University of Medicine and Pharmacy

„Carol Davila” Bucharest

Doctoral School

Medicine

The importance of detailed knowledge of the anatomy and the relationships of the maxillary sinus

ABSTRACT OF THE DOCTORAL THESIS

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CONTENT

INTRODUCTION

The maxillary sinus, the largest of the paranasal sinuses, represents the central part of one half of the face.

It is surrounded by the following topographic regions: orbit, infraorbital region, zygomatic region, nasal cavity, oral cavity, hard palate, pterygopalatine fossa, and infratemporal fossa.

In this configuration, sinus pathology can evolve and become intertwined with pathologies of neighboring regions.

Sinus exploration is performed endoscopic and imagistic, providing evidence for the diagnosis of sinus lesions and guiding further clinical investigations towards neighboring regions.

Due to its relationship with the orbit, sinus inflammations can be accompanied by inflammation of the fat around the eyeball (periorbital cellulitis) and almost always by infraorbital nerve neuralgia. Orbital tumor formations can easily extend into the sinus due to the very thin and easily penetrable wall.

Moreover, maxillary sinus tumors can invade the nasolacrimal duct, affecting the tear drainage and leading to serious consequences for the ocular health.

The sinus opening is located in the middle nasal meatus, in a complex region called the semilunar hiatus. The borders of this hiatus, as well as the neighboring bony prominences, can be affected by inflammatory or tumor pathologies, influencing both the sinus and nasal drainage.

The size of the inferior nasal meatus can vary in parallel with sinus retraction, mainly due to age-related changes and associated pathologies. The nasal wall is also the location through which, in increasingly rare situations, the endoscope can be inserted into the maxillary sinus. The prelacrimal recess can serve as a surgical approach to almost any sinus territory and, at the same time, provide a trans-sinus route to the deep regions at the base of the skull.

The posterior wall is related to the pterygopalatine fossa, and through it, via the sphenoid recess, access can be gained to the pterygopalatine fossa, where a variety of pathological manifestations can occur, ranging from maxillary artery aneurysms to nerve tumors like neurinomas. Furthermore, through the posterior wall, a pathway can be created to access the infratemporal fossa or further towards the base of the skull.

The inferior angle of the maxillary sinus is related to the roots of the canines and premolars. In fact, the alveolo-sinus relationship is much more variable and can involve a smaller or larger number of upper teeth.

Based on this relationship, a new branch in dentistry was practically born, namely dental implantology. The main procedure performed here is the sinus lift intervention, in which the sinus mucosa is lifted from the concavity of the alveolar recess, and the space thus obtained is filled with a bone graft, which will later provide increased resistance to the respective region. In this way, the region is prepared to support a dental implant.

In this context, it can be understood why I chose this research topic.

The maxillary sinus is practically the mandatory transit point, beyond which the true symptomatology of maxillofacial surgery can be addressed.

At first glance, the anatomical study of the maxillary sinus may seem straightforward, but in reality, clinicians need an accurate sinus topography and an intuitive and easily reproducible terminology.

The fact that I did not find an exhaustive sinus description in the literature, introducing anatomical description and terminology of surgical interest, prompted me to research sinus anatomy in order to provide in one place a natural and useful description of all sinus recesses.

Why recesses? Because basically at the level of these spaces, the walls change direction and the surgeon can approach different regions with a simple angulation.

Working Hypothesis

For the completion of my doctoral research, I focused on several areas of interest that I considered would bring practical benefits through an in-depth anatomical knowledge. For each area, I conducted a dissection study.

I must emphasize from the beginning that my studies do not have statistical value (due to limited access to a large number of cadavers); they are purely descriptive studies, where I focused on identifying anatomical landmarks that could be useful in everyday practice.

Scientific Objectives

Throughout the course of these studies, I have set the specific objectives of descriptive anatomy: the description of structures, their pathways, their neighbourhood and distance relationships and the topographic regions traversed by these structures. Specifically, I focused on highlighting anatomical relationships that would find relevance in everyday practice.

Method and Methodology

For the embryological study, we performed light microscopy slides by sectioning frontal and sagittal planes of embryo-fetal skulls at different ages.

For the dissection studies, we performed detailed dissections, highlighting all osseous, dental, muscular, and vascular-nervous structures of loco-regional interest.

For the sinus relations, we opened the maxillary sinus and we obtained images of the dissection field through bone transillumination.

Additionally, we also performed an accurate sinus topography by correlating the anatomical appearance found on cadaver dissection, i.e. of the skulls, with the appearance of the maxillary sinus obtained imagistically.

The large volume of bibliographic research studied for each individual study is noteworthy.

1. Working Hypothesis and General Objectives

The thesis is structured into a general part and a part of personal contributions.

The general part consists of two chapters:

1. Embryology notions;
2. Facial anatomy notions;

These chapters present, in detail, the current state of knowledge regarding the subject of our study.

The part of personal contributions is designed as four studies:

Study I: Contributions to the embryological development of the mid-facial region. For this study, we performed microscopic sections on embryos and fetuses of various ages, as well as maxillo-mandibular dissections, highlighting the process of formation and ossification of the facial mass. We conducted this study based on the idea that understanding bone formation and subsequent development of the maxillary sinus and the adjacent regions provide a solid scientific basis for understanding the dento-maxillary anatomy and its anomalies. We have successfully highlighted the mandibulo-maxillary ossification process and documented all stages of dental development.

Study II: Contributions to the study of palatine nerves and palatine arteries regarding their relations with the maxillary sinus. **The importance of these relationships in implantology.**

For this study, we focused on the disposition and topography of palatine nerves, which represent a crucial aspect of regional anatomical knowledge. These nervous structures are involved in maintaining palato-dental trophicity, zonal sensitivity, and can also cause trigeminal neuralgia complications. We aimed to dissect these structures accurately and place them in the loco-regional topographic pattern. We performed dissections of the pterygopalatine fossa, highlighting the pterygopalatine ganglion and its relations with the maxillary artery. Through dissection, we traced the path of the palatine bundle to the maxillary teeth.

Study III: Contributions to the study of the relationships between upper teeth and the maxillary sinus.

The dissection and anatomical description of the relationships between the roots of the upper teeth and the maxillary sinus represent a strong point of my research. During the insertion of maxillary implants, there is a significant risk that the implant damage to the sinus structures. The obtained information is useful for both the dentist, particularly the implantologist, and the maxillofacial surgeon called to perform sinus lift interventions. We have shown that practically all maxillary teeth can be in relation to the maxillary sinus, and after total tooth loss, the pneumatization of the maxillary sinus changes, reducing its volume, while the inferior nasal meatus increases.

Study IV: Contributions to the topographic and anatomo-imagistic study of the maxillary sinus.

In this study, I demonstrated the necessity of accurate maxillary sinus topography. We performed dissections of the maxillary sinus, illustrating the relationships of its walls and all sinus recesses, enumerating and highlighting them and their involvement in both sinus and trans-sinus approaches to neighboring regions.

We successfully compared the anatomical and imagistic appearances of the maxillary sinus, showing that the knowledge of maxillary sinus anatomy is multidisciplinary, involving clinicians, surgeons, and radiologists.

2. General Research Methodology

My studies are mainly based on dissections, as I believe that in this way I can achieve the most beneficial research, with the highlighting of anatomical relationships that find relevance in everyday practice.

The dissections were performed on cadavers preserved in 9% formalin solution from the Anatomy Department of U.M.F. "Carol Davila," Bucharest. The dissections were conducted in successive planes, with digital photography of each dissection field at each stage. To maintain the quality of the images, lamps and photographic reflectors were used to allow deep observation of the field and eliminate shadows. The obtained images were processed without affecting their scientific value.

For the embryological study, dissections were performed on fetuses from the Anatomy Department's laboratory. Part of the study was also conducted by preparing optical microscopy slides on serial sections of embryonic-fetal skulls at various stages.

The multidisciplinary nature of my study was also contributed by the creation and study of computed tomography images. I emphasize that each study includes detailed objectives and methodologies.

3. Study I: Contributions to the embryological development of the mid-facial region

3.1. Introduction

The formation of the face involves a significant number of primordia: the fronto-nasal bud, the medial and lateral nasal buds, the maxillary buds, and the optic placodes.

The development of the midface is practically around and in relation to the nasal cavity. The maxillary sinus appears as an evagination in the lateral wall of the nasal cavity with different growth curves.

Its development is based on tissue differentiation, apoptosis processes, and proliferation processes.

The midface undergoes dramatic modifications during the amphibian phase of facial development. During this period, there is a wide communication between the oral and nasal cavity through a space called the primitive choana [1].

The natural evolution is towards the closure of the choana and the separation of the two cavities. Consequently, the development of the midface is complex and can be marked by significant anomalies.

3.2. Results

Fig. 3.1.: Three month old fetus, indicating the positions of the facial primordia.
1. Medial nasal buds; 2.Lateral nasal buds; 3. Maxillary buds; 4. Mandibular arch.

Fig. 3.2.: Frontal section at the level of the embryonic face, in the posterior third of the mandible body - week 8.

1. Meckel cartilage; 2.Mandibular center of desmal ossification; 3.Lingual nerve; 4.Tongue; 5.Primitive oral cavity; 6.Nasal spine; 7.Nasal septum. The arrow indicates the penetration of the inferior alveolar nerve into the mandible.

3.3. Conclusions and personal contributions to this study

Our study practically provides an overview through which the clinician understands the main stages of facial formation, the development of the nasal cavities, maxillary sinuses, and mandible. We highlighted the process of odontogenesis, its evolution, and how dental primordia change their position in relation to the mandibular and maxillary alveolar processes.

We managed to capture the stages of maxillofacial formation and ossification, as well as the development of the maxillary sinus. We identified the positions of dental buds at the maxillary bone level, as well as in the mandibular primordium, demonstrating how the positions of dental primordia vary with fetal age.

We identified the stages of tooth formation, covering the entire process of fetal odontogenesis from 6-7 weeks until the fifth month.

We also performed a mandibular dissection that highlights the formation of the mandibular canal between the Meckel's cartilage, located lingually, and the vestibular cortex of the mandible. The mandibular canal is formed by the fusion of posterior canicular segments.

4. Study II: Contributions regarding the study of palatine nerves and palatine arteries concerning their relationships with the maxillary sinus. The importance of these relationships in implantology

4.1. Introduction

The palatine nerves and vessels provide innervation and vascularization to the palate up to the alveolar crest [2]. The origin of these structures is deep within the pterygopalatine fossa, posterior to the maxillary sinus, and their course is complex, traversing the pterygopalatine fissure and canal (in relation to the maxillary sinus) before reaching the palate region and ending near the alveolar crest [3]. They contribute to the blood supply and innervation of the upper teeth. Following the insertion of maxillary implants, neuralgia or hemorrhages may occur, involving these structures [4]. Palatine nerves are the anatomical substrate for trigeminal neuralgia. The insertion of maxillary implants can trigger such an incident, with the following pathway involved: alveolar branches of palatine nerves - pterygopalatine ganglion - maxillary nerve - trigeminal ganglion. As for palatine vessels, they partially serve the alveolar crest, and depending on their variability and topography, implant insertion can lead to hemorrhagic incidents if these vessels are not protected during the implantation procedure. Therefore, a thorough understanding of the origin, course, and distribution of these structures keeps the specialist on alert to avoid and recognize the occurrence of complications [5].

4.2. Results

I present below two of the most suggestive images:

Fig. 4.1.: The course of the palatine vessels in the posterior and infero-medial walls of the maxillary sinus.

1. The maxillary sinus aspect of the semilunar hiatus; 2. Infraorbital nerve in the roof of the maxillary sinus; 3. Intrasinusal fibrous band; 4. Palatine vessels, seen by transillumination on the maxillary tuberosity; 5. Root of molar III, protruding into the sinus cavity; 6. Palatine recess on the floor of the maxillary sinus; 7. Cyst in floor of palatine recess; 8. Lateral wall of nasal cavity, corresponding to medial wall of maxillary sinus.

Fig. 4.2.: Identification of the pterygopalatine ganglion and the bundle of origin of the palatine nerves.

1. The infraorbital nerve, which continues the maxillary nerve; 2. The common bundle of palatine nerves, originating in the inferior angle of the pterygopalatine ganglion; 3. The anterior face of the pterygoid process; 4. The origins of the palatine nerves; 5. The mucous membrane of the middle nasal meatus; 6. The mucous membrane of the inferior nasal meatus. The green dotted line indicates the sphenopalatine foramen. The green arrows indicate the orbital branches of the pterygopalatine ganglion. Yellow circles indicate the pterygopalatine nerves, which arise from the maxillary nerve and pass into the pterygopalatine ganglion. Red arrows indicate the nasal branches from the pterygopalatine ganglion, which enter into the nasal cavity through the sphenopalatine foramen.

4.3. Conclusions and personal contributions to this study

We managed to highlight in a single dissection image the entire pathway of palatine vessels and nerves. Simultaneously, we provided detailed information about their relationships in each traversed region. There are numerous clinical situations where the anatomical approach we performed can be useful: various types of anesthesia, tumor resections, the creation of palatal mucosa flaps, Le Fort surgery, etc. All of these procedures can benefit from a clear anatomical presentation of the pathways of palatine nerves and vessels.

Demonstrating the pterygopalatine ganglion and its relationships facilitates endoscopic interventions in the pterygopalatine fossa. Our results show that meticulous dissection, combined with a simple and clear anatomical presentation, can have significant clinical utility.

As shown, our study results far exceed the initially proposed objectives. However, we want to emphasize the importance of understanding the topography of palatine vasculonervous bundles at the level of the palatine foramina, where they approach the palate.

In this way, we can highlight the anatomical risk associated with anesthesia frequently performed before implantation procedures.

The risk of hemorrhage is evident. Injury to palatine vessels can lead to the formation of hematomas between the palatal mucosa and the hard palate. There is a possibility of the locoregional fusion of these hematomas.

Damage to palatine nerves can result in the establishment of permanent anesthesia in the respective palate and hemiarch.

5. Study III: Contributions to the study of the relationships between upper teeth and the maxillary sinus

5.1. Introduction

The anatomical configuration of the upper jaw makes the insertion of implants at this level more challenging compared to interventions on the mandible. The maxillary alveolar process naturally provides less space for implant insertion. The relationship with the maxillary sinus and the floor of the nasal cavity are risk factors in implantology [6]. A detailed understanding of the anatomical configuration is an advantage for the practicing surgeon. The risk of sinus injury, with subsequent migration of the implant into the sinus, is present in any upper jaw implantation procedure [7]. Additionally, as we have shown in the study related to palatine nerves, knowledge of the distribution of vasculonervous bundles along the alveolar process is crucial [8].

Understanding the existence and course of the sinuous canal (containing the antero-superior alveolar nerve - a branch of the infraorbital nerve [9]) is essential to comprehend why anesthesia at the incisors level should be gingival because otherwise, the anesthetic does not reach the intraosseous nerve branch.

We considered the dissection of the sinus mucosa at the level of the sinus floor [10] as highly important because this is where the sinus lift procedure takes place, involving the insertion of bone grafts to increase the necessary substrate for implant placement in the maxillary arch [11].

5.2. Results

The following are two of the most suggestive images:

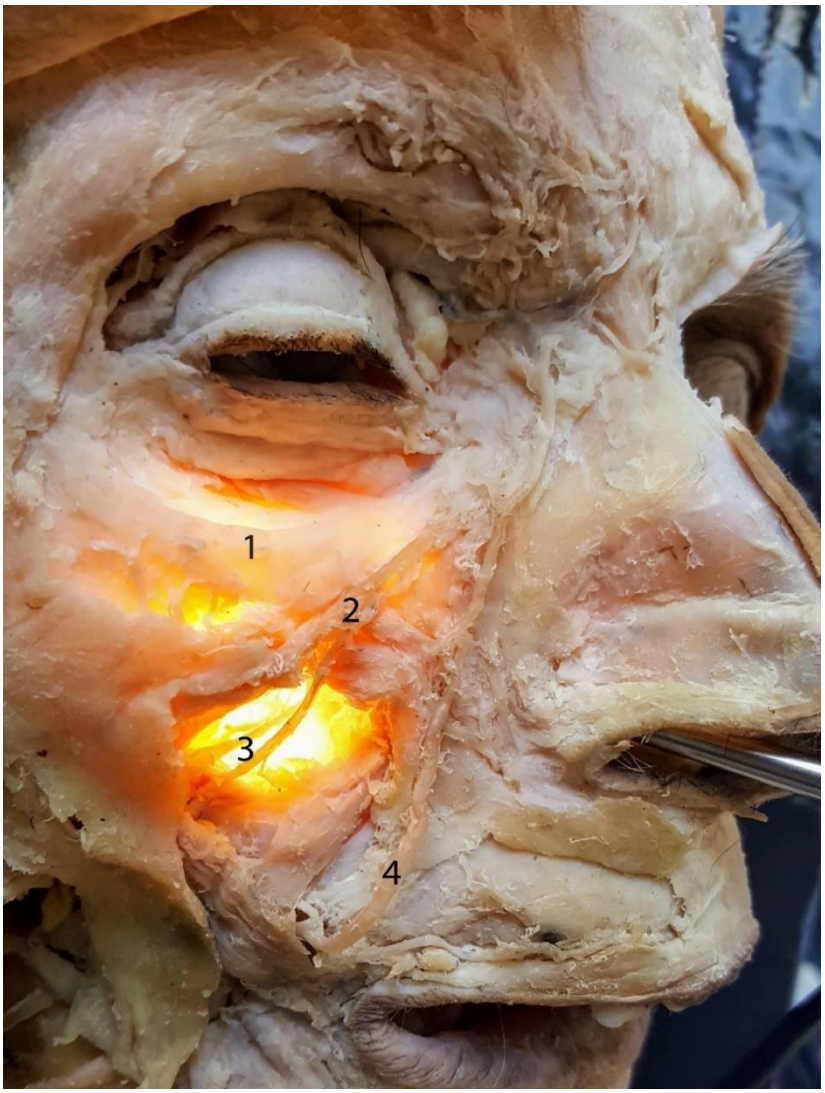

Fig. 5.1.: Endoscopic transillumination of the maxillary sinus with identification of the middle superior alveolar nerves.

1. The inferior orbital rim; 2. The infraorbital nerve; 3. The superior-middle alveolar nerves; 4. The facial artery.

Fig. 5.2.: Evidence of maxillary sinus mucosa, the antero-superior alveolar nerve and the antero-superior alveolar arterial branch.

1. The alveolar recess; 2. The naso-palatine recess; 3. Maxillary alveolar crest; 4. Hard palate; 5. Incisive cyst; 6. The ethmoidal recess; 7. The zygomatic recess; 8. The infraorbital neurovascular bundle; 9. The antero-superior alveolar nerve; 10. The antero-superior alveolar artery.

5.3. Conclusions and personal contributions to this study

As a result of observing the external aspect of the maxilla and the mode of insertion of the upper teeth, it is clear that there is small compact bony plate between the tooth roots and the maxillary surface. If the implant is inserted into the edentulous maxilla in the natural direction of the original teeth, there is a risk of penetrating the superficial cortical plate of the maxillary bone.

The presence of the superior-middle alveolar nerves between the sinus mucosa and the sinus wall represents a risk factor during sinus lift procedures. Normally, the sinus mucosa is thin, semi-opaque, and can be easily injured by hasty maneuvers during the sinus lift procedure. Demonstrating the superior alveolar nerve and the way it enters the sinus canal draws attention to the need for radiological identification of the sinus canal. An important anatomical reference is the distance of 3-4 mm between the lateral edge of the piriform aperture and the sinus canal. Even if the sinus canal cannot be radiologically demonstrated, this reference is crucial for the surgeon, prompting him to avoid implant placement at this level.

The anterior wall of the maxillary sinus is thin and semi-opaque. Not considering this observation when creating the bone window during the sinus lift procedure can lead to the inadvertent injury of the sinus mucosa with the piezoelectric scalpel.

Regarding the internal aspect of the maxillary sinus, understanding the topography of the two inferior recesses is particularly important: the alveolar recess that partially corresponds to the maxillary alveolar process and the nasopalatine recess, which can be perforated if the position and length of implants in the frontal region are not adapted accordingly.

The alveolar recess has a vertical portion corresponding to the maxillary tuberosity and a horizontal portion corresponding to the maxillary alveolar process. It is bounded by two crests, a median and a lateral one, which can be well-demonstrated radiologically.

The identification of perforating veins at the base of the maxillary alveolar process during dissection represents an important risk factor during the insertion of upper implants.

The course of the nasopalatine vasculonervous bundle through the incisive foramen must be known, as orienting the implant tip posteriorly in the case of frontal teeth can lead to nerve interception in the incisive canal. The path of the greater palatine nerve overlaps with the wall of the nasopalatine recess. This observation is particularly important to avoid damaging the vasculonervous structures.

The dissection of the postero-superior alveolar nerves and vessels practically provides the theoretical substrate necessary to be known for vestibular anesthesia of the upper molars. The clarification that the vasculonervous formations have a close relationship with the bone is extremely useful for the surgeon during anesthesia, warning them to avoid contact between the needle tip and the sinus bone wall. The needle tip should remain submucosal.

In the preoperative radiological assessment of the maxillary sinus, cord-like structures traversing the sinus lumen can be identified. They may be mistaken for vasculonervous

structures, but as we have shown, they could actually be fibrous cords without functional importance.

The sinus mucosa can be altered in appearance and size either due to age or due to pre-existing chronic inflammatory processes. The information obtained through patient history regarding sinus pathology is valuable as it alerts the surgeon to structural changes in the sinus mucosa.

The variability of maxillary sinus dimensions is recognised in the literature. With age, the sinus may narrow posteriorly at the detriment of increasing dimensions of the inferior nasal meatus. This may result in the sinus lift procedure actually addressing the inferior nasal meatus.

During the sinus lift procedure, the initial step is the dissection of the muco-periosteal complex. The surgeon carefully seeks to enter the existing cleavage space between the periosteum and the cortical bone of the maxilla. During the creation of the bone flap, the condition of the mucosa and the presence of any maxillary sinus pathologies associated should be carefully considered.

6. Study IV: Contributions to the topographic and anatomo-imagistic study of the maxillary sinus

6.1. Introduction

The maxillary sinus is the largest of the paranasal sinuses [12]. Its position in the central part of a hemiface gives it a special topographical relevance, practically all the structures of the face are connected to the sinus. Consequently, the clinician's ability to objectively detail the complexity of these relationships depends, in fact, on the correct topography of the maxillary sinus.

The tomographic investigation is performed by following consecutive sectional planes, both in sagittal and cross section.

The sinus has walls and at their junction recesses. Basically we aim to highlight anatomically and radiologically these recesses and to detail the most important relationships. A unified language between anatomists and clinicians is given by a good understanding of the topographic names.

The interest in sinus topography is expanding in many clinical disciplines.

Thus, orbito-sinusal wall damage is of ophthalmological interest, medial wall damage is of ENT interest, alveolar recess damage is of dental interest (especially in dental implantology), approach through the sphenoid recess is of major interest in neurosurgery as a route to the base of the skull.

At the same time, an understanding of sinus topography is mandatory for good descriptions in exploratory imaging.

6.2. Results

I present some of the most evocative images:

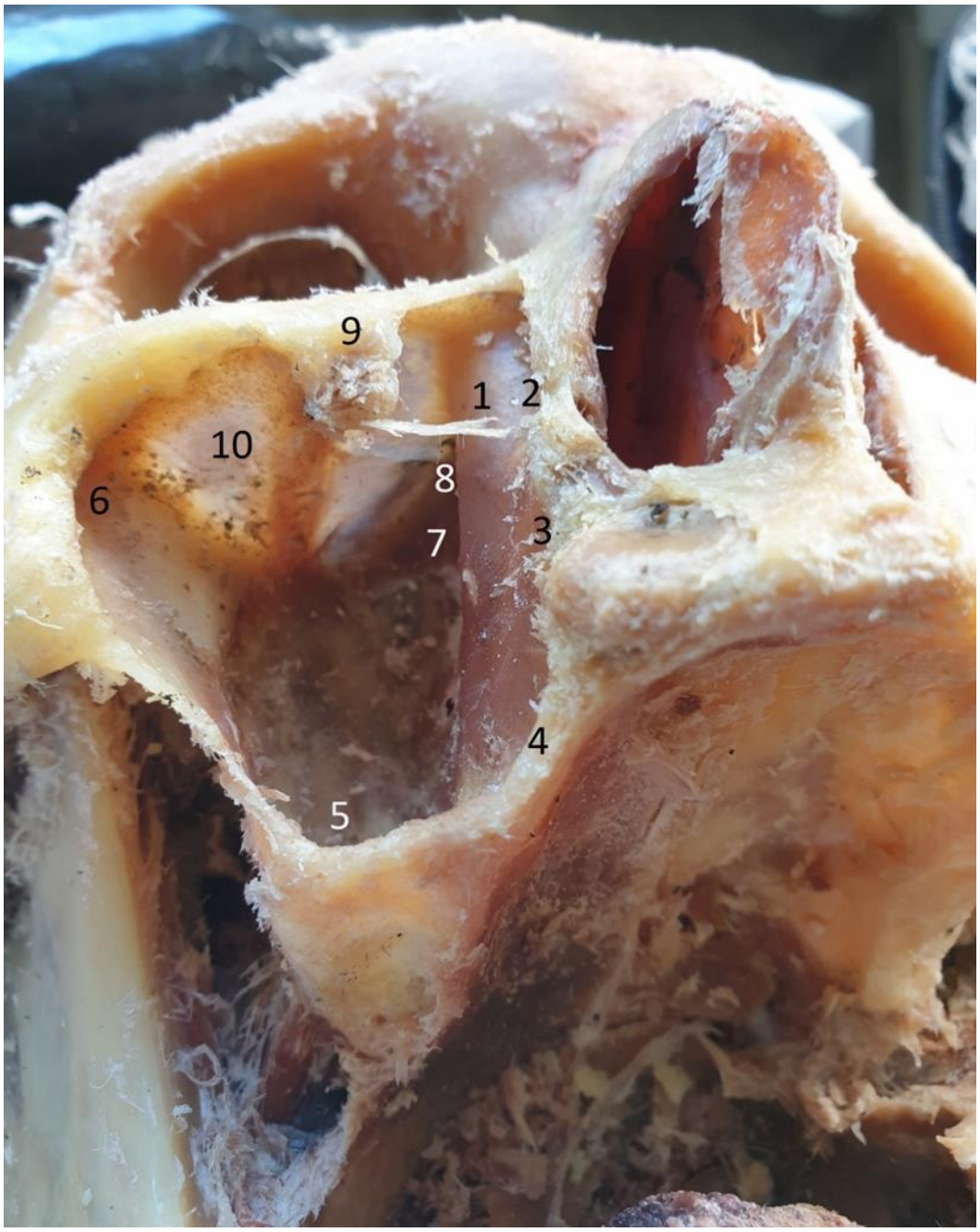

Fig. 6.1.: The appearance of the maxillary sinus cavity after removal of the anterior wall. 1. The prominence of the nasolacrimal duct in the sinus cavity; 2. The pre-lacrimal recess; 3. The naso-palatine recess; 4. Hard palate; 5. The alveolar recess; 6. The zygomatic recess; 7. The sphenoidal recess; 8. The ethmoidal recess; 9. The infraorbital nerve; 10. The roof of the maxillary sinus (semi-transparent).

Fig. 6.2.: Transverse plane CT scan showing the lines used for measurements between the anterior maxillary wall (green line) and anterior margin of the nasolacrimal duct (red line).

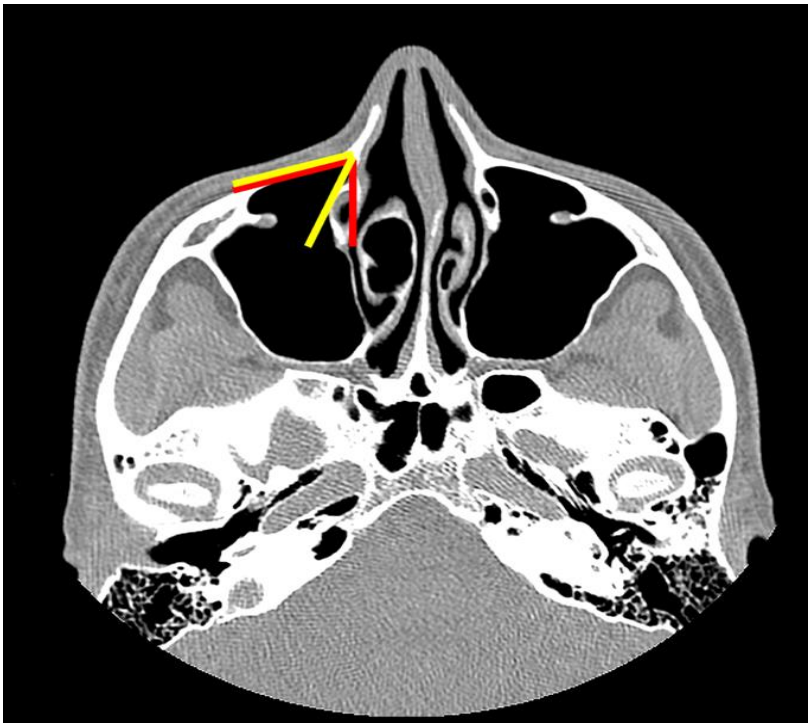

Fig. 6.3.: Transverse plane CT scan showing the measurements of the angles: the angle between the anterior and medial maxillary walls (angle 1) – red lines, and the angle between the anterior maxillary wall and the lateral margin of the nasolacrimal duct (angle 2) – yellow lines.

Fig. 6.4.: The evidence of the sinuous course of the upper labial artery (red arrow) and upper labial salivary glands (black arrows).

6.3. Conclusions and personal contributions to this study

In my study, I managed to demonstrate, define, and parallelly compare anatomically and imaging-wise the sinus recesses. Nowhere in classical anatomical literature are all sinus recesses described. Even simply listing them in the same text is an achievement. I want to reiterate the names of these recesses: pre-lacrimal, ethmoidal, sphenoidal (pterigoidian), zygomatic, alveolar, naso-palatine.

The topography of the maxillary sinus becomes a subject of interest with the evolution of medical imaging and the evolution of skull base surgery (the sinus representing an important surgical access route to the skull base).

Thus, in my study, I managed to evaluate the types of pre-lacrimal recesses, as well as the angles between the anterior and medial walls of the maxillary sinus and between the anterior wall of the maxillary sinus and the lateral edge of the nasolacrimal duct to demonstrate the feasibility of addressing the pre-lacrimal recess in intrasinusal lesions and those at the skull base from infratemporal and pterygopalatine fossae [13].

Through meticulous dissection at the anterior wall level, we proposed to assess the perioral risk, including the possibility of damaging the facial artery, superior labial artery, or its branches, as well as the upper labial salivary glands during this pre-lacrimal sinus approach procedure [14].

In this topographic study, we emphasized how the posterior wall of the maxillary sinus participates in delimiting the entrance to the pterygopalatine fossa, the anatomical space where the ganglion of the same name is located, as well as the main vasculonervous bundle as the source of vessels and nerves for the maxillary sinus.

Among the sinus relationships, we have highlighted some of major clinical importance: the relationships with the roots of the upper teeth; this classic relationship involves common pathologies at the border between two regions (sinus pathology affects the dento-alveolar territory and inversly), and dental implant interventions involve sinus lift procedures to elevate the sinus mucosa from the sinus alveolar recess.

The relationship with the nasolacrimal canal is well demonstrated in my study, even showing the variability of this relationship.

The variability of the relationship with the inferior nasal meatus describes an inverse proportional relationship: as the meatus increases, the sinus diameter decreases.

The relationship with the palatine vessels is extensively highlighted. This relationship is described in the article "The Pterygopalatine Ganglion, Palatine Nerves and Vessels: Dissection and Pathway" [3] published in the International Journal of Morphology as part of the doctoral study.

I conducted this research based on the observation that organs occupying the center of a topographic region establish a heterogeneous relationship with the surrounding regions and structures. As a consequence, investigating and diagnosing such organs will almost always be correlated with explorations beyond the limits of the respective organ.

I started from this challenge, but during the study, I was much more surprised than I expected. Investigating the pterygopalatine fossa and demonstrating the pathways of palatine nerves and vessels in relation to the maxillary sinus was also a remarkable revelation for me.

The embryological development of the sinuses, as it appeared in the study, deviates slightly from the expectations raised by the study of specialized literature.

Studying the necessary bibliography, step by step, I came to understand the importance of small-sized regions that others easily overlook. Thus, I demonstrated the importance of the surgical access to the sinus and to regions at the skull base through the pre-lacrimal recess of the maxillary sinus.

Finally, the fact that I did not find all the mentioned and exemplified sinus recesses in specialized literature in one place leads me to believe that the effort to put together the elements of sinus topography, in a way that clinicians can benefit from, represents a major gain.

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The list of published scientific articles on the topic of the doctoral thesis

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