

AERODYNAMIC FEATURES OF THE OLFACTORY AREA IN NASAL BREATHING

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Abstract. The passive of air through the upper nasal passage ensures the delivery of odorivector molecules to sensitive areas of the olfactory analyzer. The study of the characteristics of the air flow in the upper nasal passage allows us to determine the boundaries of the near-wall laminar air sublayer and to study nasal aerodynamics at the micro level. Turbulent flow contributes to the excessive drying of the mucous membrane of the nasal cavity, leading to its morphological rearrangement towards the subatrophic process. It was found out that the thickness of the laminar sublayer is about 1 mm, therefore, the lining of the mucous membrane is subjected to drying with an increase in the turbulence of the flow at the sites of narrowing of the nasal cavity (olfactory cleft).

Keywords: air flow, olfactory cleft, laminar air sublayer, nasal cavity, mucous membrane, turbulent flow.

Introduction. The study of the olfactory analyzer not only makes it possible to identify various diseases in the early stages, but also serves as a tool for evaluating the effectiveness of rhinosurgical intervention, and a full sense of odors influences the quality of human life. With violations of smell, it becomes impossible to perform odoriferous substances signaling functions: nutritional function, sexual function, guard function, orienting function. At the same time, the quality of life is significantly reduced, and the level of risk increases with the use of household gas appliances. Topical are the problems associated with predicting and evaluating the functional results of endonasal surgery, which, in the case of respiratory and olfactory disorders, are the condition for air flow through the upper nasal passage and restoration of the olfactory sensitivity.

Changing the direction of the main air stream with nasal breathing leads to constant irritation of certain sections of the mucous membrane (for example, a portion of the mucosa of the nasal cavity that contains olfactory receptors, the so-called olfactory zone), which will subsequently lead to cellular infiltration in this region and then to hypertrophy of the mucosa shells.

Results of the study. An important characteristic of nasal breathing is the distribution of air flow rates along the sections of the nasal cavity.

For a laminar regime in a section with radius a , we obtain a parabolic dependence of the velocities W on the distance from the center r .

$$W = 2W_{cp} \left(1 - \frac{r^2}{a^2}\right), \quad (1)$$

where W_{cp} – the average air velocity, r – the distance from the center, a – radius.

For the turbulent regime, the velocity is determined in this way:

$$U = U_{max} \left(\frac{r}{a}\right)^{0.9\sqrt{\lambda}}, \quad (2)$$

U_{max} – the maximum air velocity, λ – loss factor.

With the increase in air flow rate (with forced breathing - physical activity, narrowing of the nasal passage), the thickness of the laminar boundary layer will decrease, the mucosa will be exposed to high-speed turbulent flow. Turbulization of the air flow will promote the drying of individual areas of the mucosa of the nasal cavity, and as a result traumatization of the mucosa with subsequent morphological rearrangement of individual areas. Whatever the law of velocity distribution in the section of the turbulent flow, the speed at the wall is 0, increasing to the axis of the flow.

Consequently, there should be a low-speed layer, the thickness of which depends on Re , and the speed increases from 0 to 90 % of the velocity of the core of the flow (fig. 1).

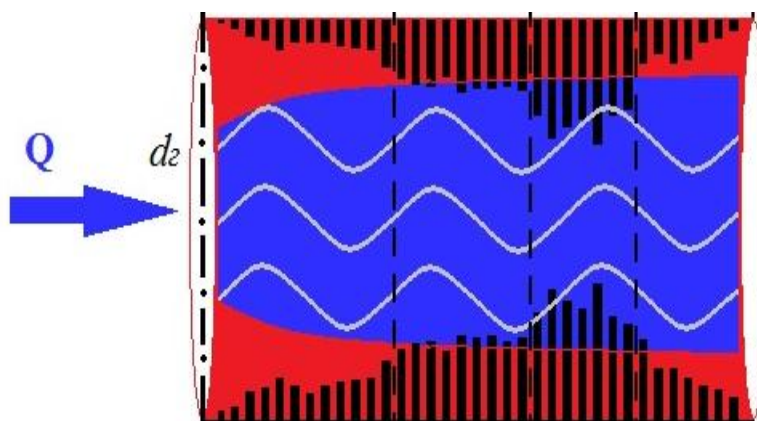


Fig. 1. Schematic representation of the turbulent core of the stream (blue) and laminar boundary layer (red color), with respect to the internal microprotrusions of the nasal cavity

Reynolds number Re , is determined by the formula:

$$Re = \frac{V \cdot d_r}{\nu}, \quad (3)$$

where V – the average air velocity in the nasal cavity;
 ν – the coefficient of dynamic viscosity;
 d_r – the hydraulic diameter:

$$d_r = \frac{4S}{P}, \quad (4)$$

S – the average cross-sectional area of the nasal passage;
 P – the perimeter of the section of the nasal passage;
 Thus, the thickness of the laminar boundary layer can be calculated as

$$\delta = \frac{32,4 \cdot d_r}{Re^{0,875}}. \quad (5)$$

The definition of the mucosal surface roughness is based on the tomographic data and is calculated by the formula:

$$\Delta_i = l_{i+1} - l_i + \left(\frac{l_{i+1} - l_i}{l_{max}} h \right), \quad (6)$$

where l_i и l_{i+1} – thickness of the mucosa on the i -th and $i + 1$ -m tomographic sections of the nasal cavity, respectively;

l_i и l_{i+1} – intensity levels on the boundary between the mucosa and air on the i th and $i + 1$ frontal tomographic sections, respectively;

l_{max} – the maximum level of intensity in the CT image;

h – the spatial resolution of CT images.

When comparing the thickness of the laminar boundary layer and the surface roughness value can be inferred about the degree of olfactory mucosa traumatization region.

There are three states:

- $\Delta_i < \delta_i$ – there is no negative impact (the lining of the mucosa is completely in the laminar boundary sublayer);
- $\Delta_i \approx \delta_i$ – the protrusions of the mucosa are near the boundary of the laminar boundary sublayer;

– $\Delta_i > \delta_i$ – the negative influence associated with the turbulent drying of the mucous membrane by the air flow is established.

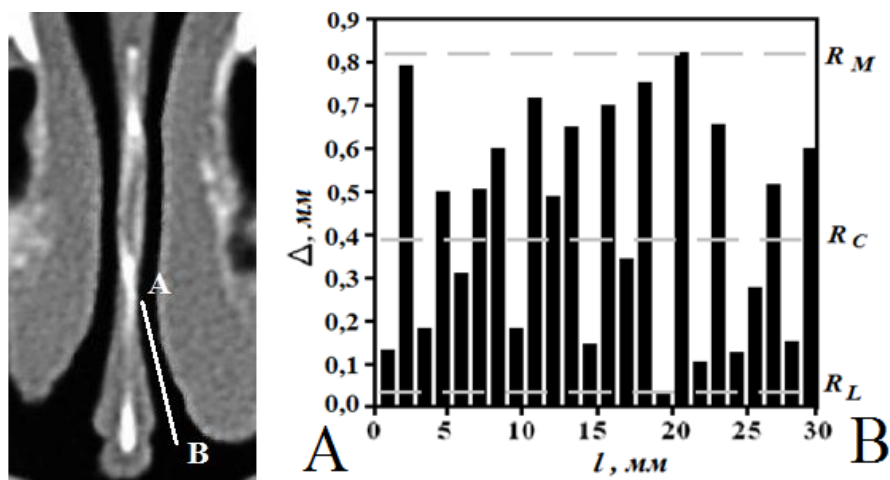


Fig. 2. Distribution of microroughnesses on the section

Conclusions. The passive of air through the upper nasal passage ensures the delivery of odorivector molecules to sensitive areas of the olfactory analyzer. The study of the characteristics of the air flow in the upper nasal passage allows us to determine the boundaries of the near-wall laminar air sublayer and to study nasal aerodynamics at the micro level. Turbulent flow contributes to the excessive drying of the mucous membrane of the nasal cavity, leading to its morphological rearrangement towards the subatrophic process.

It was found out that the thickness of the laminar sublayer is about 1 mm, therefore, the lining of the mucous membrane is subjected to drying with an increase in the turbulence of the flow at the sites of narrowing of the nasal cavity (olfactory cleft).

The prospect of work is the study of the characteristics of the boundary layer in typical pathologies in various respiratory regimes.

REFERENCES

1. Nosova Ya., Avrunin O., Semenets V. Biotechnical system for integrated olfactometry diagnostics. Innovative technologies and scientific solutions for industries. 2017, No. 1 (1) p.64 – 68.
2. Boesveldt S., Lindau S. T., McClintock M. K., Hummel T., Lundström J.N. Gustatory and olfactory dysfunction in older adults: a national probability study. Rhinology. 2011; 49 (3): 324 – 330.
3. Tavakola M. M., Ghahramanib E., Aboualib O., Yaghoubibc M., Ahmadid G. Deposition fraction of ellipsoidal fibers in a model of human nasal cavity for laminar and turbulent flows. Journal of Aerosol Science. November 2017, Volume 113, P. 52-70.
4. Curle N. The Laminar Boundary Layer Equations. Courier Dover Publications, 2017, 176 p.
5. Jong-HoonLee YangNa Sung -KyunKim Seung-KyuChung. Unsteady flow characteristics through a human nasal airway. Respiratory Physiology & Neurobiology. July 2010, Volume 172, Issue 3, P. 136-146