Determination of nasal breathing disorders according to computer tomography

Yana Nosova
Department of Biomedical Engineering
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
yana.nosova@nure.ua

Oleg Avrunin
Department of Biomedical Engineering
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
oleh.avrunin@nure.ua

Maksym Tymkovych
Department of Biomedical Engineering
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
maksym.tymkovych@nure.ua

Sofiia Khudaieva
Department of Biomedical Engineering
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
sofiia.khudaieva@nure.ua

Nadiia Yurevych
Otorhinolaryngology Department
Kharkiv National Medical University
Kharkiv, Ukraine
urevichi@ukr.net

Birgit Glasmacher
Institute for Multiphase Processes
Leibniz University of Hannover
Hannover, Germany
glasmacher@imp.uni-hannover.de

***Abstract*—The most important factor that determines the normal functional state of the nasal mucosa is that which passes through it during inhalation and exhalation air flow, which, entering the nasal cavity, due to the active expansion of the chest feels resistance from the surrounding structures. This factor is influenced by an indicator such as air flow resistance, with 54% of the total resistance of the respiratory system to the upper respiratory tract, including 46% of the resistance of the nasal cavity. In addition, it is necessary to study the aerodynamic laws that play an important role in the regulation of the degree of nasal resistance. Nasal resistance can be affected by a variety of external factors and pathological processes in the nasal mucosa: cold air inhalation, hyperventilation, allergy and inflammation, alcohol abuse. Thus, the blood supply in the cavernous venous plexuses promotes swelling of the nasal membranes, an increase in their size, and narrowing of the lumen of the nasal valve to completely block the nasal cavity, causing changes in normal function. Such air flow supports clearly require an objective study to overcome it. Given that the objective assessment of nasal resistance is extremely difficult, it is necessary to create additional diagnostic methods, tools and criteria based on data from a complex of diagnostic measures, such as computed tomography, endoscopy, rhinomanometry.**

Keywords—aerodynamics, resistance, tomography, diagnostics, physiology, imaging, model, rhinomanometry

I. INTRODUCTION

The progress of medicine at the present stage of development is largely based on the widespread adoption of cutting edge and information technology. The use of scientific, technical and industrial potential to improve and develop innovative methods and medical supplies is an important task for Ukrainian precision instrumentation [1-2].

Modern medical diagnostics is based on an evidence-based approach, which is based on the use of high-precision equipment and methodologically correct information technologies to obtain reliable quantitative data on pathological processes in the human body. Currently, the most active evolution is observed in functional methods of diagnosis, which are aimed at recording the quantitative indicators of the physiological functions of any organ, or the whole organism and the detection of their disorders, depending on the specific pathology [1-4]. This information is especially useful for the practitioner-clinician, because it allows to link the anatomo-morphological and physiological parameters of the investigated organ to clarify the picture of the pathological process.

The upper airway system consists of the nasal cavity, nasopharynx and oropharynx, and partially the oral cavity, which can be used for breathing. From the point of view of physiology, normal external breathing is breathing through the nose [5-6]. This introduces the concept of aerodynamic nasal resistance - the resistance of the structures of the nasal cavity to the air stream when breathing. Normally, the presence of nasal resistance is not subjectively felt. However, as it increases, there is a lack of oxygen and there is a transition to oral breathing, which is non-physiological in modern terms, and can lead to brain hypoxia due to the decrease in the intensity of the gas-mine process that occurs in the mucous membrane of the nasal cavity.

II. MATERIALS AND METHODS

The most important factor that determines the normal functional state of the nasal mucosa is that which passes through it during inhalation and exhalation air flow, which, entering the nasal cavity, due to the active expansion of the chest feels resistance from the surrounding structures. Nasal resistance can be affected by various external factors and pathological processes in the nasal mucosa: cold air inhalation, hyperventilation, allergy, and inflammation. Blood filling in the cavernous venous plexuses contributes to the swelling of the nasal shells, narrowing the lumen of the nasal valve thereby causing disturbance not only respiratory, but also olfactory properties, for this purpose it is necessary to create additional diagnostic methods, means and criteria based on these complex measures , such as computed tomography, endoscopy, rhinomanometry.

Nasal resistance can be obtained using functional diagnostic methods, such as rhinomanometry. But you can also do this indirectly, using spiral computed tomography data, knowing in advance the theoretical values of air flow and respiratory rate.

Purpose: development of information technology for determination of aerodynamic nasal resistance in various pathologies of the nose according to computer tomography.

The paper used methods of theoretical physics, engineering hydraulics, methods and algorithms for digital processing, analysis and visualization of tomographic data

978-1-7281-9713-5/20/$31.00 ©2020 IEEE

based on X-ray computed tomography spyralnoho Siemens Somatom Emotion +.

III. Determination of nasal breathing disorders

One of the diagnostically significant indicators of respiratory function is the general aerodynamic resistance of the respiratory tract. Aerodynamic nasal resistance with normal breathing is normally assumed to be approximately equal to half of the total airway resistance [7-10].The most modern quantitative method for assessing the function of nasal breathing is rhinomanometry, a method that measures the differential pressure on the nasal cavity and the corresponding flow of air through the nose. Commonly accepted in recent years, the method of computer rhinomanometry [11-14] allows to characterize the degree of violation of the nasal breathing by determining the index of aerodynamic nasal resistance in the form of the ratio of pressure drop in the nasal cavity to the value of the volume flow rate of air in different phases of the same respiratory cycle.

To predict and evaluate functional results in rhinosurgery requires knowledge of the anatomical and functional structures of the upper respiratory tract. Thus, the work investigates the physiological role of the nasal septum, which divides the nasal cavity into two nasal passages, the curvature of which causes not only to increase aerodynamic resistance in the narrowed nasal canal, but also to the subsequent obstruction of the opposite (enlarged) nasal passage due to the postural an increase in the volume of the nasal shell mucosa. The role of the size and location of the co-mouth of the adnexal sinuses in the formation of aerodynamic nasal resistance and the development of pathological conditions is investigated [15]. It is shown that the "gold standard" in the diagnosis of pathological processes in the paranasal sinuses today is SCT (spiral computed tomography), allows to provide resolution in coordinates within one cut to 0.1 mm at a distance between the intersection planes up to 0, 5 mm. In rhinology, SKT allows visualization of bone structures, air cavities, and sutures of the paranasal sinuses, the presence of changes in the mucous membrane of the upper respiratory tract (eg, cystic lesions and polyposis processes).

Computer-aided planning should be based on a complex anatomically-functional model that combines anatomical tomography data from the results of functional studies. The flow of air in nasal breathing is a pressure movement of the mass of air at a velocity V through the limited nasal cavity wall paired nasal canals with variable cross-section of complex configuration. Hereinafter referred to as the nasal canal, the isolated (left or right, unless otherwise specified) respiratory area of the nasal cavity from the anterior nose to the hoan (holes that connect the nasal cavity and the nasal pharynx) will be understood.

The movement of air in the nasal cavity is caused by a pressure drop Δp between the environment and the lungs. When inhaled in the lungs there is a discharge, which promotes the inspiratory movement of air, while exhalation - on the contrary, excess pressure in the lungs causes expiratory movement of air.

Passing from the average air flow V velocity to the volumetric flow rate measured Q by the rhinomanometry method, we obtain the expression (1) (which was obtained by us empirically):

$$\Delta p = \sum_{i}^{N} \Delta p_{l_j} + \sum_{j}^{M} \Delta p_{r_j} = \sum_{i}^{N} \lambda_i \cdot \rho \frac{L_i}{d_{h_i}} \frac{Q^2}{2S_i^2} + \sum_{j}^{M} \xi_j \cdot \rho \frac{Q^2}{2S_j^2} \quad (1)$$

where S_i and S_j - the areas of live sections of the nasal cavity at the i-th section and in the region of the j-th local resistance (it should be borne in mind that the localization of areas for determining the values of the average air flow velocities and areas of live intersections of the nasal canal is given by reference data and depends on the type of local resistance and the method of its calculation).

In the nasal cavity, the following types of local aerodynamic resistance may occur according to Fig. 1

- associated with changes in the intersection of the nasal canal (sudden or smooth expansion / narrowing of the air flow (Fig. 1, a));

- associated with changes in the direction of flow of the nasal canal (Fig. 1, e).

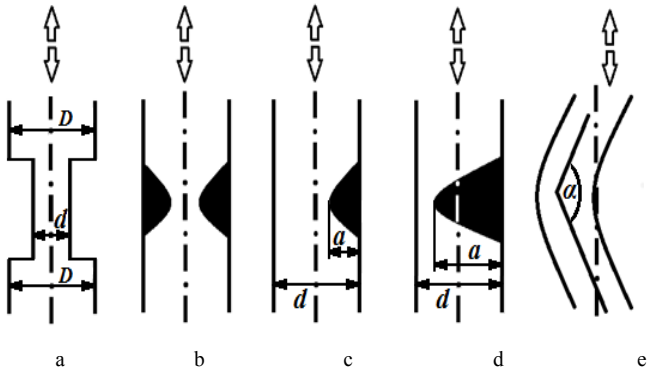
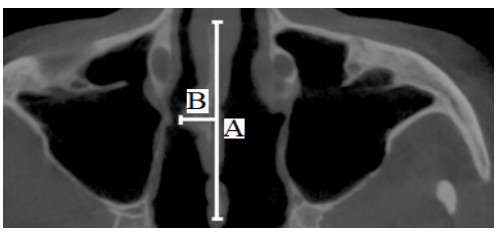
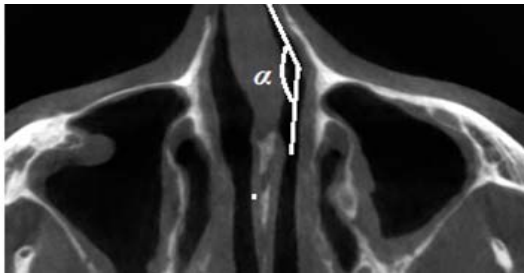


Fig. 1. Types of local aerodynamic resistance, most commonly found in nasal cavity: a) an illustration of the definition of D large and small diameter d of channel interference b) throttle washer, c), d) latch with different degree of flow overlap (d is the diameter of the nasal canal, a is the magnitude of the entry of the obstacle into the stream), e) the turn of the flow (α is the angle of rotation)

Considering the introscopic picture of such widespread functional rhinological pathologies associated with impaired passage of air flow through the nasal cavity (curvature of the nasal septum (Fig. 2), it should be noted that the most characteristic local aerodynamic resistance is the compensation of flow on the valves with marked valves with marked in Fig. 2, a. The value of b visually shows the largest deviation of the crest of the nasal septum from the midline a and is not directly related to the magnitude of occurrence n erectile dysfunction to the canal, since there is a transition to the equivalent diameter of the nasal passage, and quite often you do not turn the flow (see Fig. 2, b).



a)



b)

Fig. 2. Computed tomographic sections in the axial projection of patients: a) with a curvature of the nasal septum to the right (b - the value of the largest deviation of the crest of the nasal septum from the midline a), b) with a curvature of the nasal septum in the anterior compartments (α - angle in the flow direction)

IV. Results and Discussion

In accordance with expression (1), pressure drops through each nasal passage will be determined by the following formulas

$$\Delta p_L = \sum \Delta p_{l_L} + \sum \Delta p_{r_L} = \\ = \sum \lambda_L \cdot \rho \frac{L_L}{d_{h_L}} \frac{Q_L^2}{2S_L^2} + \sum \xi_L \cdot \rho \frac{Q_L^2}{2S_L^2} = Q_L^2 A_L \quad (2)$$

$$\Delta p_R = \sum \Delta p_{l_R} + \sum \Delta p_{r_R} = \\ = \sum \lambda_R \cdot \rho \frac{L_R}{d_{h_R}} \frac{Q_R^2}{2S_R^2} + \sum \xi_R \cdot \rho \frac{Q_R^2}{2S_R^2} = Q_R^2 A_R \quad (3)$$

where λ_L , λ_R - Darcy coefficients (longitudinal pressure loss) for the left and right nasal passages, respectively;

ξ_L , ξ_R - local resistance coefficients for left and right nasal passages, respectively;

L_L , L_R - the length of the left and right nasal passages, respectively;

Q_L , Q_R - air flow through the left and right nasal passages, respectively;

d_{h_L} , d_{h_R} - hydraulic diameters of the left and right nasal passages, respectively;

S_L , S_R - the intersection area of the left and right nasal passages, respectively;

ρ - density of air;

A_L , A_R - coefficients of aerodynamic nasal resistance for the left and right nasal canals, which of formulas (2) and (3) are respectively

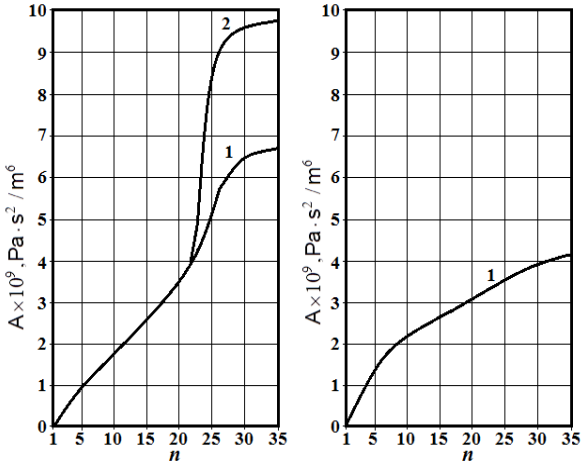
$$A_L = \sum \lambda_L \cdot \rho \frac{L_L}{d_{h_L} \cdot 2S_L^2} + \sum \xi_L \cdot \rho \frac{1}{2S_L^2} \quad (4)$$

$$A_R = \sum \lambda_R \cdot \rho \frac{L_R}{d_{h_R} \cdot 2S_R^2} + \sum \xi_R \cdot \rho \frac{1}{2S_R^2} . \quad (5)$$

Expressing the pressure loss in each nasal canal because of the cost in one of them, we get

$$Q_\Sigma = Q_L + Q_L \sqrt{\frac{A_L}{A_R}} = Q_L \left(1 + \sqrt{\frac{A_L}{A_R}} \right) \quad (6)$$

As can be seen, taking into account the local resistance of the type of latch in the right nasal passage increases by approximately 30% (Figure 2) the coefficient of aerodynamic nasal resistance obtained when determining only the pressure loss along the length of the nasal cavity (curve 1). There are no pronounced local supports on the opposite curved side (Fig. 3b). The average diameter of the nasal passage is 0.4 mm, forced breathing, flow rate 2 l / s. Type of Dominant Local Resistance - Gate Type Narrowing. Gate valve 3.2 mm.



a b

Fig.3. Integral characteristics of the coefficient of aerodynamic nasal resistance along the intersections of the nasal cavity with right-sided local curvature of the nasal septum for the right (a) and left (b) nasal canals, taking into account only the pressure loss along the length (graphs 1) and taking into account the local resistance (graph 2) (n- numbers of live sections perpendicular to the air flow)

With a calmer breathing, leading to a decrease in flow velocity, turbulence will decrease, and by how much, it will depend on the configuration of the nasal canal. Given the complex geometric configuration of the nasal canal, laminar flow is very difficult to obtain. Having physiological parameters (values of air flow and pressure drop), by analyzing the anatomical configuration of the nasal cavity according to the computer tomography, we can determine the value of the coefficient of aerodynamic nasal resistance.

This method of determining the coefficient of aerodynamic nasal resistance, as opposed to experimental - rhinomanometric th, should be considered theoretical, since it is based on calculations. This method is relevant, first of all, for the planning of functional rhinosurgical interventions, as it allows the virtual change of the configuration of structures of the nasal cavity to predict the change of aerodynamic nasal resistance. The rhinomanometric method in pure form allows to obtain these values only experimentally and directly for the planning of surgical operations is not suitable.

The proposed method consists of the following steps:

- obtaining and analysis of rhinometric parameters (air flow and pressure drop) to determine the breathing regime;

- computer tomography examination of the patient for anatomical mapping of the nasal cavity.;

- construction of a spatial model of the nasal cavity based on segmented computed tomographic data. The first stage in the analysis of tomographic data given by a 3-dimensional structured data set is the segmentation of air cavities;

- construction of an aerodynamic model of the nasal cavity on the basis of combined data of rhinomanometry and computed tomography under different modes of air flow;

- determination of pressure losses along the length of the nasal cavity. Determination of the air flow regime is based on the calculation of Reynolds numbers;

- determination of pressure losses at local nasal cavities;

- determination of the integral coefficient of aerodynamic nasal resistance.

V. Conclusions

When modeling the passage of air flow through the nasal cavity, it is necessary to determine the pressure loss, both in length and at local supports, which allows to take into account not only the friction of the air flow against the walls of the nasal cavity, but also the effect of vortex formation on local changes in the radio configuration. of the nasal canals, which is especially important in planning the planning of interventions and the evaluation of the morpho-functional influence of intrasosseous structures on nasal aerodynamics.

The main mode of air flow in the nasal cavity is turbulent, in which the logarithmic velocity profile at typical flow values is set at about half the length of the nasal cavity. Therefore, when modeling the air flow in the nasal cavity, the main calculated dependencies for the turbulent flow regime should be used, in which the pressure drop across the nasal passages depends on the square of the value of the flow pass. Conducted analysis of the configuration of the nasal cavity showed that the most common local perturbation of air flow in the nasal passages is the resistance of the type of "latch" and "turn of the flow", due, as a rule, the presence of local curvatures of the nasal septum.

The small length of the nasal cavity in comparison with the area of mutual impulse local resistance (more than 2 times less) does not allow to take into account their joint resistance to the air flow, so it is advisable when determining the total local aerodynamic nasal resistance to take into account only the local resistance, which contributes maximum head. The account of local resistance significantly increases (by 30% or more) the coefficient of aerodynamic nasal resistance, obtained in determining only the loss of thousand-cu along the length of the nasal cavity, which allows more fully take into account the factors that affect the development of nasal breathing disorders.

The advantage of our proposed method of finding nasal drag is that the aerodynamic model is constructed using computed tomography data. And the study is carried out by setting the physiological norms of respiration in various respiration modes. That is, it is possible to study the aerodynamic drag along the configuration of the nasal canal along perpendicular sections.

Acknowledgment

The exchange program with East European Countries funded by DAAD (Ostpartnerschaften, project number 54364768) and joint Ukraine-Germany project MESU-BMBF 2019-2020 “3D-Model - Implementation of rapid prototyping to design and model the upper respiratory tract in normal and typical pathologies”

References

[1] S. Kherani, A. Javer, J. Woodham, H. “Stevens Choosing a computer-assisted surgical system for sinus surgery” J Otolaryngol, № 32(3), P. 190-197, 2003.

[2] P. A. Clement, F. Gordts “Standardisation Committee on Objective Assessment of the Nasal Airway. Consensus report on acoustic rhinometry and rhinomanometry” Rhinology, № 43, P. 169–179, 2005.

[3] Sergey S. Krivenko, Anatolii A. Pulavskyi, Stanislaw A. Krivenko, “Determination of low hemoglobin level in human using the analysis of symbolic dynamics of the heart rate variability”, IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON), Kyiv, Ukraine, pp. 271-274, 2017.

[4] V.M. Kozko, A.V. Bondarenko, A.V. Gavrylov, O.S. Shevchenko, V.V. Gargin “Pathomorphological peculiarities of tuberculous meningoencephalitis associated with HIV infection”. Interv Med Appl Sci. Sep;9(3):144-149, 2017. doi: 10.1556/1646.9.2017.31.

[5] H.F. Ismail Saied, A.K. Al_Omari, O.G. Avrunin. “An Attempt of the Determination of Aerodynamic Characteristics of Nasal Airways” Image Processing & Communications, challenges 3, AISC 102, Springer-Verlag Berlin Heidelberg. P. 311-322, 2011

[6] A.K. Al_Omari, H.F. Ismail Saied, O.G. Avrunin, “Analysis of Changes of the Hydraulic Diameter and Determination of the Air Flow Modes in the Nasal Cavity” Image Processing & Communications, challenges3, AISC 102. Springer - Verlag Berlin Heidelberg. P. 303-310, 2011.

[7] O.G. Avrunin, Y. V. Nosova, N. O. Shuhlyapina, et al. “Principles of computer planning in the functional nasal surgery”. Przegląd Elektrotechniczny, 2017, № 3/2017, P. 140-143.

[8] V. G. Abakumov, S. G. Antoschuk, V. N. Kryilov “Basic methods for processing biomedical images”, Electronics and communications. Special Issue. Electronics problems, 2008. Ch. 2. №3-4, P. 53-56.

[9] G .Yu. Gladyryeva “Analysis of algorithms for improving the visual quality of images”, Proceedings of the 2nd International Conference "Biomedical Engineering and Technology": Coll. Materials, K:NTUU «KPI», 2011, P. 32-33.

[10] Schaafs L.A., Pfeil J., Köhlitz T., Hamm B., Niehues S.M. “Low-dose computed tomography of theparanasal sinuses: performance of two different iterative reconstruction algorithms”. Radiat Prot Dosimetry. 2018 Aug 25. doi: 10.1093/rpd/ncy153

[11] Nosova, Ya.V., Faruk, Kh.I., Avrunin, O.G. “A tool for researching respiratory and olfaction disorders” Telecommunications and Radio Engineering (English translation of Elektrosvyaz and Radiotekhnika) 77(15), p. 1389-1395

[12] Shushliapina N.O. “Analysis of the aerodynamic parameters influence of nosebreasing for diagnostics of respiratory-olfactory disorders” Klin. inform. telemed. 2018, vol. 13, iss. 14, pp. 74–80. https://doi.org/10.31071/kit2018.14.09

[13] Smirnov I. V., Vishnyakov V. V. “Olfactory function of patients with polypous rhinosinusitis after endoscopic operations on the paranasal sinuses”. Vestnik otorinolaringologii [Bulletin of Otorhinolaryngology], 2011, no. 5, pp. 19-21 (In Russ.).

[14] Fokkens W. J., Lund V. J., Mullol J., Bachert C., Alobid I., Baroody F., Cohen N., Cervin A. “A summary for otorhinolaryn-gologists”. EPOS 2012: European position paper on rhinosi-nusitis and nasal polyps 2012. Rhinology, 2012, vol. 50, no. 1, pp. 1–12. doi: 10.4193/Rhino50E2.

[15] Fonteyn S., Huart C., Deggouj N., Collet S, Eloy P., Rombaux P. “Non-sinonasal-related olfactory dysfunction: A cohort of 496 patients”. Eur. Ann. Otorhinolaryngol., Head. Neck Dis., 2014, vol. 131, no. 2, pp. 87–91. doi: 10.1016/j.anorl.2013.03.00