, endocrinological (Grave's disease) and oncological disease, traumas, congenital anomalies and acquired defects (traumatic, post-resection, etc.), as well as diseases with unclear etiology (silent sinus syndrome).

The close relations of the MS with the nasal and oral cavities, orbit, pterygopalatine and infratemporal fossae are precondition for spreading of pathological processes from the sinus to neighboring areas and vise versa. The ophthalmic symptoms by the silent sinus syndrome are due to proximity between the orbit and the sinus, and the proximity between the floor of the MS and the roots of the upper molars and premolars allows odontogenic infections to induce changes in the sinus mucosa, also acute and chronic sinusitis. The thin or missing bone plate between the dental apex and the floor of the sinus is a factor that can lead to post-extraction hemorrhages, oro-antral communications, luxation of tooth roots and foreign bodies, compression of canal fillers, penetrations of cysts and invasion of tumors in the sinus, etc.

As an important anatomical structure, the maxillary sinus is a subject of various surgical interventions in rhinological, endoscopic, ophthalmic and maxillofacial surgery, and neurosurgery. The main aim of maxillary sinus operations is to preserve its anatomical and functional integrity. This is possible after preoperative assessment of the morphological characteristics of the sinus, such as its volume, linear dimensions, wall thickness, septa, position and permeability of its drainage ostium.

Regeneration of orofacial functions often requires reconstruction of the damaged alveolar process. The reduction of the dento-alveolar segment occurs under the influence of various etiological factors (dental extractions, inflammatory and systemic diseases, traumas, tumors, congenital anomalies). The resulting bone defects disrupt the anatomy, biomechanics and the relations between the two jaws. The quantity of bone loss determines the severity of morphological and functional lesions in the orofacial system – nutrition, speech, breathing, facial expressions, common and specific senses, social contacts. According to this the reconstruction of bone defects and deficits of both jaws has psych-social significance.

Detailed research and modern clinical interpretation of the anatomy, physiology and pathology of the maxillary sinus are an important condition for the development and improvement of modern operative and reconstructive techniques and for the prevention of postoperative complications. This contributes both to regeneration and maintenance of the health and self-esteem of the individual, as well as to his social realization.

2. Development of the maxillary sinus

MS begins its development in the tenth gestation week (GW) by primary pneumatization. It arises from the middle nasal meatus and spreads into the ethmoid cartilage. Initially, a small ridge is formed above the inferior nasal concha, from which *processus uncinatus* develops. The already formed uncinate process of the ethmoid bone grows in medial direction and forms the ethmoid infundibulum. It presents as a groove between the nasal infundibulum and the lateral wall. The mucosa of the anterior wall of the ethmoid infundibulum, lateral to the uncinate process, forms several invaginations in the surrounding mesenchyme. These invaginations form a furrow, named uncibullous groove. During the 11th week a cavity is formed from this furrow, which represents the primary MS [1].

In the 20th gestation week the secondary pneumatization of the sinus begins and spreads within the maxilla. The dimensions of MS increase at different rates during the different periods of the fetal development. The antero-posterior (AP) dimension increases most significantly, being larger in male fetuses [2].

During its development, variations in the shape of the MS are observed due to its growth in different directions, but at the end of the embryonic period it is oval-shaped. In the cavity of the sinus, septa and recesses can be observed, but after the 29th week they disappear. From 10 to 16 GW the floor of the sinus is located above the attachment of the inferior nasal concha, in 17-20th weeks it is at the level of the attachment, and after 21st week - below its level. Ossification is observed for the first time in the lateral wall of the MS in the 16th GW. Subsequently, in the 20th gestation week, it spreads into the anterior wall, and in the 21st week it comprises its posterior wall. Up to 37 GW, the medial wall does not ossify. The drainage ostium of MS is located in the anterior one-third of the ethmoid infundibulum, between processus uncinatus and lamina papiracea. No additional openings are observed during embryonic development. Asymmetry between the sinuses was found in 30% of the cases, but maxillary hypoplasia was absent [3].

The secondary pneumatization of the maxilla begins in the 5th month after birth, and at this stage the MS is presented as a triangular space located medially to the infraorbital foramen. The growth of the sinus slightly precedes the development of the maxilla and is accomplished by resorption of its walls, except the medial one, which plays a role of a depot. The lateral wall of the nasal cavity (NC) is also resorbed, and this leads to its expansion. The lack of resorption in the medial wall of MS prevents the development of an extensive communication between the sinus and the nasal cavity [4].

At birth, the MS presents as a longitudinal furrow filled with fluid. It is found on the medial surface of the maxilla above the germs of the upper first molars. The dimensions of the MS at birth are: length (antero-posterior direction) - 7,3 ± 2,7 mm; height - 4,0 ± 0,9 mm; width - 2,7 ± 0,8 mm. At the age of 16 the dimensions are respectively: length 38,8 ± 3,5 mm; height 36,3 ± 6,2 mm; width 27,5 ± 4,2 mm [4]. It is considered that the growth of the sinus is 2 mm per a year in vertical direction and 3 mm in the antero-posterior direction [5].

At the end of the 1st year the lateral border of the MS is located below the medial part of the orbit, in the 2nd year - it reaches the level of the infraorbital canal, and in the 3rd and 4th years it is located inferolateral to the infraorbital canal [6].

The increase of the MS in height of up to 3 years of age is directly related to the maxilla and depends on several factors such as: the pressure of the eye bulb on the orbital floor; the traction of the maxilla as a result of the action of the facial muscles, the muscles of the soft palate and the muscles attached to the mandible; teeth eruption. After the age of 3, the influence of the eyeball decreases, but the pulling action of the muscles continues, which leads to a growth of the frontal process of the maxilla. The growth of the MS is directly related to the eruption of the upper teeth. At the age of 9 years, the lateral border of the sinus reaches the floor of the nasal cavity [6].

In the 15th year after birth, the lateral growth of the MS stops. In early childhood, its floor is located at the level of the middle nasal meatus; in the 8-9th year - close to the floor of the NC, and in the 12th year it reaches the level of the hard palate. The sinus reaches its final dimensions after the eruption of the third molar [6].

As a result of the rapid development of the MS, its floor after birth is located lower than its drainage opening to the nasal cavity. As the sinus grows, close relationships arise with the roots of the upper molar and premolar teeth. During the eruption of each tooth, its bone bed is occupied by the pneumatic sinus, as a result of which the sinus floor is located initially at the level of the floor of the NC, and subsequently below it. The MS can grow not only between the roots of neighboring teeth, but also between the roots of the same tooth, resulting in their protrusion into the cavity of the sinus. As the MS grows within the maxilla and at its expense, recessions are gradually formed, which are designated as zygomatic, alveolar, infraorbital and palatine.

3. Anatomy of maxillary sinus

The MS is located entirely inside the maxilla and is the largest of the paranasal sinuses. It usually represents a single-chamber cavity, but in some cases two sinuses separated by bone septa can be found. It has a shape of four-walled pyramid with a base located medially to the NC (the lateral wall of the nose) and an apex directed towards the zygomatic arch.

3.1 Dimensions and volume of the maxillary sinus

The size of the sinus varies, and according to literature data, its average dimensions are depth - 34 to 45 mm, width - 25 to 35 mm, height - 33 to 44 mm and volume - 3 to 30 cm^3 (**Figures 1** and **2**).

The highest value of the cranio-caudal dimension in 93% of cases was measured around the second molar, and for the medio-lateral and antero-posterior in 90% of cases - at the level of the root of the zygomatic complex. In females, the size of the MS is smaller. A cadaveric study of 31 semi-heads shows that the height (cranio-caudal dimension) of the MS ranges between 10,98 mm and 39,14 mm (mean - 24,05 ± 6,3 mm); the antero-posterior dimension - between 14,27 mm and 42,09 mm (mean - 28,65 ± 7,2 mm), and the medio-lateral dimension - between

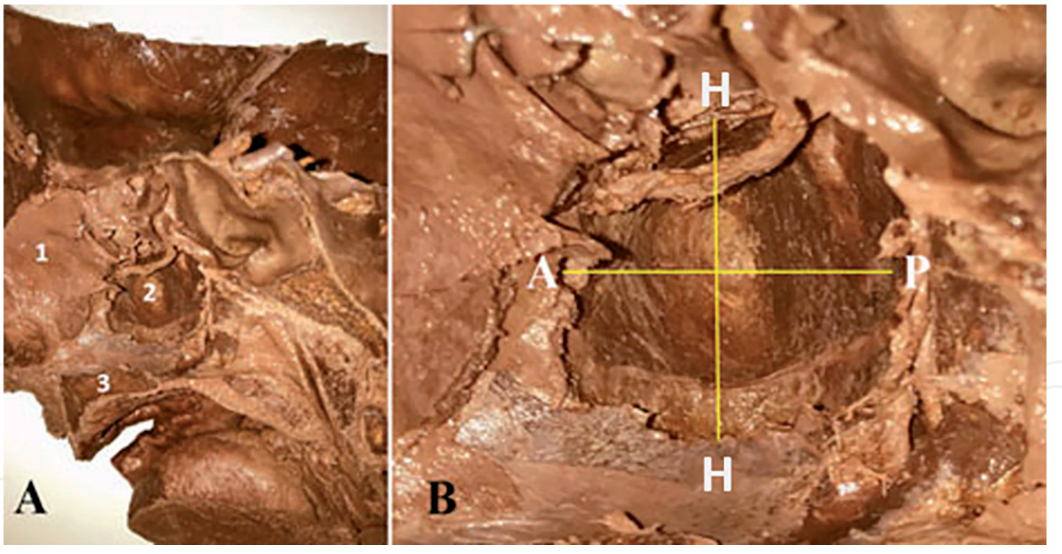

Figure 1.
Schematic representation of the antero-posterior (A–P) dimension and the height (H) of the MS on cadaveric head with medial access: A. sagittal section of cadaveric head (1 – Nasal septum; 2 – мaxillary sinus; 3 – Hard palate); B. maxillary sinus on the same cadaveric head (A-P – Antero-posterior dimension; H – Height).

Figure 2.
Schematic representation of the medio-lateral dimension (M-L) of the MS on cadaveric head with anterior access.

11,38 mm and 36,19 mm (mean - 20,08 ± 5,04 mm). This study reveals that the medio-lateral dimension is the smallest. The volume of the MS ranges between 4,00 and 19 cm^3. The average volume of the sinus is 11,7 ± 3,98 cm^3 [7].

3.2 Walls of the maxillary sinus

3.2.1 Medial wall

From a surgical point of view, the medial wall can be divided in two parts: a lower one, called a "surgical" wall, which corresponds to the inferior nasal meatus and is bounded superiorly by the tuberosity of the inferior nasal concha, and inferiorly - by the floor of the nasal cavity; and upper, called "physiological", located in the middle nasal meatus, and enclosed between the inferior and middle nasal concha. In the surgical part the sinus hiatus is found, which is extremely easily fractured and is bounded by the frontal and palatine processes of the maxilla. Here is also located the crest of the inferior nasal concha [8].

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The medial wall of the MS has a quadrangular shape and corresponds to the inner (nasal) surface of the maxilla, on which there is a large opening - hiatus maxillaris. It represents the base of the pyramid and is at the same time a lateral wall of the NC. This wall descends below the level of the nasal floor and is attached directly to the palatine process of the maxilla. Its thickness varies in different areas – it is thinnest in the middle of its lower end, and thickest – in its antero-inferior angle. The medial wall has a complex structure, with the nasal conchas lying on the outside. It is formed mostly by the mucosa of the middle nasal meatus, the lining of the MS, and a layer of connective tissue between them. On the side of the NC, the medial wall also includes the inferior nasal meatus and the floor of the nasal fossa.

After removal of the middle nasal concha, the medial wall is composed of bulla ethmoidalis, processus uncinatus and hiatus maxillaris, which has a semi-lunar shape and represents a gap between processus uncinatus (below) and bulla ethmoidalis (above). Hiatus maxillaris is narrowed by several bones. The lacrimal bone is located anteriorly, the labyrinth of the ethmoid bone with the superior and middle nasal concha – superiorly, the perpendicular plate of the palatine bone and the medial plate of the pterygoid process of the sphenoid bone – posteriorly, and below – the ethmoid and lacrimal processes of the inferior nasal concha. Processus uncinatus is a sickle-shaped bone plate that divides the hiatus maxillaris into anterior, posterior, and superior orifices. The upper opening is called hiatus semilunaris. In 1870, Zuckerkandal [9] introduced the term fontanelle. The fontanelle is an area in the middle nasal meatus, located below the uncinate process and above the inferior nasal concha, and covered medially by the nasal mucosa, and laterally - by the mucous membrane of the MS, with connective tissue between them. In this area there is no bone, therefore it is prone to perforation. Depending on their location relative to processus uncinatus, the anterior and posterior fontanelles differ. The anterior fontanelle is located between the lower edge of the uncinate process and the attached edge of the inferior nasal concha, while the posterior one is in postero-superior direction relative to the anterior one. The drainage opening of the MS opens in hiatus semilunaris. The mucosa of processus uncinatus along its upper border is attached loosely to the underlying bone, forming laterally a depression in a shape of a shallow pocket. At the antero-superior end of hiatus semilunaris a funnel-shaped fossa is located called infundibulum ethmoidalis, which extends to the recessus frontalis. The frontal sinus is drained in it.

Ostium maxillare (**Figure 3**) is located in the upper third of the medial sinus wall and drains into the posterior part of the semilunar hiatus in about 52–78% of cases [10]. It has an oval shape and is located in a transverse direction. Its

Figure 3.
Medial wall of maxillary sinus with ostium maxillare (arrow).

dimensions range from 1 to 17 mm, on average about 2–4 mm in diameter [11]. The opening is found 18–35 mm superiorly to the floor of the nasal cavity and about 28 mm superiorly to the sinus floor. In women, the distance between the floor of the nasal cavity and the opening is less [12].

Due to the high position of ostium maxillare, the drainage of the MS is difficult and is accomplished due to the active oscillations of the cilia of the epithelium. As a result, infections in the middle nasal meatus can compromise the sinus drainage.

Sometimes additional drainage openings are also found. Their frequency ranges from 0–43% [13]. The size of the openings is from 1 to 10 mm, and their number is variable. They are located in the area of the anterior fontanelle or distal to the natural opening, in the area of the posterior fontanelle [13]. Additional drainage openings can also occur as a result of pathological processes. They are detected in 30% of patients with chronic rhinosinusitis and in 10–20% of healthy individuals [14]. In some cases, ostium maxillare merges with the additional openings and a large drainage opening is formed.

The drainage of the MS occurs only through ostium maxillare, therefore the presence of additional openings can lead to reabsorption of mucus through them [15]. They do not participate in the physiological drainage of the sinus, even if its natural opening is blocked [9].

3.2.2 Superior wall

The superior wall of the MS usually has a triangular shape and represents the orbital surface of the maxilla, which participates in the formation of most of the orbital floor. Its width is greater than that of the inferior wall and is inclined downwards and forwards and laterally. It is extremely thin and fragile, further weakened by the passing sulcus et canalis infraorbitalis, which are located in its middle third and 5–7 mm to 10 mm from the lower orbital border. The canal causes a well-defined bone ridge along the upper wall. It opens on the anterior surface of the maxilla through foramen infraorbitale. The infraorbital nerve-vascular bundle is located in it. Often on some places in the infraorbital canal there is no bone plate and in these cases the nerve-vascular bundle is covered only by the mucous membrane of the sinus. The highest part of the roof of the MS is located below the orbital apex.

3.2.3 Anterior wall

The anterior wall of the MS represents the anterior surface of the maxilla, extending from the inferior orbital margin to the alveolar process, and posteriorly - to zygomaticoalveolar crest. The external surface is covered with soft tissues. On the anterior surface of the maxilla lie the facial artery and vein, lymphatic vessels, motor branches of the facial nerve and sensory branches of the infraorbital nerve. On this wall there is a well-defined depression, called fossa canina, which is located above the root of the upper canine. This is the place with the thinnest cortical plate. The suborbital sulcus is also located on this surface. The cortical plate of the anterior wall thickens at its periphery. On the internal surface of the anterior wall, under the mucosa, the nerve-vascular bundles for the frontal teeth and premolars descend – middle and anterior superior alveolar nerves (branches of the infraorbital nerve), which participate in the formation of superior dental plexus, and anterior superior alveolar arteries and veins.

3.2.4 Posterior (infraorbital) wall

The posterior wall of the MS lies behind the zygomaticoalveolar ridge. It is divided into two sections: medial or pterygomaxillary and lateral or zygomatico-tuberal.

The medial part of the wall is thin, corresponds to the maxillary tuber and behind it are located the infratemporal and pterygopalatine fossae.

The lateral part of the wall is formed by the zygomatic process of the upper jaw with zygomaticoalveolar crest and the surface anterior to the tuber. On this place is also located the intraosseous anastomosis between the infraorbital and posterior superior alveolar artery, which is of great clinical importance in surgical interventions. Some anatomical structures such as the zygomatic wall and maxillary tuberosity can affect the thickness of the lateral wall.

The lateral wall of the sinus increases in thickness from the second premolar to the second molar from 5 to 15 mm. The average thickness of the lateral wall in partially edentulous jaws is 1,71 ± 0,12 mm, while in totally edentulous it was 1,57 ± 0,07 mm [16]. The lateral wall thickness is 1,69 ± 0,71 mm in the area of the first premolar; 1,50 ± 0,72 mm in the area of the second premolar; 1,77 ± o,78 in the area of the first molar; and 1,89 ± 0,85 mm in the area of the second molar [17].

The height of the residual alveolar ridge, the type of edentulousness (partial or total) and age affect the thickness of the lateral wall. The smaller the residual height of the alveolar ridge is, the lateral wall is thinner [16]. The smaller thickness of the lateral wall also implies lower bone density [18].

3.2.5 Inferior wall (floor)

The inferior wall of the MS is formed by the lateral region of the alveolar process of the maxilla, in which the premolars and molars are located. Its boundaries are usually the first premolar anteriorly and a small recess behind the third molar. The floor of MS in about 63% is located lower than that of the NC, in about 33% it is at the level of the floor of the NC, and in 5–10% - higher [19]. Most often it is located 1.5 cm below the floor of the NC along the horizontal line connecting the lower edges of ala nasi. According to other authors, the sinus floor is located 7–8 mm below the floor of the NC [10].

The shape of the sinus floor is concave (rounded), most often mono- or biconcave. In other cases, the floor of the MS has an irregular or flat shape [20].

The inferior wall is composed of basal and alveolar bone. The alveolar bone consists of cortical plate, which is in contact with the teeth, and spongiosis is located inside.

The floor of the MS is located downwards and laterally to the alveolar ridge of the maxilla, as a result of which recesses may form between the roots of the posterior teeth. An alveolar recess is found in approximately 50% of the maxillary sinuses, which can lead to perforations of the floor during endodontic and surgical treatment.

The roots of the upper lateral teeth are located in close proximity to the floor of the MS. The relationship between the roots of the teeth and the floor of the sinus can be divided into three main groups: distant - there is a thick bone wall between the apices of the dental roots and the sinus floor; tangential - there is a very thin bone plate between the roots and the floor of the MS; and penetrating - the roots of the teeth are covered only by the sinus mucosa. The bony lamella separating the floor of the sinus and the roots of the teeth decreases in thickness from 6,9 mm in canines to 1,7 mm at the second molar, and in the area of the third molar it increases to 2,8 mm [20].

Approximately 78% of the posterior maxillary teeth are located in dangerous proximity to the floor of the MS or protrude into it, which is a prerequisite for the occurrence of various complications during their endodontic treatment or extraction. The protruding roots are usually separated from the sinus with a thin bone plate of varying thickness, and sometimes covered only by a mucous membrane. They form conical elevations on the floor of the sinus. The roots of the first and second molars most often protrude into the cavity of the MS (**Figure 4**).

Figure 4.
Protrusion of the mesio-buccal root of upper left second molar in the cavity of the maxillary sinus (MS).

Most of the roots of the first and second premolars (77–98%) are not in close relations with the floor of the MS. In contrast, the roots of molars are in close proximity to the sinus floor: 37% of the first molars, 55% of the second and 31% of the third molars are in close contact with the floor of the MS [21]. The roots of the second molars are located in close proximity to the sinus floor, and most often tangential or penetrating relations are found. In this area is also the lowest point on the floor of the MS [20, 21]. The buccal roots of the second molar protrude most often in the cavity of the MS [22]. Regarding the first molar, the buccal roots most often protrude in the MS, while their palatine roots most often protrude laterally.

There are no statistically significant differences between genders, and the right and left sinus [22–24].

Different classifications of the relationships between the roots of the upper lateral teeth and the floor of the MS have been created in order to predict and avoid possible complications during endodontic, orthodontic and surgical treatment. All modern classifications are based on those created by Freisfeld et al. [25] and Kwak et al. [26].

Freisfeld et al. [25] offer three types of vertical relationships: class 0 - the dental roots of the upper lateral teeth are not in contact with the floor of MS; class 1 - the roots are in contact with the sinus floor, but do not protrude into the sinus cavity; class 2 - the roots of the teeth protrude into the sinus.

In 2004, Kwak et al. [26] classify the relationships between the floor of the MS and the roots of the upper teeth into five classes: class 1 - the floor of MS is located above the line connecting the buccal and palatine root apices; class 2 – the sinus floor is located below the line connecting the buccal and palatine root apices, without the presence of apical protrusion; class 3 - apical protrusion of the buccal root tip above the sinus floor; class 4 - apical protrusion of the palatine root tip above the sinus floor; class 5 - apical protrusion of the buccal and palatine root tips above the sinus floor. The authors also create a classification for the horizontal relationships between the MS floor and the upper lateral teeth. These relations are divided into three classes: class 1 - the alveolar recess of the floor is located to a greater extend in the direction of the buccal wall compared to the buccal root; class 2 - the alveolar recess is located between the buccal and palatine roots; class 3 - the alveolar recess is located to a greater extend in the direction of the palatine wall than the palatine root.

Didilescu et al. [27] offer a classification based on the measured distance between the root apex and the floor of the MS (thickness of the bone plate between the root tip and the sinus floor). The topographic relations between the floor of the sinus and the root apices of the first upper molars are divided into five classes: class 0 – the distance between the root apex and the sinus floor is 0 mm; class 1 - the distance between the root apex and the floor of the MS is between 0 and 2 mm; class 2 - the distance between the root apex and the sinus floor is between 2 and 4 mm; class 3 - the distance between the root apex and the sinus floor is between 4 and 6 mm; class 4 - the distance between the root apex and the sinus floor is greater than 6 mm.

This classification also allows an assessment of the topography of the root furcation relative to the floor of the sinus. In the relationships of the roots of the upper first molar with the floor of MS of class 2, 3 or 4, the lowest mean value of the bone plate between the floor of the sinus and the furcation is 7,64 mm respectively; 9,69 mm; and 12,41 mm These cases favor direct implant placement after tooth extraction without lifting the MS floor. In class 0 and 1, the implementation of endodontic treatment, tooth extraction and immediate placement of dental implants requires special attention.

The close relationships between the apices of the dental roots and the floor of the MS determine the possibility of spreading dental infections to MS and influence endodontic, orthodontic and surgical treatment, as well as the planning and implementation of dental implant treatment.

The tangential and penetrating relations between the roots of the teeth and the floor of the MS are a predisposing factor for the occurrence of various complications during the extraction of upper molars such as oro-antral fistulas or root penetration into the sinus cavity. They are also the cause of various complications during surgical interventions in oral implantology, resulting in development of chronic maxillary sinusitis [20].

3.3 Septa

The septa (**Figure 5**) were first described by Underwood [28, 29] and are called the septa of Underwood. He described different in type, location, size and direction ridges in the MS. According to Underwood, these ridges in the sinus are formed as a result of the development and eruption of teeth, and in the absence of teeth – due to increased osteogenic activity. The septa can be incomplete and complete and divide vertically or horizontally the MS into pockets or cavities. Some of them separate the sinus almost completely and thus chambers are formed with a small drainage communication between them. According to the location of the bony septa, Underwood classified them into three groups: anterior, located between the second premolar and the first molar, middle - between the first and second molar, and posterior - distal to the third molar.

Krennmair et al. [30] analyzed 41 cadaveric maxillary sinuses, 61 sinuses observed during sinus floor augmentation surgeries and 92 computer tomographic scans and reported the frequency, location and height of antral septa in edentulous and non-edentulous patients. The authors found that sinus septa had a higher

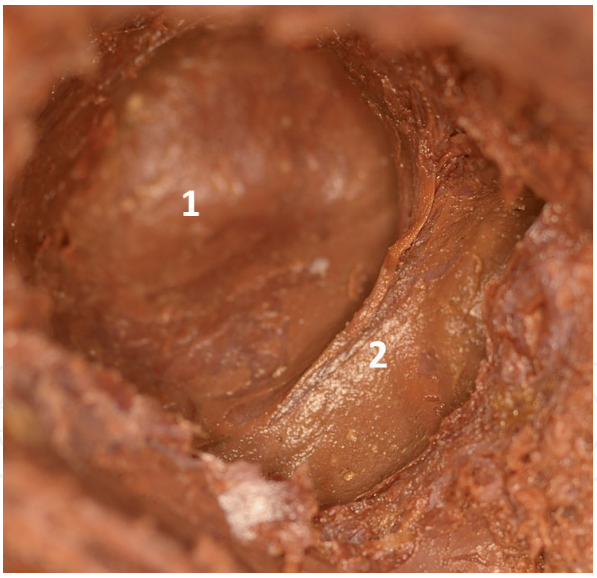

Figure 5.
Septa in the maxillary sinus on cadaveric head: 1 – Maxillary sinus; 2 – Septa.

frequency and lower height in edentulous and atrophic maxillae compared to jaws with preserved dentition. They reported that septa were more common in the anterior regions of the sinus. The authors divided the septa into primary (congenital), which are formed with the normal development of the sinus and the middle facial third [8, 31]; and secondary (acquired), which occur as a result of reshaping of the bone under the action of the masticatory pressure exerted by the teeth. Secondary septa may also occur as a result of tooth loss and bone resorption [29, 31].

The septa are defined as complete when they divide the sinus into separate chambers; and incomplete, dividing the sinus into separate pockets. According to some authors the incidence of the complete septa is 0,3% [32], but it can reach up to 11% [22].

The septa have usually an oblique direction and their function is to absorb and redistribute the masticatory pressure. Occasionally, a bone septum may be found in the sinus, that has formed as a result of the growth of a posterior ethmoid cell in the sinus. It divides it into anterior and posterior compartments. When the septum is horizontal, an upper and lower compartment or a medial and lateral section are separated.

Apart from the floor of the sinus, septa can also arise from its other walls [10, 33], as they are located in two planes – sagittal and transverse. The sagittal septa are most often found in the anterior and middle areas of the sinus, and transverse - in the posterior region [33].

The frequency, location and morphology of septa vary widely.

The frequency of septa varies between 20% and 35% [10, 12, 30]. According to some authors, septa are more common in edentulous alveolar ridges [10, 32], and they are also of greater height.

According to literature, there is no evidence of a relationship between the frequency of bone septa and gender and the age of the individual.

Pommer et al. [32] reported that the incidence of multiple septa in one sinus was 4,2%, and that of bilateral septa was 17,2%.

The distribution of septa in the premolar, molar and retromolar region is 24,4%, 54,6% and 21% respectively [32]. A number of authors reported that the highest incidence of septa is in the middle region [10, 32, 33]. According to other authors, septa are most often located in the posterior area of the sinus [12, 29].

Gosau et al. [12] found that septa are more common in the right sinuses, while according to Pommer et al. [32] their frequency is equal for the left and right sinuses.

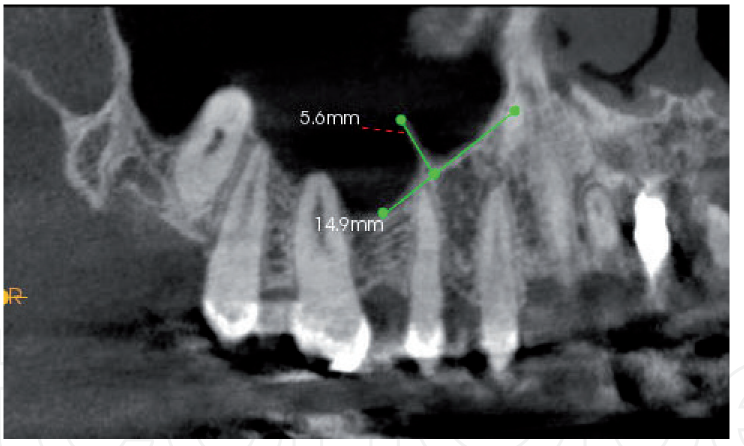

Figure 6.
Height of septa on 3D-cone-beam computer tomography.

According to their shape, the septa can be sagittal, which are most often located in the anterior area of the maxilla; and coronary, which are found in the middle and posterior area of the upper jaw. Coronary septa are divided into three groups: arising from the floor of MS, which are most often transverse; originating from its lateral wall; and septa located in the upper anterior quadrant of the sinus, which are sagittal and are comprised by branches of the infraorbital nerve [10]. Pommer et al. [32] identified three groups of septa - transverse, sagittal and horizontal, with a frequency of 87,6%, 11,1% and 1,3%, respectively.

The average height of septa most often ranges from 5,4 to 7,5 mm [12, 32] (**Figure 6**).

4. Blood supply, lymph drainage and innervation of the maxillary sinus

The blood supply of the MS is mainly by the maxillary artery (MA). It is supplied mainly by three sources: posterior superior alveolar artery (PSAA); infraorbital artery (IOA) and its branches; and lateral posterior nasal arteries - branches of sphenopalatine artery [34]. Arterial blood also comes from the middle nasal concha as the main ostial artery. There are also branches from the anterior and posterior ethmoidal arteries.

The posterior and anterior walls of the sinus are supplied mainly from the posterior superior alveolar and infraorbital arteries.

The PSAA is divided into two branches: an external (gingival branch), which supplies part of the cheek and mucous membrane, covering the alveolar ridge in the area of molars and premolars; and internal (dental branch).

The IOA lies in the infraorbital canal on the inferior orbital wall. In the canal the artery gives off branches for the orbit and the superior anterior alveolar arteries, which supply the gingiva, anterior teeth and premolars, and the corresponding part of the oral mucosa and MS [35].

The gingival branch of PSAA anastomoses with extraosseous branches of the IOA in 10 of 30 sinuses [1]. The dental branch travels anteriorly and inferiorly, passes under the zygomatic process and appears inside the orbit where it also anastomoses with the IOA, forming an arterial circle.

Internal (intraosseous) and external (extraosseous) anastomoses are formed [34, 35]. They supply the Schneiderian membrane, periosteal vestibular tissues and the antero-lateral wall of the sinus [1]. According to the literature data, the incidence of the extraosseous anastomosis ranges from 44–90% [34].

The intraosseous anastomosis is also called alveolar antral artery (AAA) and is of greater clinical importance. It was first described by Strong in 1934. It is most often located in the area where the bone window for sinus lift is prepared. According to various authors and depending on the type of materials used (computer tomography or cadavers), the incidence of AAA varies from 10,5% to 93,9% for computer tomographic studies [36, 37]. In studies on cadavers, the incidence of AAA is 100% [1, 34, 38].

Watanabe et al., 2014 [39] reported that AAA occurs in the area of the first premolar at 28,9%, in the area of the second premolar – in 58,6%, in the area of the first molar – in 48,2%, and in the area of the second molar - in 41,4%.

AAA is entirely intraosseous (in 100% of cases) at its both ends and partially intraosseous in the area from the second premolar to the second molar (in 100% of cases) [1]. Partially the intraosseous part is adjacent to the Schneiderian membrane and is partly enclosed by the lateral sinus wall.

The course of AAA can be intraosseous or intrasinus. The incidence of intraosseous location is higher. According to Kang et al. [40] the intrasinus location was detected in 29,1% of cases. In 26%of the cases the position of the AAA is below the sinus membrane [36]. AAA is located along the outer corticalis of the lateral wall in 5,2–13% of cases [36, 40, 41].

Hur et al. [42] classify the artery as straight (type 1) and U-shaped (type 2). The straight artery occurs much more often (78,1%) compared to U-shaped (21,9%).

According to the literature, the AAA is located at an average distance of 16,4 to 19 mm from the edge of the alveolar ridge [34, 38, 41]. In 20% of cases, it is at a distance of less than 15 mm [38]. Yang et al. [37] found that intraosseous anastomosis is located 19,6 ± 5,64 mm from the edge of the alveolar ridge in the area of the first premolar; 19,9 ± 5,87 mm in the area of the second premolar; at 15,6 ± 4,06 mm in the area of the first molar; and at 16,5 ± 4,75 mm in the area of the second molar. They reported that the distance between the floor of the sinus and the artery is at least at the height of the alveolar ridge of more than 8 mm.

The AAA is found closer to the ridge of the alveolar process (excluding the second molar area) in edentulous patients [43].

The distance between the AAA and the medial sinus wall varies from 11 to 24,9 mm [36, 41].

Extraosseous anastomosis is detected at a distance of 23 to 26 mm [34].

The average length of the intraosseous artery is 44,6 mm and that of the extraosseous is 46 mm [34].

The diameter of the AAA varies from 0,2–3,5 mm, on average 1,09 mm. Arteries with a diameter of less than 1 mm are found in 36,1%, with a diameter between 1 and 2 mm - in 51,4%, and with a diameter of more than 2 mm - in 12,3% [41].

In females, arteries of smaller diameter are found. The diameter of the artery increases with the thickness of the bone wall [40]. In terms of position relative to the upper lateral teeth, the diameter of the AAA slightly decreases to the premolar region [39].

AAA injury is not a life-threatening condition, but it significantly complicates sinus lift operations. The intraosseous artery is of extremely important for determining the length of the dental implant and the position of the incisions in sinus augmentation procedures. Artery injury can cause intense bleeding, difficult visualization of the operative field and subsequently perforation of the Schneiderian membrane. AAA is essential for avoiding local bone necrosis during surgery and for healing the bone graft [38].

The posterior wall of the sinus is supplied by PSAA, greater palatine artery, and branches of the sphenopalatine artery.

The sphenopalatine artery gives off the lateral nasal arteries, which are involved in the blood supply of the maxillary, ethmoid, sphenoidal and frontal sinuses. Branches for the MS enter it through the lateral wall of the nasal cavity.

The venous blood of the sinus is drained by a venous plexus, located around its drainage opening. Anteriorly the venous blood drains into the facial vein and via it – into internal jugular vein; posteriorly – into the maxillary vein, which merges with superficial temporal vein in the parotid gland, forming retromandibular vein, which drains into internal jugular vein. The maxillary vein also anastomoses with the venous pterygoid plexus and via it with the cavernous sinus.

Lymphatic drainage is to a lymphatic plexus, located around the pterygopalatine plexus, to the Eustachian tube and nasopharynx, from where it reaches the lateral cervical and retropharyngeal lymph nodes. Lymphatic vessels from the sinus drain also into the submandibular lymph nodes.

The sensory innervation of the MS is by the maxillary nerve and its branches posterior superior alveolar nerves, middle superior alveolar nerve and anterior superior alveolar nerves, branches of the infraorbital nerve, posterior inferior nasal branches (greater palatine nerve). The ostium of the sinus is innervated by the greater palatine nerve. The glands located in the mucosa of the MS receive post-ganglionar parasympathetic fibers from the greater petrosal nerve, a branch of *n. intermedius* of the facial nerve. The vasoconstrictor innervation is by means of sympathetic fibers, originating from the carotid plexus.

5. Histology of the maxillary sinus

The walls of the MS are covered with a mucous membrane, which is made up of epithelium (lamina epithelialis), lying on a basement membrane, and subepithelial connective tissue (lamina propria). The mucous membrane of the sinus is thinner than that of the nasal cavity, contains fewer blood vessels and is therefore pale blue in color. In the MS its thickness is approximately about 0,3–0,8 mm [44]. However, in smokers it varies widely, and the epithelium is usually squamous.

The epithelium is pseudostratified columnar ciliated epithelium. It originates from the respiratory epithelium of the nasal mucosa. In addition to the typical columnar ciliated cells, there are also basal (stem) cells, columnar cells without cilia and goblet cells that produce and secrete mucin.

The cilated cells have an electronic-light cytoplasm in which a large number of mitochondria, organelles producing enzymes and basal bodies are detected. The basal bodies play the role of attaching apparatus for cylindrical microtubules to the cell membrane in the apical part of the cell. The cilia are approximately 50–200 in number and are composed of 9 + 1 pairs of microtubules. The rate of their oscillations, which are synchronous and undulating, is 700–800 beats/minute [45]. The motor activity of the cilia is not regulated in a nervous way but is automatic. They help to purify the sinus epithelium from the debris, microorganisms and mucus secretion that move in the direction of the ostium and through it to the nasal cavity. Due to the high location of the drainage opening, the ciliated cells must overcome gravity. The speed of movement of secretions is 9 mm/sec [45].

The non-ciliated columnar cells possess microvili, which significantly increase the surface of the epithelium, which helps to better warm and moisturize the air.

Basal cells are inherently stem cells that give the beginning of different types of epithelial cells.

The goblet cells are single-celled glands that synthesize and secrete mucus. In their shape, they resemble inverted wine glasses. The nucleus is located at their basal end, and secretory granules - at their apical end. They produce glycoproteins and thus increase the viscosity and elasticity of the mucus secretion produced by the subepithelial glands. The goblet cells pour their secretion by merging the secretory granules with their cell membrane with its subsequent rupture. Therefore, these cells are apocrine. They are in the largest amount in the MS - 9600 mm^2 [44].

Lamina propria is much thinner compared to this of the mucosa of the nasal cavity. It is composed mainly of loose connective tissue. In the intercellular space are found mainly collagen and a small number of elastic fibers. This layer is moderately blood supplied and contains subepithelial antral glands. These glands are of a mixed nature and are composed of serous and mucus acini or sero-mucus acini and myoepithelial cells. The antral glands are in a particularly large amount around the drainage opening of the sinus. They secrete their secretions through their excretory ducts. When stimulated by the parasympathetic system, they secrete a thick mucus secretion, and when stimulated by the sympathetic system, the secretion is sparse.

On the surface of the mucous membrane, a mucous covering is formed, which is composed of two layers. The first is a *sol* layer *(serous layer).* It is thin, produced by the microvilli and facilitates the movements of the cilia. It serves as a lubricant. The second is a *gel* layer *(surface mucoid layer)*. It is located on the surface of the mucosa and is a thick mucus secretion, composed mainly of glycoproteins. This secretion is produced by the goblet cells and subepithelial glands. Thanks to it, the underlying mucous membrane is protected from low temperatures and humidity. The secretion also has a cleansing function, as it captures foreign particles and microorganisms. It also contains factors of the immune system: Ig A, Ig G and interferon, lactoferrin, lysozyme.

In the healthy sinus there is a continuous cycle, which consists in the production of mucus secretion, its movement through the cilia of epithelial cells and drainage through the ostium. Serous and goblet cells produce up to 1 l. secretion per day. The cilia of epithelial cells and the produced secretion form the muco-ciliary transport system. Muco-ciliary clearance is responsible for the continuous removal of foreign substances on the mucous membrane.

Bacterial or viral infections, contaminants, allergens, smoking negatively affect the normal activity of the ciliated epithelium. The functioning of the muco-ciliary transport depends to a large extent on the patency of the drainage opening and on the adequate supply of oxygen to the sinus. Obstruction of the drainage opening is due to edema of the nasal mucosa, which leads to the retention of secretion in the sinus, to the resorption of gases and the creation of negative pressure, which facilitates the invasion of pathogenic microorganisms. On the other hand, when the sinus ostium is permeable, the environment in the sinus is aerobic and normal ciliary function is present. When the opening is impermeable, the environment becomes anaerobic, and as a result, the bacterial flora in the sinus changes. The colonization and growth of anaerobic bacteria, which cause the development of maxillary sinusitis, is favored.

With inflammation of the mucosa, there is a sharp reduction to complete paralysis of the movements of the cilia under the influence of toxins of viruses and bacteria, as a result of which their cleansing effect is affected. In chronic rhinosinusitis, limited or diffuse epithelial metaplasia and impaired transport function may occur. As a result, there are edema of the mucous membrane, accumulation of mucus secretion and bacterial colonization.

The sinus mucosa is firmly attached to the underlying periosteum, which is why it is referred to as a muco-periosteal membrane. This membrane is called Schneiderian. The muco-periosteum is loosely attached to the underlying bone, therefore peels off easily. It contains osteoclasts and osteoblasts. The thickness of the Schneiderian membrane can vary widely – 0,16–34,61 mm [46].

Very often as a result of various pathological processes the Schneiderian membrane thickens, which further complicates the treatment of rhinosinusitis and sinus augmentation surgery. Therefore, the assessment of the thickness of the sinus mucosa is of great importance for endoscopic sino-nasal surgery and oral implantology. Mucosal thickness higher than 2 mm is considered pathological [46]. Odontogenic sinusitis develops as a result of chronic limited inflammation, a cyst or granuloma at the root of the upper premolars and molars, or as a result of foreign body or root filling during tooth extraction and endodontic treatment. There is a direct relationship between the presence of periapical processes and the thickness of the Schneider membrane. The thickening of the sinus mucosa increases proportionally with the degree of apical periodontitis. By lesions infiltrating the floor of the MS, pathological mucosal thickening occurs in 90% [47]. The thickness of the Schneiderian membrane is greater near restored teeth and periodontal and endodontic lesions, and this dependence is strongly expressed in the molar areas, when there is a thin bone plate between the dental roots and sinus or periapical lesions are present [47, 48]. Other factors for mucosal thickening are infections, allergies, smoking.

The frequency of thickening of the sinus mucosa varies widely - from 34–66% [47, 48]. The frequency of thickening of the Schneiderian membrane increases with age, and it is highest in the age group 40–60 years. With roots, protruding into the sinus, a higher incidence of mucosal thickening is also observed.

Most often, the thickness of the mucous membrane is 2–4 mm, its average is 2,70 ± 3,73 mm [47]. According to Bozhikova et al. [48] the Schneiderian membrane thickness ranged between 0 and 15,90 mm, average 2,24 ± 3,11 mm. The highest mean values (2,16 – 3,11 mm) were found in the middle sagittal region of the MS. In the presence of sinusitis, the average thickening of the membrane reaches 7.4 mm [49]. Flat thickening of the Schneiderian membrane is most common [46].

6. Physiology of the sinuses

There is still no consensus on the functions of paranasal sinuses. It is assumed that they help moisturize and warm the inhaled air; provide voice resonance; increase the olfactory surface; regulate intranasal pressure; their mucosa secretes mucin, which further moisturizes the nasal cavity; promote facial growth; reduce the mass of the skull; build a kind of framework for the brain and absorb the shock effects of injuries to the face and skull, reducing their severity.

The mucous membranes of the nasal cavities and sinuses form a single transport system that protects the respiratory tract. In the sinuses, the secretions move only to their drainage openings. The muco-ciliary system captures 80% of inhaled solid particles between 3 and 5 micrometers in size and 60% of particles more than 2 micrometers in size. These particles are exposed to the action of mast cells, polymorphonuclear leukocytes, eosinophils, lysozyme, immunoglobulins and interferon.

7. Conclusion

Preliminary assessment of the morphology of the MS – linear dimensions and volume, bone wall thickness, presence of septa, locations and permeability of the maxillary ostium, thickness of the sinus mucosa, relations to the neighboring structures are prerequisite for diagnosis and treatment of sinus diseases, and restoration of the edentulous distal maxilla. The study of the sinus anatomy allows to determine its degree of pneumatization, the position of its ostium, the thickness of the mucosa, to detect the anatomical variations and to diagnose the pathological process in it. These parameters are essential when conducting various dental, nasal and paranasal procedures, as in many cases may complicate or compromise treatment. Conducting sino-nasal surgery and implant treatment of the distal area of the maxilla is impossible without assessment of the morphology of the sinus in order to prepare an appropriate treatment plan, prevention of intra- and postoperative complications and prediction of the results of treatment.

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