DOI: 10.35784/IAPGOS.681

USING 3D PRINTING TECHNOLOGY TO FULL-SCALE SIMULATION OF THE UPPER RESPIRATORY TRACT

Oleg Avrunin[1], Yana Nosova[1], Ibrahim Younouss Abdelhamid[1], Oleksandr Gryshkov[2], Birgit Glasmacher[2]
[1]Kharkiv National University of Radio Electronics, Kharkiv, Ukraine; [2]Institute for Multiphase Processes of the Leibniz University of Hannover, Hannover, Germany

Abstract. *The project "Implementation of rapid prototyping for modelling the upper respiratory tract in normal and typical pathologies" investigates the urgent problem of improving the reliability of diagnosis and effectiveness of treatment of disorders of the nasal breathing. Possibilities of modern 3D-printing technology for creation of individual natural anatomical models of the upper respiratory tract and determination of their aerodynamic characteristics are considered. The characteristics of the laminar boundary layer of the air flow in the parietal region of the nasal cavity are investigated under different modes of breathing in normal and with typical disorders of the nasal breathing. The concept of investigation of the aerodynamic indices of the anatomical structures of the respiratory system by the results of test tests of individual full-scale 3D models, obtained by the data of spiral computed tomography, is being developed. Theoretical bases of the method of computer planning of restorative rhinosurgical interventions in patients with chronic diseases of the nasal cavity are grounded, based on the change of the configuration of the anatomical structures of the nasal cavity taking into account the aerodynamic parameters of respiration. Modern distance learning and testing tools are being created to demonstrate the technology developed, to provide theoretical knowledge, practical skills and to solve situational tasks for a wide range of specialists. Development and research of natural patterns of the upper respiratory tract allows for supplementing and expanding the knowledge about the aerodynamic characteristics of the nasal cavity, to make decisions about therapy in a short period of time. Experience of the Laboratory of the Institute for Multiphase Processes (IMP) of the Leibniz Universität Hannover (LUH) in the development and use of rapid prototyping capabilities in biotechnology will provide technical support to the project.*

Keywords: rhinomanometery, nasal breathing, full-scale models, tomography, virtual model

WYKORZYSTANIE TECHNOLOGII DRUKOWANIA 3D DO MODELOWANIA GÓRNYCH DRÓG ODDECHOWYCH W PEŁNEJ SKALI

Streszczenie. *Projekt „Wdrożenie szybkiego prototypowania do modelowania górnych dróg oddechowych w normalnych i typowych patologiach" bada pilny problem poprawy wiarygodności diagnozy i skuteczności leczenia zaburzeń oddychania przez nos. Rozważane są możliwości nowoczesnej technologii druku 3D do tworzenia indywidualnych naturalnych modeli anatomicznych górnych dróg oddechowych i określania ich właściwości aerodynamicznych. Charakterystyka laminarnej warstwy granicznej przepływu powietrza w okolicy ciemieniowej jamy nosowej jest badana w różnych trybach oddychania w normalnym i typowym zaburzeniu oddychania przez nos. Opracowywana jest koncepcja badania wskaźników aerodynamicznych struktur anatomicznych układu oddechowego na podstawie wyników testów testowych poszczególnych pełnoskalowych modeli 3D, uzyskanych z danych spiralnej tomografii komputerowej. Podstawy teoretyczne metody komputerowego planowania rekonstrukcyjnych interwencji nosorożców u pacjentów z przewlekłymi chorobami jamy nosowej są oparte na zmianie konfiguracji struktur anatomicznych jamy nosowej z uwzględnieniem parametrów aerodynamicznych oddychania. Tworzone są nowoczesne narzędzia do nauki na odległość i testowania w celu zademonstrowania opracowanej technologii, zapewnienia wiedzy teoretycznej, umiejętności praktycznych i rozwiązywania zadań sytuacyjnych dla szerokiego grona specjalistów. Opracowanie i badanie naturalnych wzorów górnych dróg oddechowych pozwala uzupełnić i poszerzyć wiedzę na temat właściwości aerodynamicznych jamy nosowej w celu podjęcia decyzji o terapii w krótkim okresie czasu. Doświadczenie laboratorium Instytutu Procesów Wielofazowych (IMP) Leibniz Universität Hannover (LUH) w zakresie rozwoju i wykorzystania możliwości szybkiego prototypowania w biotechnologii zapewni wsparcie techniczne dla projektu.*

Słowa kluczowe: rhomanomanometria, oddychanie przez nos, modele w pełnej skali, tomografia, model wirtualny

Introduction

One of the most present actual social problems in all industrially developed countries around the world is the development and introduction of new medical technologies to improve quality of health care, which is confirmed, in particular, by the priority areas of the 7th Framework Program of the European Union and its continuation – the program EU ″Horizon 2020″. The use of modern information technologies in medicine can significantly improve the quality of diagnosis and treatment of various pathologies by providing the clinician with additional, advanced information about the disease process.

Rhinology is one of the least well-conclusive means of functional diagnostics fields of medicine, but in industrialized countries, according to statistical data, only rhinosinusitis affects approximately 10% of the population. It appears that there is no clear correlation between subjective sensations of the patient and characteristics of nasal airflow, communication of respiratory and olfactory functions, etc. In spite of the possibilities of the modern rhinomanometry equipment and related specialized software that can define and calculate the aerodynamic performance with high accuracy [2, 5–7, 9].

The basic laws of the aerodynamics of the upper respiratory tract are studied well enough. However, at this stage, it is advisable to assess not only the macro-indicators of airflow but also to explore the near-wall flows. Their indicators directly affect the mucosa of the nasal cavity with its morpho-functional features and located in the nervous limbs that will allow for a more detailed assessment of the impact of air flow in the pathogenesis of several rhinology diseases. On the basis of these data, by means of computer methods of planning surgical interventions and modelling of the nasal cavity required configuration it is possible to predict functional outcome operation.

1. Analysis of recent research and publications

In diseases of the upper respiratory tract, there are often violations of the configuration of the airways (nasal passages) and anastomosis of the paranasal sinuses. A fairly large number of publications has been devoted to studying the spatial arrangement of anatomical objects and to studying the aerodynamics of the nasal cavity [8, 10, 14]. However, the problem of visualizing this area in the context of surgical planning procedures is only at the initial stage of development. Traditionally, introscopic diagnosis of diseases of the nasal cavity was performed using X-ray. At the present stage, to determine the configuration of the upper respiratory tract, it is advisable to use the data of X-ray spiral computed tomography (CT), which allows us to identify the bone and airborne structures with a spatial resolution of less than 1 mm [7, 8]. Determining the morphometric parameters of these structures from flat tomographic slices in an interactive (manual) mode is a rather time-consuming procedure, which also provides a small amount of information about their spatial configuration. Therefore, the development of algorithms for automated segmentation and spatial visualization of the airways of the upper respiratory tract are relevant [1, 11].

The introduction of rapid prototyping technologies into rhinology allows us to base and predict the functional result of the operation, not only according to mathematical modelling of the process of air flow through the nasal cavity during breathing, but also taking into account the analysis of full-scale aerodynamic models of the studied area. The introduction of such simulation technologies takes the planning process of surgical operations to a qualitatively new level and improves the reliability of the results of procedures associated with predicting the functional results of surgical interventions [3, 4, 13, 15].

2. The aim of the study

The proposed work is aimed at the study of parietal air currents in normal and typical pathologies on spatial models of upper respiratory tract, obtained by the 3D prototyping technology according to tomographic studies of specific patients, taking into account individual variability, which will allow to reveal the possible effects of air flow shell of the nasal cavity and increase the reliability of functional diagnostics of disorders of the nasal breathing and increase the effectiveness of conducting com planning of rhinosurgical interventions.

3. Experimental

The object of research is the development and analysis of the aerodynamic characteristics of the individual natural of 3D-models of the upper respiratory tract created by rapid prototyping technology (3D-printing) according to CT.

The problem of research is improving the reliability of diagnosing disorders of nasal breathing by means of the analysis of the aerodynamic characteristics of the near wall air flow based on production and natural studies of the individual 3D-models of the upper respiratory tract (Fig. 1).

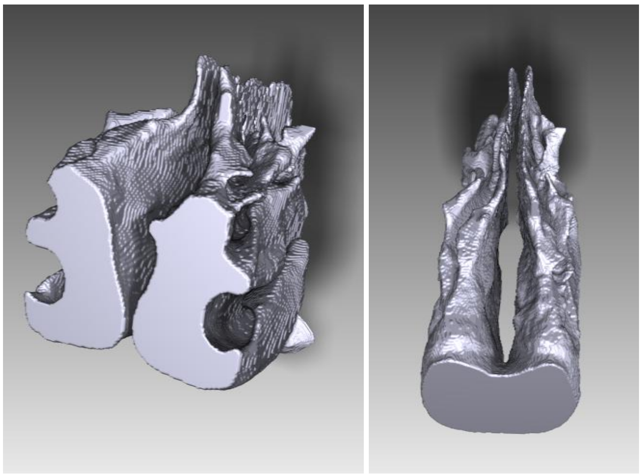


Fig. 1. 3D model of upper respiratory tract

The present international study is based on the experience of scientific and practical developments of the project participants.

The task of creating an implant model using rapid prototyping tools according to the spiral computed tomography consists of 6 main stages:

- segmentation – the selection on the images of tomographic sections of bone structures,
- determination of the location and selection of the bone defect replacement method,
- creation of a large implant reconstruction,
- preparation of data for prototyping in stl format,
- creating a layer-by-layer model of the implant in the G-code format for 3D printing on specific equipment,
- 3D printing of the full-scale model.

4. Results and discussion

The main working hypothesis is to study the impact of the near-wall flow (laminar boundary layer) air to the mucosal surface anatomical structures of the upper airway disorders in the diagnosis of nasal breathing [12].

The scientific basis of the work is the application of boundary-layer theory to identify the negative influence of air flow to the nasal cavity walls at various modes of breathing.

On the basis of the conducted researches it is planned to develop the theoretical bases of computer planning of restorative rhinosurgical interventions in patients with chronic diseases of the nasal cavity, based on the change of the configuration of the anatomical structures of the nasal cavity with taking into account the aerodynamic parameters of breathing during verification of the full-scale models. (Fig. 2).

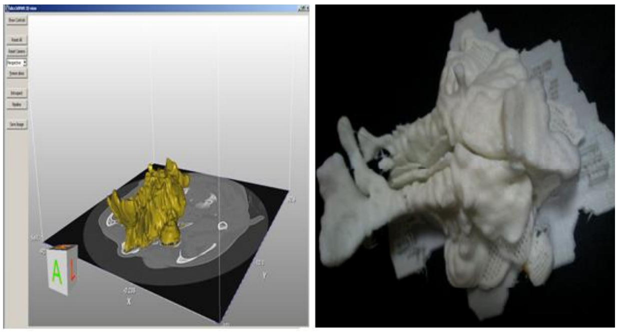


Fig. 2. Personalized Upper Airway Model according to spiral computed tomography: a) virtual model; b) full-scale model

The initial data for the studies are sets of images of axial tomographic sections with a thickness of 1 mm, obtained using a Siemens Somatom + Emotion tomograph according to the scanning protocol parallel to the plane of the skull base with standard patient laying.

The image of the tomographic slice is represented by a discrete function of intensity B(i, j) [0.255] for i, j [0.255], which determines the degree of X-ray absorption in each element of the raster. The total number of N slices was determined based on the spatial characteristics of the upper respiratory tract and amounted to about 60 slices (N | 60).

For spatial visualization of tomographic data, it is necessary to perform a complex of transformations of coordinate systems, performed, for the purpose of universality, in matrix form. So, for n-dimensional coordinate systems with bases $(k_1,k_2,...,k_n)$ and $(m_1,m_2,...,m_n)$, the coordinate transformation problem can be represented as transformations:

$$\begin{cases} m_1 = f_1(k_1,k_2,...,k_n); \\ m_2 = f_2(k_1,k_2,...,k_n); \\ m_N = f_N(k_1,k_2,...,k_n), \end{cases}$$

where f_i is the function of recalculating the i-th coordinate, and the arguments of this function are the coordinates of the object in the basis k_i.

Accordingly, the inverse coordinate transformation problem is written as follows:

$$\begin{cases} k_1 = F_1(m_1,m_2,...,m_N); \\ k_2 = F_2(m_1,m_2,...,m_N); \\ k_n = F_n(m_1,m_2,...,m_N), \end{cases}$$

where F_i is the inverse transformation function with arguments – the coordinates of the object in the basis m_i.

If the transformation functions are linear and the dimensions of the coordinate systems coincide, then such transformations are called affine. For visualization, an important condition for the unambiguous transformation of coordinates is the coincidence of the dimensions of the coordinate systems.

Affine coordinate transformations are visually written in the matrix form:

$$\begin{bmatrix} m_1 \\ m_2 \\ . \\ m_N \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{1N} \\ a_{21} & a_{22} & a_{2N} \\ a_{31} & a_{32} & a_{3N} \end{bmatrix} * \begin{bmatrix} k_1 \\ k_2 \\ . \\ k_N \end{bmatrix}$$

and are calculated using the formula:

$$m_i = \sum_{j=1}^{N} a_{ij} \cdot k_j$$

For the purpose of universality, when performing matrix affine transformations, points and vectors are conveniently represented in homogeneous coordinates. Thus, the coordinates of a vector in homogeneous coordinates are specified as:

$$\begin{bmatrix} x \\ y \\ z \\ 0 \end{bmatrix}$$

and coordinates of the point

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

The transformation of the coordinates of the point can be represented in the analytical:

$$\begin{cases} X = Ax + By + Cz + D; \\ Y = Ex + Fy + Gz + H; \\ Z = Kx + Ly + Mz + N, \end{cases}$$

or in the matrix form using a uniform representation:

$$\mathrm{T{=}M{\cdot}T'} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = \begin{bmatrix} A & B & C & D \\ E & F & G & H \\ K & L & M & N \\ P & R & Q & S \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

where *A, B, …, N* are the constants.

Display in the surgical field is performed in the coordinate system of the surgical field (X_{op}, Y_{op}, Z_{op}) using the transformation matrix:

$$\begin{bmatrix} 1 & 0 & 0 & x_{op} \\ 0 & 1 & 0 & y_{op} \\ 0 & 0 & 1 & z_{op} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where x_{op}, y_{op}, z_{op} are the coordinates of the base point of the object in the coordinate system of the surgical field.

Moving the object on dx, dy, dz is respectively performed using the transfer matrix:

$$\begin{cases} X = x - dx; \\ Y = y - dy; \\ Z = z - dz; \end{cases} \begin{bmatrix} 1 & 0 & 0 & -dx \\ 0 & 1 & 0 & -dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Next, the coordinate system of the operating field is transformed into the coordinate system of the display using the projective transformation. As a type of projection, a parallel orthographic projection is selected, the transformation matrix for which it is specified in the form:

$$\begin{bmatrix} \frac{2}{x_r - x_l} & 0 & 0 & -\frac{x_r + x_l}{x_r - x_l} \\ 0 & \frac{2}{y_t - y_b} & 0 & -\frac{y_t + t_b}{t_t - y_b} \\ 0 & 0 & \frac{-2}{z_f - z_n} & -\frac{z_f + z_n}{z_f - z_n} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where x_r, x_l, y_t, y_b, z_f, z_n, the bounding coordinates of the three-dimensional region of visibility along the x, y, z axes, respectively. These actions are performed using the OpenGl glortho library procedure. The procedure is called with the parameters glortho (-2.5, 2.5, -2.5, 2.5, -12, 12), clamping the output region with a width and height of 5 relative units, and the distance between the front and rear clipping planes is 24 relative units.

Further, the picture plane is displayed on the graphic output window using the procedure. glViewport (), the first two parameters of which specify the initial coordinates of the output area, and the last two – the width and height of the output area. The output is carried out on the standard component VCL TPanel (graphic panel) with the properties panel1.width, panel1.Height. Accordingly, the glViewport () procedure call is performed as follows: glViewport (0, 0, panel1.width, panel1.Height).

For the implementation of a comprehensive multi-angle visualization, it is necessary to provide for the implementation of geometric transformations.

Then, geometric transformations are performed, associated with additional movements, rotations, and scaling.

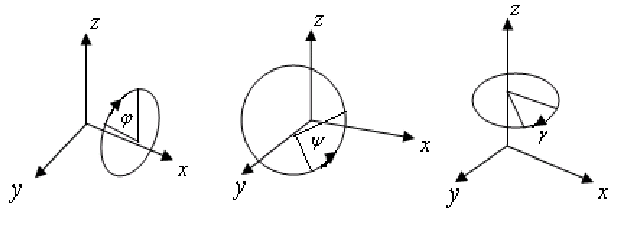
The scaling operation is performed using the glscalef (kx, ky, kz) command, the parameters of which determine the scale factors along the corresponding coordinate axes. The corresponding transformation matrix is given below:

$$\begin{cases} X = x / k_x, \\ Y = y / k_y, \\ Z = z / k_z, \end{cases} \begin{bmatrix} 1/k_x & 0 & 0 & 0 \\ 0 & 1/k_y & 0 & 0 \\ 0 & 0 & 1/k_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Turns are carried out using the trigonometric functions in the coefficients of the transformation matrix. The universal OpenGl library procedure for executing rotations is glRotatef (φ, x, y, z), the first parameter of which indicates the magnitude of the rotation angle, the other three specify the axis relative to which the rotation is performed. Consider the rotation matrix relative to the main coordinate axes.

Rotation around the axis x by an angle φ (see Fig. 3).

$$\begin{cases} X = x, \\ Y = y\cos\gamma - z\sin\phi, \\ Z = y\sin\phi + z\cos\phi, \end{cases} . \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi & 0 \\ 0 & \sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



a) b) c)

Fig. 3. Rotation: a) the rotation around the axis x by an angle φ; b) the rotation by an angle ψ around the axis y; c) the rotation around the axis z by an angle γ

The rotation around the axis y by an angle ψ

$$\begin{cases} X = x\cos\psi - z\sin\psi, \\ Y = y, \\ Z = x\sin\psi + z\cos\psi, \end{cases} . \begin{bmatrix} \cos\psi & 0 & -\sin\psi & 0 \\ 0 & 1 & 0 & 0 \\ \sin\psi & 0 & \cos\psi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The rotation around the axis z by an angle γ

$$\begin{cases} X = x\cos\gamma - y\sin\gamma, \\ Y = x\sin\gamma + y\cos\gamma, \\ Z = z, \end{cases} \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 & 0 \\ \sin\gamma & \cos\gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Development and research of natural patterns of the upper respiratory tract allows for supplementing and expanding the knowledge about the aerodynamic characteristics of the nasal cavity and to make decisions about therapy in a short period of time. Experience of the Laboratory of the Institute for Multiphase Processes (IMP) of the Leibniz Universität Hannover (LUH) in the development and use of rapid prototyping capabilities in biotechnology will provide technical support to the project. In addition, the project participants have already gained considerable experience in the development of methods and models in the subject area. Considering the modern high technology and technogenic approach to the diagnosis and treatment of diseases, it is advisable to introduce the ability to showcase a wider audience of the proposed methods professionals wishing to develop new scientific approaches both in theoretical and practical terms.

5. Conclusions

Project implementation is based on the results of scientific and practical research of the participants, which were obtained as a consequence of the executed joint international programs: DAAD project ″Eastern Partnership″ and Erasmus+ Program Key Action 1 – Mobility for learners and staff – Higher Education Student and Staff Mobility during the years 2016–2018.

Perspective of work. Considering the modern high technology and technogenic approach to the diagnosis and treatment of diseases, it is advisable to introduce the ability to showcase a wider audience of the proposed methods professionals wishing to develop new scientific approaches both in theoretical and practical terms. To do this, it is possible to use the opportunities of Massive open online course (MOOC) service for remote e-learning theoretical knowledge, mathematical demonstration and natural (obtained using rapid prototyping technology) models as well as the acquisition of practical skills through the analysis of clinical cases and test solutions of situational problems. We plan to produce a pneumatic test stand to define the aerodynamic characteristics of the upper airway and corresponding theoretical and experimental parameters according to the data from the pressure transducer and the air flow situated in the received control natural positions models.

Acknowledgments

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] Abizov R. A., Pavlishin Yu. D.: Disturbances in the functions of the olfactory analyzer and practical aspects of their research methodology and further tactics of conducting such patients. Family Medicine 4(48), 2013, 100–102.

[2] Al_Omari A. K., Saied H. F. I., Avrunin O. G.: Analysis of Changes of the Hydraulic Diameter and Determination of the Air Flow Modes in the Nasal Cavity. Image Processing and Communications Challenges 3. Advances in Intelligent and Soft Computing 102, 2011, 303-310 [DOI: 10.1007/978-3-642-23154-4_34].

[3] Aras A., Akay M., Cukurova I. et al.: Dimensional changes of the nasal cavity after transpalatal distraction using bone-borne distractor: an acoustic rhinometry and computed tomography evaluation. J. Oral Maxillofac. Surg. 68(7), 2010, 1487–1497.

[4] Cole P., Fenton R.: Contemporary rhinomanometry. Otolaryngol. 35(2), 2006, 83–87.

[5] Fyrmpas G., Kyrmizakis D., Vital V., Constantinidis J.: The value of bilateral simultaneous nasal spirometry in the assessment of patients undergoing septoplasty. Rhinology 49(3), 2011, 297–303.

[6] Govidaraj S.: Endoscopic sinus surgery: evolution and technical innovations. J. Laryngol. Otol. 24(3), 2010, 242–250.

[7] Halawi A. M., Smith S. S., Chandra R. K.: Chronic rhinosinusitis: epidemiology and cost. Allergy Asthma Proc. 34(4), 2013, 328–334.

[8] Ismail Saied H. F., Al_Omari A. K., Avrunin O. G.: An Attempt of the Determination of Aerodynamic Characteristics of Nasal Airways. Image Processing and Communications Challenges 3. Advances in Intelligent and Soft Computing 102, 2011, 311–322, [DOI: 10.1007/978-3-642-23154-4_35].

[9] Nosova Ya. V., Faruk Kh. I., Avrunin O. G.: A tool for researching respiratory and olfaction disorders. Telecommunications and Radio Engineering 77(15), 2018, 1389–1395, [DOI: 10.1615/TelecomRadEng.v77.i15.90].

[10] Tingelhoff K., Moral A. I., Kunkel M. et al.: Comparison between manual and semi–automatic segmentation of nasal cavity and paranasal sinuses from CT images. 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2007, 5505–5508, [DOI: 10.1109/IEMBS.2007.4353592].

[11] Vogt K., Jalowayski A. A.: 4-Phase-Rhinomanometry Basics and Practice. Rhinology 21, 2010, 1–50.

[12] Wójcik W., Pavlov S., Kalimoldayev M.: Information Technology in Medical Diagnostics II. Taylor & Francis Group, CRC Press, London 2019, [DOI: 10.1201/9780429057618].

[13] Zambetti G., Moresi M., Romeo R., Filiaci F.: Study and application of a mathematical model for the provisional assessment of areas and nasal resistance, obtained using acoustic rhinometry and active anterior rhinomanometry. Clin. Otolaryngol. Allied Sci. 26(4), 2001, 286–293.

[14] Zhang G., Fenton R., Rival R., Solomon P., Cole P., Li Y.: Correlation between subjective assessment and objective measurement of nasal obstruction. Chinese journal of otorhinolaryngology head and neck surgery 43(7), 2008, 484–489.

[15] Zhang G., Solomon P., Rival R. et al.: Nasal airway volume and resistance to airflow. Am. J. Rhinol. 22(4), 2008, 371–375.

Prof. Avrunin Oleg
e-mail: oleh.avrunin@nure.ua

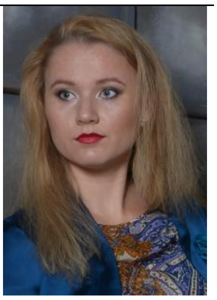
Doctor of Technical Sciences, professor, head of Biomedical Engineering Department, Kharkiv National University of Radio Electronics, Ukraine. Scientific supervisor of research work on research of theoretical and technical principles of diagnostics, assessment and correction of medical and social human conditions. Invited Professor in Gottfried Wilhelm Leibniz Universität Hannover (Germany) and Harbin Engineering University (China).

ORCID ID: 0000-0002-6312-687X

Ph.D. Nosova Yana
e-mail: yana.nosova@nure.ua

Assistant of the Department of Biomedical Engineering, Kharkiv National University of Radio Electronics, Ukraine. As part of the team of authors of the patent "Device for the testing of respiratory disorders of smell" was awarded the diploma of the winner of the All-Ukrainian contest "Invention of the Year – 2016" in the nomination "Best invention in Kharkiv region". Research Interests: biomedical signal processing and images.

ORCID ID: 0000-0003-4310-5833



M.Sc. Ibrahim Younouss Abdelhamid
e-mail: ibrahim.younouss.abdelhamid@nure.ua

Ph.D. Student, Department of Biomedical Engineering, Kharkiv National University of Radio Electronics, Ukraine. Research Interests: biomedical signal processing and images, functional diagnostics of nasal breathing.

ORCID ID: 0000-0003-2611-2417

Ph.D. Oleksandr Gryshkov
e-mail: gryshkov@imp.uni-hannover.de

PostDoc, Ph.D., Leibniz University of Hannover, Institute of Multiphase Processes, Hannover, Germany. Research Interests: Tissue engineering and biomaterials; cell therapies based on encapsulation of stem cells and cellular therapeutics in alginate 3D micro-environment; Medical implant engineering / 3D Printing; novel medical implants based on Magnesium and Silicon-Carbide porous ceramics; new methods for generating bioactive and bioinert coatings for medical applications.

ORCID ID: 0000-0002-3116-8792

Prof., Dr.-Ing. Birgit Glasmacher
e-mail: secretariat@imp.uni-hannover.de

Head of the Institute for Multiphase Processes of the Leibniz University of Hannover, Germany.
Research Interests: Tissue engineering and biomaterials; cell therapies based on encapsulation of stem cells and cellular therapeutics in alginate 3D micro-environment; Medical implant engineering / 3D Printing; novel medical implants based on Magnesium and Silicon-Carbide porous ceramics; new methods for generating bioactive and bioinert coatings for medical applications.

ORCID ID: 0000-0002-2452-1666

otrzymano/received: 09.11.2019 *przyjęto do druku/accepted: 06.12.2019*