The aim of our study is to determine the histo-topographic and morphometric features of the structural components of the mucous membrane of the human frontal sinus on different walls. Materials and methods: to achieve the goal, we used a set of methods for morphological studies including the method of serial semi-thin sections, histochemical studies, and the morphometric method. The thickest mucous membrane on the lower wall has an average epithelium thickness of 51.45±1.59 μm on the left and 50.78±1.64 μm on the right. On the left, the lamina propria thickness is 42.49±5.34 μm, and on the right, it is 43.05±2.22 μm. The submucosal base has a thickness of 423.67±21.33 μm on the left and 426.45±16.77 μm on the right, which is four times higher than the average thickness of the back wall and septum (p<0.05). The average diameter of the lumen of the resistive and capacitive links of the hemomicrocirculatory channel is the largest in the mucous membrane of the front wall of the human frontal sinus (respectively, 11.16±0.37 μm on the left and 11.34±0.31 μm on the right (p<0.05); 7, 63±0.08 μm on the left and 7.57±0.09 μm on the right), the smallest is in the mucous membrane of the back wall (respectively, 6.96±0.19 μm on the left and 6.56±0.35 μm on the right; 8.82±0.16 μm on the left and 9.02±0.43 μm on the right (p<0.05)). Exchangeable hemomicrovessels with the smallest diameter had a measurement of 3.89±0.08 μm on the left and 4.19±0.02 μm on the right (p<0.05) within the specified area. The study revealed the largest capillaries in the mucosal lining of the lower wall, which measured 4.88±0.07 μm on the left and 4.73±0.12 μm on the right (p<0.05). Furthermore, complex alveolar-tubular glands were evident in the submucosal base of the mucosal lining in all walls of the designated sinus. It has been found that the glands on the lower wall have the largest diameter of the terminal sections, whereas those on the septum have the smallest. On the left, the glands on the lower wall have a diameter of 30.42±2.36 μm, while those on the septum have a diameter of 25.42±1.68 μm. On the right, the corresponding measurements are 31.01±1.34 μm and 25.89±1.38 μm (p<0.05). In conclusion, this study highlights the distinct differences in gland diameter and type among different sections of the organ. The glands on the front and back comprised a mixture of protein and mucous types, while two types were identified on the lower wall and septum. The statistical processing of the obtained histo-topographic, histological, histochemical, and morphometric data significantly enhances the comprehension of the microscopic structure of the mucous membrane in the frontal sinus. These findings can be important in modern morphology and otorhinolaryngology.

Key words: human subjects, frontal sinus, mucous membrane, histological structure, morphometric method.

The study is a part of the research project “Regularity of the morphogenesis of organs, tissues and vascular and nervous formations in normal, pathological and under the influence of exogenous factors”; state registration No. 0118U004457.

Introduction

Nowadays, the clinical, diagnostic and morphological characteristics of frontitis have been extensively investigated. Nevertheless, recent findings suggest that the morphological alterations of the mucous membranes in the frontal sinus do not consistently align with the clinical manifestations of inflammatory processes [1,2,3,4]. Issues on treating the sinuses, particularly the frontal sinus, are pertinent to current otorhinolaryngology research. Endoscopic techniques [5, 6] require a detailed understanding of the macro-microscopic structure of the mucous membrane in the specified sinus.

Thorough research of literature and scientific sources has revealed that there is a lack of information pertaining to the histo-topographical features, morphometric data on structural components of the mucous membrane of the human frontal sinus and quantitative and qualitative characterization of all links of the vascular hemomicrocirculatory channel, glandular apparatus and epithelium of the mucous membrane of the specified sinus. Only minor fragments of information could be found on the subject matter we were investigating.

Therefore, the aforementioned factors establish the pertinence and necessity of our investigation into the analysis of the structural configuration, histo-topographical and morphometric properties of the components of the mucus membrane found within the frontal sinus of human beings as a whole, as well as on every individual wall.

Aim of the study

The purpose of our study is to determine the histo-topographic and morphometric features of the human frontal sinus and the structural components of its mucous membrane on different walls.

Materials and methods

In our study, a complex of macro-microscopic, histological, histochemical, and morphometric research methods with statistical analysis was used. Mucous membrane from different walls of the frontal sinus was obtained after trepanation access to the skull cavity, removal of the brain with membranes and destruction of the back wall of the studied sinus. The microstructure of the mucous membrane of the human frontal sinus in general and
separately on each wall was studied using the methods of serial semi-thin sections and microscopy. In order to determine the qualitative content of proteins and carbohydrates in the mucous membrane the histochemical method was used. Using the morphometric method, the following morphometric data of the structural components of the mucous membrane of the frontal sinuses have been revealed: thickness (epithelium, lamina propria, submucosal base); diameter (artery, arteriole, capillaries, venules, veins); the outer diameter of the end sections of the glands. The obtained data were statistically processed [7–14].

In our work, we used age periodization according to G. Craig (2000) [15]. Quantitative distribution of research objects according to their age and gender is shown in Table 1.

<table>
<thead>
<tr>
<th>Age groups</th>
<th>Age</th>
<th>Number of researched objects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Men</td>
</tr>
<tr>
<td>Early adulthood</td>
<td>20-40 years old</td>
<td>3</td>
</tr>
<tr>
<td>Middle adulthood</td>
<td>40-60 years old</td>
<td>15</td>
</tr>
<tr>
<td>Late adulthood</td>
<td>From 60 years and older</td>
<td>49</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>67</td>
</tr>
</tbody>
</table>

The work was carried out in accordance with the requirements of the “Instructions on Conducting a Forensic Medical Examination” (order of the Ministry of Health of Ukraine No. 6 dated 7.01.1995), in accordance with the requirements and norms, the standard regulation on ethics of the Ministry of Health of Ukraine No. 690 dated 23.09.2009, “The procedure for Extracting Biological Objects from the Dead, whose Bodies are Subject to Forensic Medical Examination and Patho-anatomical examination, for Scientific Purposes” (2018).

**Results**

When examining the mucous membrane of the frontal sinus, it has been revealed that it is represented by epithelial and own laminae with a submucosal base.

When examining semi-thin sections, it has been found out that the epithelium covering the mucous membrane of all walls of the frontal sinus is pseudo-multilayered ciliated and cylindrical in nature, with occasional minor structural characteristics. The epithelial structure of the mucous membrane of the frontal sinus comprises three distinct cell types: ciliated, inserted (short and long), and mucous (goblet). In the epithelial lamina of the front and lower walls, the relative number of goblet cells was the largest, on the back they were less numerous, in the epithelium of the septum of the frontal sinus, goblet cells were not typical.

The own lamina of the mucous membrane of the frontal sinus is made of loose connective tissue and consists of cells of the fibroblastic series, collagen and elastic fibres.

In the mucous membrane of all the walls of the human frontal sinus, a submucosal base is defined, which is formed by loose fibrous connective tissue with a distinctive network of hemomicrovessels. We found glands in the submucosal base of each wall. The submucosal base is distinctive on all the walls and the septum.

In the loose connective tissue of the lamina propria of the mucous membrane of all the walls of the frontal sinus around the superficial hemomicrovessels, clusters of cells of the leukocyte series were revealed – macrophages, lymphocytes, single plasma cells and neutrophilic granulocytes, which provide the formation of a local protective barrier against foreign agents.

The study of the blood supply of the mucous membrane of all the walls of the human frontal sinus showed that the blood circulation is provided by two main components – a deep vascular network, which is represented by arteries and veins in the connective tissue of the lamina propria, and surface microvessels that provide nutrition.

When studying surface of blood vessels, arteries and veins, we have found out that the general structure of these components on each wall has certain peculiarities.

The arteries of the mucous membranes of the frontal sinuses possess a classical structure compared to those of other paranasal sinuses. Of these arteries, those of the lower wall have the most peculiarities, as they are tortuous, a phenomenon which is confirmed morphologically by a large number of tangential sections on a small section area.

During the analysis of semi-thin sections from the mucous membrane of the human frontal sinus, it was identified that the veins present in the deep vascular network of all walls displayed a wide lumen and thin walls. Typically, these veins were found parallel to the interface between the epithelium and the connective tissue of the lamina propria. This fact was supported by elongated tangential sections. The wall of the vein comprised a fine layer of collagen fibres with singular adventitial fibroblasts and a layer of endothelial cells on the basement membrane. Both transverse and longitudinal sections of veins were detected in the mucosa of all frontal sinus walls, affirming the existence of a profound venous plexus.

During examination of the hemomicrocirculatory channel within the frontal sinus's mucous membrane, we observed numerous components present on all walls, including arterioles, capillaries, and venules.

The arterioles within the superficial vascular network of the lower wall and septum have particular structural features, with a significantly higher
number of smooth myocytes, measuring between 4-6 layers when compared to the 1-2 layers on the other walls.

The venules of the mucous membrane of the frontal sinus had a classic wall structure. Vessels were detected both on transverse and tangential sections, which is a morphological confirmation of the presence of a superficial venular plexus. The specific features of the structure and location of the venules of the mucous membrane of the frontal sinus confirm their participation not only in thermoregulation, but also in the passage of leukocytes through their wall to provide an immune response.

By structure, the capillaries of the mucous membrane of the walls in the human frontal sinus are somatic ones. The average values of the diameter of their lumen were the smallest on the back wall (3.89±0.08 μm on the left and 4.19±0.02 μm on the right (p<0.05)); the largest were on the lower wall (4.88±007 μm on the left and 4.73±0.12 μm on the right (p<0.05)). First of all, the latter phenomenon is preconditioned by a large number of the terminal parts of mucous glands in the structure of the mucous membrane of the lower wall.

Complex branched alveolar-tubular glands were identified within the mucous membrane of the frontal sinus walls and septum. These glands are proteinaceous and mucous on the lower wall and septum, but mixed on the front and back walls, consisting of a system of excretory ducts with terminal parts.

Cubic-shaped cells form the terminal parts of the glands in the mucous membranes of the front wall and septum, while pyramid-shaped cells form those in the back. Two types of complex branched glands were found in the lower wall’s end sections. The first variety has cube-shaped epitheliocytes, while the second type has pyramid-shaped ones.

The morphometric analysis of the average submucosal base thickness of the mucous membrane in the human frontal sinus revealed considerable variations among different walls. This, in turn, allowed for the division of values into two distinct groups.

The thickness of the submucosal base on the front of the structure was measured to be 299.65±14.63 μm on the left and 302.34±12.98 μm on the right, with a significant difference indicated by a p-value less than 0.05. The thickness of the submucosal base on the lower walls was measured to be 423.67±21.33 μm on the left and 426.45±16.77 μm on the right, with a significant difference indicated by a p-value less than 0.05). In this study the thickness of the mucous membrane was measured in the frontal sinus. The results showed that the thickness of the mucous membrane was significantly higher on the anterior wall than on the posterior wall (11.17±3.97 μm on the left and 115.47±6.48 μm on the right, p<0.05) and septum (127.17±8.48 μm on the left and 124.93±7.89 μm on the right, p<0.05).

Similar features were also found out in relation to the thickness of the epithelial lamina, the largest values on the front (47.86±0.79 μm on the left and 47.44±1.22 on the right (p<0.05)) and lower (51.45±1.59 μm on the left and 50.78±1.64 μm on the right (p<0.05)), smaller on the back (33.67±1.70 μm on the left and 34.61±1.83 μm on the right (p<0.05)) and septum (36.01±1.23 μm on the left and 35.21±1.31 μm on the right (p<0.05)). As for the metric parameters of the lamina propria of the mucous membrane of the human frontal sinus, its maximum thickness was on the lower wall (42.49±5.34 μm on the left and 43.03±2.22 μm on the right (p<0.05)), and the minimum was on the front (23.05±2.13 μm on the left and 22.98±2.01 μm on the right (p<0.05)).

In our study, we obtained the average values of the diameter of the components of the hemomicrocirculatory bed and superficial blood vessels. The morphometric study of the blood vessels of the mucous membrane of the frontal sinuses revealed that the arteries had the largest lumen diameter on the front wall (27.58±3.07 μm on the left and 26.77±3.17 μm on the right (p<0.05)). We defined the smallest metric values on the back wall – 2.7 times (10.72±0.35 μm on the left and 11.02±0.69 μm on the right (p<0.05)) smaller than the indicators for the front wall. The metric indicators of the diameters of the lumen of the veins were the largest on the front wall (33.09±1.64 μm on the left and 32.97±1.56 μm on the right (p<0.05)), the smallest were on the back wall (15.42±0.46 μm on the left and 15.84±1.27 μm on the right (p<0.05)), which corresponded to the pattern we determined for arteries.

The average values of the lumen diameters of arterioles of the mucous membrane of the human frontal sinus were the largest on the front wall (11.16±0.37 μm on the left and 11.34±0.31 μm on the right (p<0.05)), they exceeded the indicators for the back wall by 60% (6.96±0.19 μm on the left and 6.56±0.35 μm on the right (p<0.05)) and by 45% – for the lower wall (7.60±0.34 μm on the left and 8.01±0.25 μm on the right (p<0.05)) and septum (7.71±0.12 μm on the left and 7.64±0.21 μm on the right (p<0.05)).

During the morphometric study of the capillaries, it was revealed that the average values of the diameter of their lumen were the smallest on the back wall (3.89±0.08 μm on the left and 4.19±0.02 μm on the right (p<0.05)); the largest were on the lower wall (4.88±0.07 μm on the left and 4.73±0.12 μm on the right (p<0.05)) and septum (4.82±0.06 μm on the left and 4.91±0.11 μm on the right (p<0.05)).

The results of the morphometric study of venules, which are the capacitive link of the hemomicrocirculatory channel, turned out to be interesting. The largest was the diameter of their lumen on the back wall (8.82±0.16 μm on the left and 8.02±0.45 μm on the right (p<0.05)). The identified phenomenon proves in favour of the fact that in the mucous membrane of this wall there are conditions for inhibiting the speed of blood flow and deposition of blood.
The smallest (16% smaller in comparison with the indicators of the back wall) values of the diameter of the lumen of the venules were on the front wall (7.63±0.08 μm on the left and 7.57±0.09 μm on the right (p<0.05)) of the frontal sinus, which prevents stagnation of blood in the capillaries and provides the rapid evacuation of cooled blood from the microcirculatory bed and coming of warmed arterial blood to the capillaries.

The largest average diameter of the ending parts of the glands was on the lower wall (30.42±2.36 μm on the left and 31.01±1.34 μm on the right (p<0.05)), it was 20% higher than the smallest indicator – on the septum (25.42±1.68 μm on the left and 25.89±1.38 μm on the right (p<0.05)).

The morphometric study with statistical processing of such an indicator as the outer diameter of the glands of the mucous membrane of the human frontal sinus also showed a relationship between it and the thickness of the mucosa (submucosa) on each wall separately. Specifically, the largest submucosal base thickness and largest external diameter of the glands were observed in the mucous membrane of the lower wall of the frontal sinus.

**Discussion**

It is well known the inflammatory process that develops in the frontal sinus has its own characteristics, because the frontal sinus is a closed cavity with a small amount of oxygen [16]. Our study significantly expanded the understanding of the histotopographical structure and morphometric characteristics of the structural elements of the mucous membrane of the frontal sinus in a normal person. Research by I.V. Stagnieva (2008) showed an objectively proven dependence of pathomorphological changes in the mucous membrane of the frontal sinuses on the clinical manifestations of frontitis [4].

The data obtained enable us to deduce potential complications resulting from inflammatory processes in the frontal sinus, as well as the patterns of their spread to surrounding structures of the skull, including the orbits and other sacral sinuses. This study will provide valuable insights for clinicians in diagnosing and treating patients with acute and chronic frontitis.

Thorough research of the structural elements of the mucous membrane of the human frontal sinus has shown that the data obtained revealed peculiarities on each wall of the sinus separately. Analyzing the above mentioned findings of our own research, we can conclude that the mucous membrane of each wall of the frontal sinus contains the following elements: epithelium, lamina propria, submucosal base, glands (of two types), arteries, arterioles, capillaries, venules, veins. But on each wall of the sinus separately, they possess their own histo-topographic features with different morphometric indicators and are developed differently.

Statistical analysis of the morphometric indicators of all elements of the mucous membrane of the frontal sinus enabled to reveal the features on each wall. We consider that an important characteristic of the mucous membrane of the frontal sinus is the interdependent relationship between its overall thickness and every separate constituent, including epithelium, lamina propria, and submucosal base, as well as the particular density of structural elements such as surface microvessels (arteries and veins) and the deep vascular network (arterioles, capillaries, venules). These interactions, considering the structural and functional characteristics, will provide insight into the blood microcirculation and glandular apparatus function (mucociliary clearance) in the mucous membrane area of the frontal sinus of an individual.

Thus, the obtained histo-topographic, histological, histochemical, and morphometric data, with statistical analysis of the results, significantly enhance our understanding of the microscopic structure of the mucous membrane within the frontal sinus. The statistical analysis of morphometry data confirms and complements differences in histotopography and cytoarchitectonics of the structural elements of the mucous membrane of the human frontal sinus, both generally and on each wall individually. The histological study provided insight into the structural organization of the mucous membrane in the frontal sinus of humans, both generally and specifically on each wall.

**Conclusions**

1. The mucous membrane epithelium of the septum in the human frontal sinus contains single goblet cells. Immunocompetent cells, including leukocytes and mast cells, were found in the lamina propria of the mucous membrane in all frontal sinus walls. Clusters of leukocytes were observed on the front and lower walls, whereas single lymphocytes and macrophages were localized perivascularly on the back wall and septum in the lamina propria. Mast cells were identified in the lamina propria of the anterior frontal wall either individually or as part of leukocyte clusters. Mast cells were also detected perivascularly in the submucosal region at the back wall and septum of the frontal sinus.

2. The main structural elements of the human frontal sinus mucous membrane were assessed morphometrically, and the epithelium on the lower wall was determined to be the thickest, with an average thickness of 51.45±1.59 μm on the left and 50.78±1 μm on the right. The thickness of the lamina propria was 42.49±5.34 μm on the left and 43.03±2.22 μm on the right, while the submucosal base measured 423.67±21.33 μm on the left and 426.45±16.77 μm on the right, with a statistically significant difference (p<0.05). This value is four times greater than the average thickness on the back wall and septum.

3. The average diameter of the lumen of the resistive and capacitive links of the hemomicrocirculatory channel is the largest in the mucous membrane of the front wall of the human frontal sinus (respec-
tively, 11.16±0.37 μm on the left and 11.34±0.31 μm on the right (p<0.05) and 7.63±0.08 μm on the left and 7.57±0.09 μm on the right), the smallest – in the structure of the mucous membrane of the back wall (respectively, 6.96±0.19 μm on the left and 6.62±0.35 μm on the right; 8.02±0.16 μm on the left and 9.02±0.43 μm on the right (p<0.05)). Exchangeable hemomicrovessels with the smallest diameter - 3.89±0.08 μm on the left and 4.19±0.02 μm on the right (p<0.05) are found in the specified area.

We revealed the widest capillaries in the mucous membrane of the lower wall - 4.88±007 μm on the left and 4.73±0.12 μm on the right (p<0.05) of the frontal sinus.

4. Complex alveolar-tubular glands were found in the submucosal base of the mucous membrane of all the walls of the frontal sinus. It has been found out that the largest diameter of the terminal parts of the glands on the lower wall, the smallest on the septum, respectively, is 30.42±2.36 μm on the left and 31.01±1.34 μm on the right; 25.42±1.68 μm on the left and 25.89±1.38 μm on the right (p<0.05). 2 types of glands are found on the lower wall and septum – protein and mucous, and mixed on the front and back.

Prospects for further research

Potential areas for further research include examining the microscopic relationship between changes in the morphometric indicators of surface blood vessels (arteries and veins) and the links of the hemomicrocirculatory channel (arterioles, capillaries and venules) in both acute and chronic frontitis. Additionally, it would be informative to compare the changes in the diameters of the terminal parts of the glands on different walls of the frontal sinus under normal conditions and in acute and chronic frontitis.

Conflict of interest

The authors declare no conflict of interest.

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Реферат

УЗАГАЛЬНЕННА ГІСТОСТРУКТУРНА І МОРФОМЕТРИЧНА ХАРАКТЕРИСТИКА ЛОБОВОЇ ПАЗУХИ ЛЮДИНІ У НОРМІ

Сербин С.І., Дубина С.О., Бондаренко С.В., Свяргія С.М., Котєв М.М.

Метою нашого дослідження було визначити гісто-топографічні та морфометричні особливості структурних компонентів слизової оболонки лобової пазухи людині на різних стінках. Матеріали та методи дослідження. Для досягнення поставлених мети ми використовували комплекс методів для морфологічних досліджень: метод серійних напівтонких зрізів, гістохімічні дослідження, морфометричний метод.

Одержані дані підлягали статистичній обробці. Результати. Найтовша слизова оболонка на нижній стінці – середня товщина епітелію складає 51,45±1,59 мкм зліва та 50,78±1,64 мкм справа, власної пластинки – 42,49±5,34 мкм зліва та 43,03±2,22 мкм справа, підслизової основи – 423,67±21,33 мкм зліва та 426,45±16,77 мкм справа (p<0.05), i в чотири рази перевищує середні значення товщани на
Актуальні проблеми сучасної медицини

Задній стінці і перегородці. Середній діаметр просвіту резистивної і емісійної ланок гемомікрокругляторного рулета є найбільшим в слізової оболонці передньої стінки лобової пазухи людини (відповідно 11,16±0,37 мм зліва та 11,34±0,31 мм справа (p<0,05); 7,63±0,08 мм зліва та 7,57±0,09 мм справа), найменшим — в складі слізової оболонки задньої стінки (відповідно 6,96±0,19 мм зліва та 6,56±0,35 мм справа; 8,52±0,16 мм зліва та 9,02±0,43 мм справа (p<0,05)). У визначених ділянках виявляються обмінні гемомікрорудини з найменшим діаметром — 3,89±0,06 мм зліва та 4,19±0,02 мм справа (p<0,05). Найширші капіляри визначені нами в складі слізової оболонки нижньої стінки — 4,88±0,07 мм зліва та 4,73±0,12 мм справа (p<0,05). В підслизової основі слізової оболонки всіх стінок зазначеного синусу виявлені складні альвеолярно-трубчасті залози. Встановлено, що найбільший діаметр кінцевих відділів залоз на нижньої стінці — 31,01±1,34 мм справа; 25,42±1,68 мм зліва та 25,89±1,38 мм справа (p<0,05). На нижній стінці та перегородці виявлені 2 типи залоз — білкові та слізової, а на передній і задній — змішані. Висновок. Отримані гісто-топографічні, гістологічні, гістохімічні дані зі статистичною обробкою отриманих результатів значно розширюють уяву про мікроскопічну будову слізової оболонки лобової пазухи, що має велике значення для сучасних морфології та оториноларингології.

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СУДОВО-МЕДИЧНІ АСПЕКТИ ТЯЖКОСТІ ТРАВМ ГОРТАНІ ЗА РЕЗУЛЬТАТАМИ ОБСТЕЖЕННЯ ПАЦІЄНТІВ НА БАЗІ СПЕЦІАЛІЗОВАНОГО СТАЦІОНАРУ
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²Харківське обласне бюро судово-медичної експертизи

Вступ: закрита тупа травма гортані, є приводом призначення судово-медичної експертизи. Мета роботи: визначення її судово-медичних позицій тяжкості травм гортані за результатами обстеження пацієнтів на базі спеціалізованого статево-органічного відділу залози. Матеріали і методи: досліджено 38 пацієнтів, з травмами гортані, які зверталися до Харківської міської клінічної лікарні №3 протягом останніх 10 років. Крім того, 16 хворим з зазначеними вище позиціями тяжкості травм гортані за результатами обстеження, що дозволило об'єктивізувати наявність післятравматичних змін, при травмах гортані, обґрунтувати діагностичні, імунологічні, гематологічні, гістологічні, гістохімічні, морфометричні дані зі статистичною обробкою отриманих результатів значно розширюють уяву про мікроскопічну будову слізової оболонки лобової пазухи, що має велике значення для сучасних морфології та оториноларингології.

Ключові слова: судово-медична експертиза, травма гортані, діагностичні критерії, ступінь тяжкості тілесних ушкоджень

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