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CFD MODELING OF NASAL AIRFLOW IN THE PATIENTS WITH A NASAL SEPTUM DEVIATION

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Abstract

Relevance: nasal septum deviation is a highly common pathology of the nasal cavity. The emergence of a new method of CFD modeling has made it possible to study the biophysical processes occurring in the pathological nasal cavities.

The purpose of this experiment was to study the velocity and partial pressure of the air flow inside nasal cavity for the different nasal septum deviation types.

Materials and methods: the study used CT scans of 7 patients. Using special software algorithms for CFD modeling, 3D nasal models and virtual air flows were obtained from these images. We examined the mean nasal flow velocity and partial pressure for each type of nasal septum deviation.

Results: the average flow velocity for the 4th and 7th types of nasal septum deviations was 7.3 and 7.6 m / s, and the partial pressure was -10.2 and -9.8 Pa, respectively, which was much higher than the data for other deviation types.

Conclusion: The nasal septum deviation type affects the flow velocity and partial pressure in the nasal cavity.

Key words: *CFD modeling, nasal septum deviation, velocity.*

Резюме

CFD МОДЕЛИРОВАНИЕ ВОЗДУШНЫХ ПОТОКОВ НОСА У ПАЦИЕНТОВ С ИСКРИВЛЕНИЕМ НОСОВОЙ ПЕРЕГОРОДКИ

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Актуальность. Искривление носовой перегородки является высоко распространённой патологией полости носа. Появление нового метода CFD моделирования позволило изучить биофизические процессы, происходящие в полости носа пациентов.

Целью данного эксперимента являлась изучение скорости и парциального давления воздушного потока в полости носа при разных типах искривления носовой перегородки.

Материалы и методы: в исследовании использовались компьютерные томограммы 7 пациентов. При помощи специальных программных алгоритмов CFD моделирования из данных снимков получены 3Д модели носа и виртуальные воздушные потоки. Мы изучили среднее значение скорости и парциального давления назального потока у каждого типа искривления носовой перегородки.

Результаты: средняя скорость потока у 4 и 7 го типов деформации носовой перегородки было равно 7,3 и 7,6 м/сек, а парциальное давление -10,2 и -9,8 Pa соответственно, что намного превышало данные других типов носа.

Заключение: тип искривления носовой перегородки влияет на скорость потока и парциальное давление в полости носа.

Ключевые слова: *CFD моделирование, искривление носовой перегородки, скорость.*

Түйіндеме

МҰРЫН ПЕРДЕСІНІҢ ҚИСАЮЫ БАР НАУҚАСТАРДА МҰРЫН АҒЫНЫН CFD МОДЕЛДЕУ

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Өзектілігі: мұрын пердесінің қисаюы - мұрын қуысының өте кең таралған патологиясы. CFD модельдеу сияқты жаңа әдістің пайда болуы науқастардың мұрын қуысында болатын биофизикалық процесстерді зерттеуге мүмкіндік берді.

Эксперимент мақсаты: бұл эксперименттің мақсаты мұрын пердесінің әр түрлі қисаю типтерінде ауа ағынының жылдамдығы мен ішіндегі қысымын зерттеу болды.

Материалдар мен тәсілдер: зерттеу барысында 7 науқастың компьютерлік томограммалары қолданылды. CFD модельдеуге арналған арнайы бағдарламалық жасақтама алгоритмдерін қолдана отырып, осы суреттерден мұрынның 3D модельдері мен виртуалды ауа ағындары алынды. Біз мұрын пердесінің қисаюының әрбір типі үшін мұрын ағынының орташа жылдамдығын және парциалдық қысымын қарастырдық.

Нәтижелер: мұрын пердесінің қисаюының 4 және 7 типтеріндегі орташа ағынның жылдамдығы 7,3 және 7,6 м / с құрады, ал парциалды қысым сәйкесінше - 10,2 және - 9,8 Ра құрады, бұл басқа мұрын пердесінің қисаюының типтері бойынша мәліметтерден әлдеқайда басқаша болды.

Қорытынды: мұрын пердесінің қисаю типі мұрын қуысындағы ағын жылдамдығы мен қысымға әсер етеді.

***Түйінді сөздер**: CFD модельдеу, мұрын пердесінің қисаюы, жылдамдық.*

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Introduction

The nasal septum (NS) is an important part not only for the nasal cavity formation, but also it is a functional link of the intranasal air flow system organization, which also contributes to the air distribution to the lower respiratory tract. [1]. A needing for the diagnosis and treatment of the septum deviation (SD) is evident because of the variety of consequences (nasal bleeding, chronic rhinosinusitis, airways obstruction syndromes, lower respiratory tract diseases, infectious complications, etc.) [14].

The surgical treatment of this pathology includes the middle positioning of the NS: submucosal resection, septoplasty. In order to refer the patient to the surgery, subjective feelings about nasal obstruction, the presence of snoring and a number of other aspects are assessed [17]. Rhinoscopy (anterior, endoscopic) is mandatory [19], where the doctor visually finds a nasal septum deviation (NSD) and the presence of spurs and ridges. Computer tomography provides information about deviation location at any part of the nasal cavity (NC), which will be useful for a surgery planning [6].

In addition, a number of other nasal respiratory function assessment tools are carried out, including active anterior rhinomanometry, which, due to their low correlation with the subjective sensations of patients [8] are rarely used, mainly for expertise and for research purposes. Thus, the indications for surgical treatment of NSD are determined in a complex manner, summing up the results of clinical and instrumental diagnostic methods. The final decision should be made by a doctor. However, it is not uncommon for patients to be dissatisfied with the surgery results, even in long-term follow-up periods. [20]. Accordingly, there is a lot of discussion about diagnostic standards. [4].

Many authors [3] believe that the role of the biophysical changes of the airflow inside the nasal cavity (NC) as a result of SD should not be underestimated. Nasal airflow parameters such as a partial pressure and velocity are the key characteristics [23]. These data can be obtained using relatively new 3D technologies and virtual modeling. Computational Fluid Dynamics (CFD) modeling has already established itself as a method that allows to use patient's computer tomograms of the nasal cavities to create mathematically calculated flows regulated by gas and liquid motion principles [7]. CFD modeling calculates flow velocity, partial pressure of the air movement inside a nose, temperature conditions, wall shear stress, air flow distribution, as well as can find precisely specified local changes throughout the nasal cavity and paranasal sinuses [10].

The carried out studies helped to expand knowledge about nasal cavity aerodynamics in normal [5] and in the various nasal pathologies, such as NSD [2], nasal valve pathologies [21].

The development of this technique will help clinicians not only understand the nasal airflow characteristics in healthy and pathological NCs, but also make a prognosis for certain clinical conditions of the olfactory and respiratory functions, be guided in establishing safe levels of exposure to inhaled material [25]. For various types of NSD the air flow direction and resistance were studied in detail [22, 16, 26]. However, the partial pressure and flow rate in various locations of a nose were undeservedly ignored. We believe that these parameters can be a key in the nasal obstruction severity gradation and their changes can become an important diagnostic criterion.

The aim of our study is to find the average values of the velocity and partial pressure of the nasal airflow for the different types of NSD.

Materials and methods

The research design

Pre-experimental, interventional (in vitro), non-randomized, prospective, case-control.

Patient selection

For the study we selected participants among patients of 1st ENT department of a specialized clinic (City Hospital No. 5) in Almaty, Kazakhstan. We used the R. Mladina [13] classification to distinguish different types of septum deviation. This classification takes into account the deviation directions (anterior-posterior, upper-lower), as well as the presence of a ridge. This makes it stand out from other classifications [18].

R. Mladina's classification distinguishes 7 types:

Type 1 - crest-like deviation of anterior part of nasal septum, small in size, unilateral, does not disturb nasal breathing;

Type 2 - pronounced crestal deformity in anterior part of a nose, impairing the respiratory function;

Type 3 - crestal deviation, unilateral, in posterior part of NS;

Type 4 - S-typed septum deformation - two crestal deviations located in the right and left cavities;

Type 5 - "Turkish saber" - type deviation - comb-shaped, in the back of the nose;

Type 6 - crestal deformities in the horizontal plane, in both nostrils;

Type 7 - "Crumpled" partition - many deformities in different planes, or a combination of the above types.

On clinical examination, the patient's nasal septum deviation was classified to a specific type, and the patient's data were entered into an electronic journal.

The following inclusion criteria were agreed: age over 18 years, non-pregnant, previously not undergoing surgery on nasal cavity. Also, the inclusion criterion was the presence of computed tomography of the nasal cavity with a slice step of no more than 0.6 cm [15].

Exclusion criterion: patient refusal, presence of nasal valve pathology, the electronic file’s defect, which could be disturbing for the 3D modeling. The latter criterion was tested by an on-line engineer at Nazarbayev University. Since the study does not suggest a comparison with healthy nasal airflow, a control group was not recruited. The study group included those first patients in whom the inclusion criteria were determined. In total, it was planned to include 1 patient from each type of septum deviation.

Research methodology

CFD modeling is an engineering method to create virtual air flow. Our modeling was done by the group of engineers in a special computer laboratory (Nazarbayev University, Aerospace Engineering Department). All stages of computer modeling were performed in association with otorhinolaryngology because of complexity and specify of nasal cavity construction.

Firstly, CT scans of the nasal cavities were used to take 3D models on the softwares MIMICS MEDICAL 22.0 (Leuven, Belgium) and 3-matic Medical 14.0 (Leuven, Belgium, 2019). These models were transferred to ANSYS Fluent 19.2 (ANSYS Inc., Canonsburg, Pennsylvania), where they were converted to a 3D solid model. The following input data were entered: a pressure of 0 Pa in the nostrils at the inlet, and at the outlet - a uniform flow rate of 250 cm3 / s as a boundary condition. The rest of the geometry was defined as the wall adhesion condition [2]. Further, to calculate the quasi-stationary air flow, a Navier-Stokes flow solver based on a turbulent incompressible fluid flow (k-Ω SST model) was used.

Methods of data presentation and processing

Velocity and partial pressure on each nasal half were studied along four cross-sectional planes perpendicular to the bottom of the nasal cavity (Figure 1).

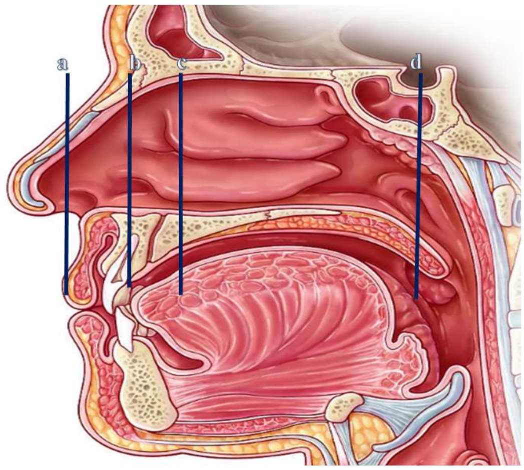

Figure 1. Sagittal view of the nasal cavity (side view) with 4 key cross-sectional planes (a) - the first area on the nasal valve, (b) the second area at the anterior end of the inferior turbinate, (c) the third area at the anterior end of the middle turbinate, (d) - the fourth area on the choan (posterior part of the nasal cavity).

The results are summed up and divided by 4, thus obtaining the average value of the measured values.

Ethical principles

The study was approved by the Higher Ethical Commission of KazMUNO, Almaty, Kazakhstan (Protocol No. 1 dated January 15, 2019). All patients signed their consent to participate in the study and to use a computed tomogram.

Results

We had 7 patients with septum deviation of each type by Mladina classification. As a result of CFD modeling, the average values of the air flow velocity and partial pressure were described and evaluated for these patients.

An average flow velocity of each type of deviation (Figure 2)

The average air flow velocity was generally uniform (2.6-4.0 m / s), with the exception of sharp rises in the 4th and 7th types of SD, where the flow velocity reached 7.3 and 7.6 m / s for each type. The 1st and 5th types of deviation had the lowest flow velocities (2.6 and 2.9 m / s) (Diagram 1).

2. An average partial pressure, Pa (Figure 3)

Diagram 2 shows that the partial pressure in all types was negative, and it fluctuated between - 2.8 and -5.5 Pa. However, in the 4th and 7th types of NSD, the pressure was significantly different, -10.2 and -9.8 Pa, respectively. These values were the lowest for all types. In the first and fifth types of SD, the average pressure was much higher than in others.

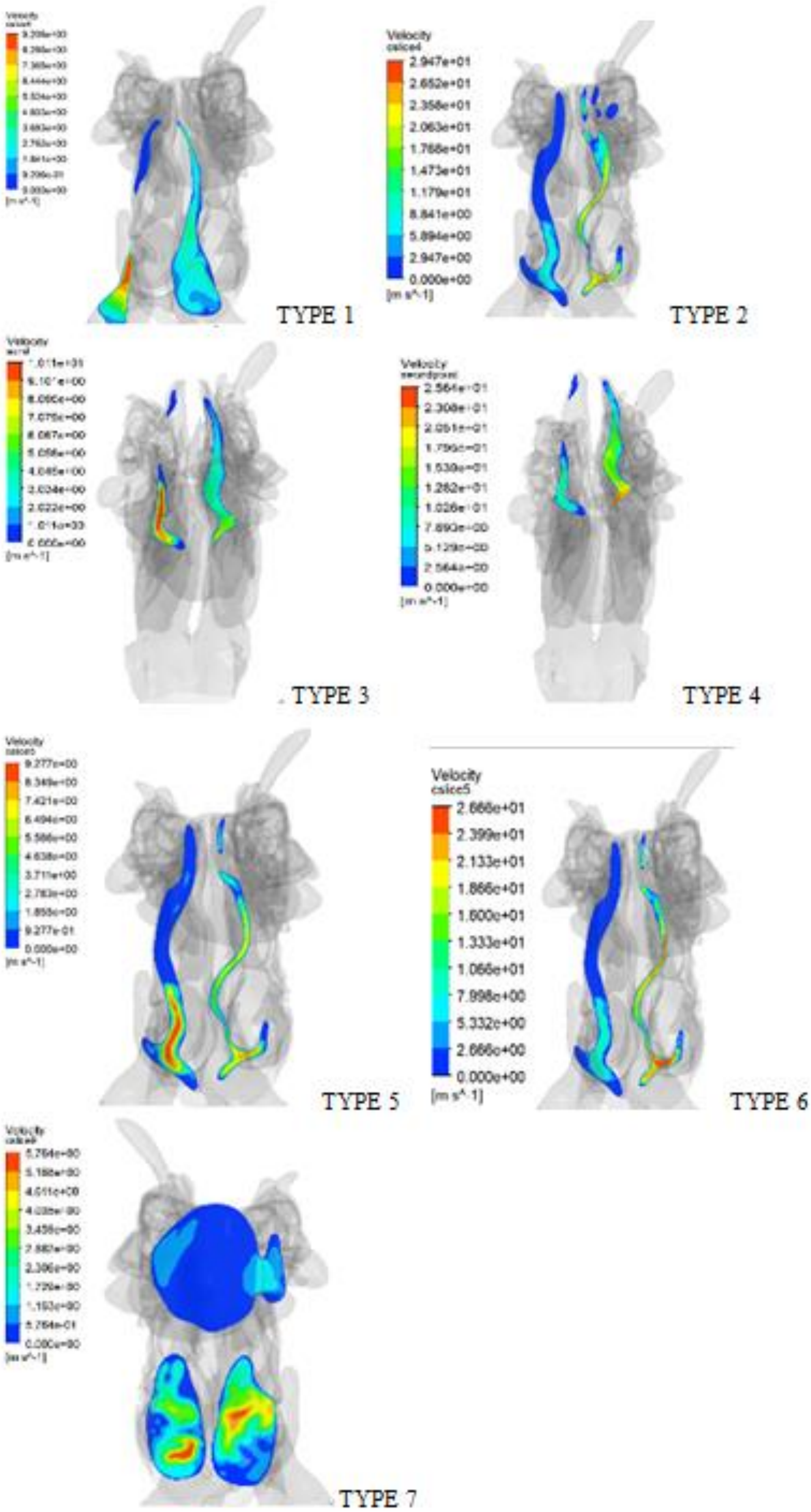

Figure 2. Nasal airflow velocity (m / s) in different types of septum deviation (coronary cut).

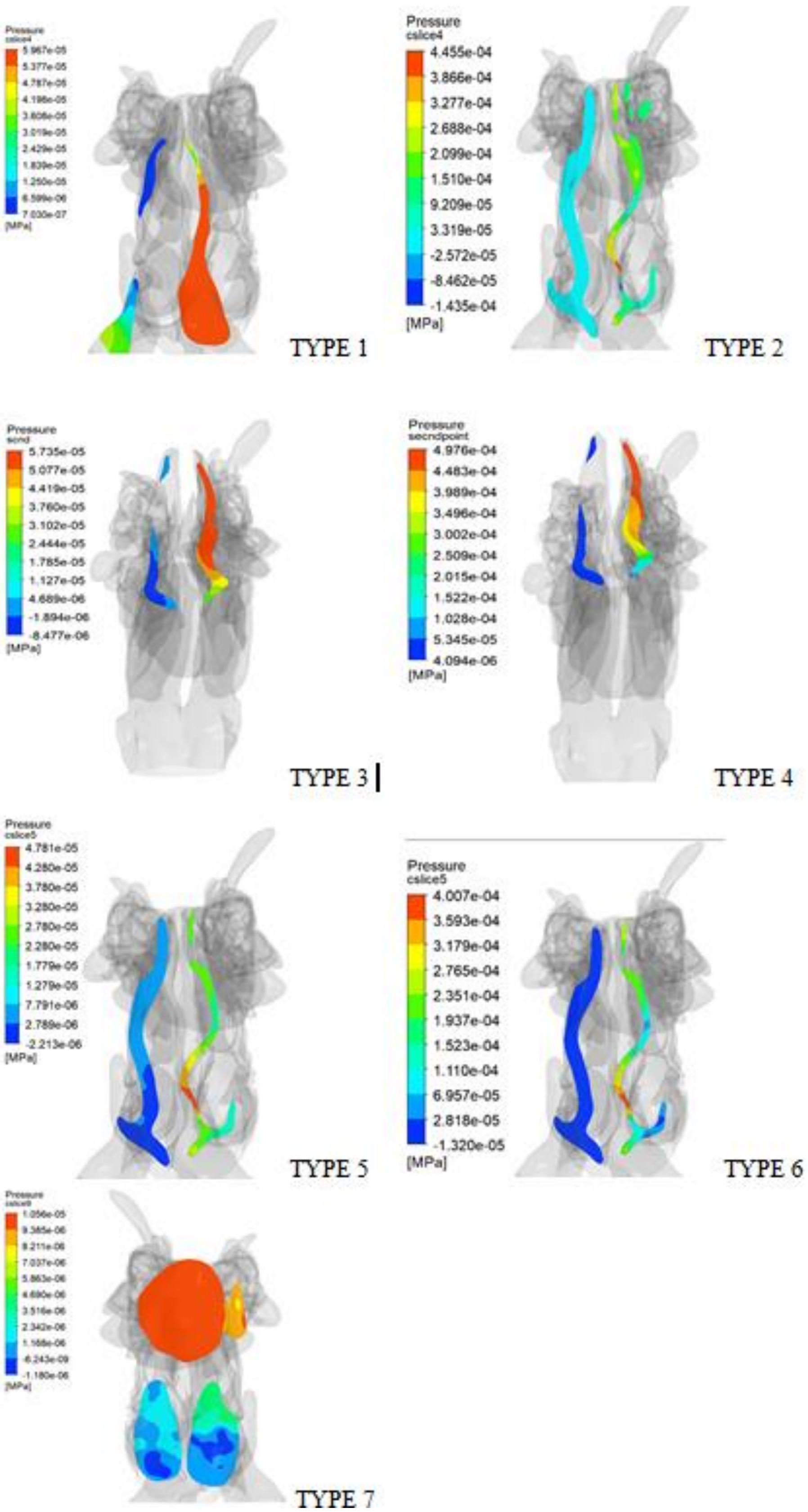

Figure 3. Nasal airlow partial pressure (Pa) in different types of septum deviation (coronary cut).

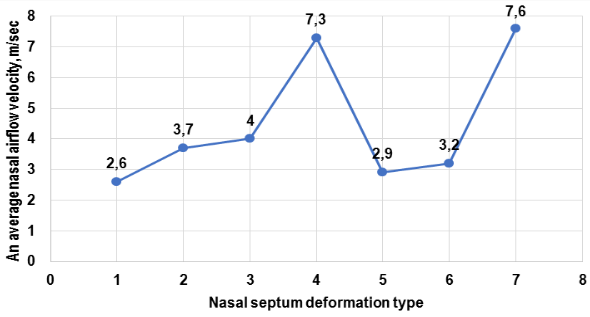

Diagram 1. An average nasal airflow velocity in 7 types of nasal septum deviation.

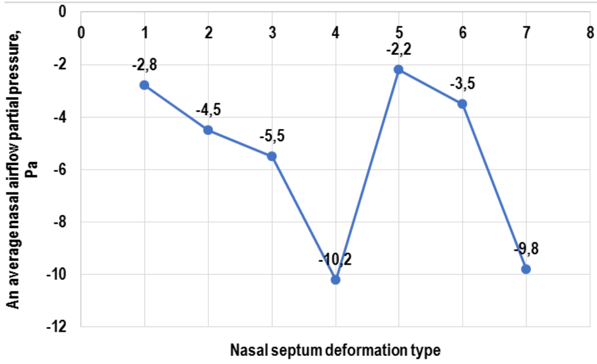

Diagram 2. An average nasal airflow partial pressure in 7 types of nasal septum deviation.

Discussion

In this experiment, we studied the mean values of nasal air flow velocity and partial pressure in nasal cavity of patients with seven different types of nasal septum deviation. For the experiment, the CFD modeling technique was used using computer images of the nasal cavities. During the virtual modeling, 4th and 7th types of NSD were identified with the maximum flow rate and the lowest pressure.

The CFD modeling method is relatively new, therefore, at this time, the boundaries of the norm for certain biophysical parameters of the nose have not yet been formed [24].

Among presented models of pathological nasal cavities, the patients with 4th and 7th types had the most pronounced septum deviation in contrast of healthy nasal cavities, which led to bilateral obstruction of the nasal passages. The obstruction leads to a change in the laminar flow to turbulent, the appearance of pathological eddies and the acceleration of the flow.

The results found coincide with the previous studies, where an increase in the flow rate in the curved part of the nasal septum was also found [12]. In another research, with an S-shaped deformity, the flow velocity was equal to 7.67 m/s [2], which was very close to our results (7.3 and 7.6 m/s).

In a study of healthy people, Wang noted a negative partial pressure in the nasal cavity, which gradually decreases in the direction from the nasal entrance to the nasopharynx [21]. Patients with a deviated nasal septum also showed negative pressure [9], but the values vary greatly depending on the area of study. This is due to the variety of types of SD and the lack of homogeneous groups in the patient selection. In our study, types of SD with total bilateral obstruction (4th and 7th types) of nasal tracts showed the lowest possible pressure, which is associated with the formation of a vacuum in the nasal cavity. Other researchers have also found a significant drop in nasal cavity pressure in patients with unilateral or bilateral SD [11]. There is no doubt that the SD type, leading to block both nasal passages, is already an indication for surgery. However, there is still a little information about the physical processes taking place inside the nasal cavity, and these kind studies can expand the concept of nasal obstruction.

Research disadvantages

To get statistically significant results, a larger number of participants are required, as well as a control group of healthy patients.

It is necessary to compare the data of biophysical parameters with the subjective sensations of patients to determine the CFD modeling method's sensitivity to the nasal air flow.

Conclusion

4th and 7th types of nasal septum deviations had the most different average values of flow velocity and partial pressure in the nasal cavity than other types of SDs.

The type of the nasal septum deformation affects the biophysical parameters of air movement in the nasal cavity. Further study with a statistically significant sample of patients will help to identify the type of deformity of the nasal septum, which has a pronounced violation of the parameters. These studies will expand the concept of the NSD classification and may become the "gold" standard to determine the indications for surgery.

Contribution of the authors:

Nazym S. Sagandykova: processing of the primary material, correction of the primary materia, statistical data processing with the creation of diagrams, summing up the results, conclusions, English translation;

Michael Yong Zhao: scientific Director, the project developer, a synthesis of the material;

Saule A. Taukeleva: scientific Director, provision of primary material;

The authors declare that there is no conflict of interest.

The authors claim a lack of funding.

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