Mashhad University of Medical Sciences (MUMS)

Reviews in Clinical Medicine

Clinical Research Development Center Ghaem Hospital

Computational Fluid Dynamic Application In Patients Suffering From Nasal Obstruction Due To Septal Deviation: A Review Article

Hamedreza Kafash (MD)[1*], Asghar Baradaran Rahimi (MD)[1], Sirous Nekooei (MD)[2], Seyede Fatemeh Mahmoudi Hashemi (MD)[3]

[1] *Department of Mechanical Engineering, Faculty of Engineering Ferdowsi University, Ferdowsi University of Mashhad, Mashhad, Iran*
[2] *Associate Professor, Radiologist, Ghaem Medical Center, Mashhad, Iran*
[3] *Department of Otorhinolaryngology, Faculty of Medicine, Mashhad University of medical Science, Mashhad, Iran*

ARTICLE INFO

Article type
Original article

Article history
Received: 07 Nov 2022
Revised: 08 Dec 2022
Accepted: 11 Dec 2022

Keywords
Computational Fluid Dynamics (CFD)
Nasal airflow obstruction (NAO)
Septal deviation

ABSTRACT

Introduction: Nasal airway obstruction (NAO) could be a common symptom that influences a person's quality of life. It can be assessed by patient perception or by physical measurements. Computational fluid dynamics (CFD) can be used to analyze nasal function. There is a need of comparative studies for assessment of airflow regimes using CFD.
Assessment of the different CFD utilities as an objective method for evaluation of nasal airflow characteristics was our main goal.
Studied were collected from MEDLINE (Ovid), Google Scholar ,Cochrane Library and EMBASE using a combination of the MeSH terms "septal deviation", "nasal obstruction", "Computational fluid dynamics (CFD)".
Methods: We investigated all the results obtained by the authors with respect to the CFD parameters and the evaluation of nasal obstruction (clinical or physical).
Results: To compare nasal obstruction with CFD parameters, most studied used heat flow, Wall Shear Stress (WSS), pressure drop, velocity and streamlines. We found that heat flux appeared to be the CFD parameter which most strongly correlated with patient perception. Pressure drop, wall shear stress and velocity were moreover valuable and appeared a great relationship.
Conclusion: More and more research on CFD on the nasal cavity has caused a better understanding of nasal obstruction. Further studies need to be done, including temperature and humidity exchange.

Please cite this paper as:
Kafash H, Baradaran Rahimi A, Nekooei S, Mahmoudi Hashemi SF, Kianifar HR. Computational Fluid Dynamic Application In Patients Suffering From Nasal Obstruction Due To Septal Deviation: A Review Article. Rev Clin Med. 2024;11(3): 5-12.

Introduction

The septum is a main structure of the nasal cavity. In addition to serving as the supporting supporting mechanism, the space between the septum and the lateral walls of the nasal cavity regulates nasal airflow and breathing. In the nasal cavity, a straight septum leads to laminar airflow, allowing inspired air to be warmed, cleaned and humidified and therefore gas exchange would be optimized. By the way, deviated nasal septum can cause varying degrees of nasal obstruction and decrease nasal breathing capacity [1, 2].

Septoplasty is the foremost common surgery in grown-ups performed by an otolaryngologist [3, 6]. Each year, 10,000 to 95,000 septoplasties

***Corresponding author:** Hamedreza Kafash
Department of Mechanical Engineering, Faculty of Engineering Ferdowsi University, Ferdowsi University of Mashhad, Mashhad, Iran
***E-mail:** kafashhamidreza@gmail.com*
***Tel:** 09154409434*

are performed in European nations [3, 6] and 260,000 in the United States [7, 8]. The overall taken a toll per operation can indeed go up to $10,559 within the US [5]. In spite of the fact that this surgery is routinely done around the world, Ear Nose and Throat (ENT) societies have pointed out that one of the greatest misguided judgments of modern ENT specialty is the need of objective method for evaluating septoplasty [1]. In specific, the nonattendance of a clear association between the subjective sensation of nasal obstruction and the objective effect of nasal septal deviation (NSD) may be deluding within the evaluation of patients who ought to treated surgically [9].

The utilize of numerical modeling, particularly airflow modeling with CFD, has ended up an important and popular field of research in recent years [10]. Earlier studies in the 1990s oversimplified the modeling of the nasal cavities and were limited to only one side [11, 12]. With the enhancement of computing power, 3D reconstructions of the nasal cavities have gotten to be more exact and complex airflow patterns have been recognized whithin the nasal cavity [13-17]. Diseases related to nasal cavity are evaluated wll using numerical simulation, such as empty nose syndrome or deviated septum [18–20]. Nowadays authors recommend virtual surgical planning using the CFD model [21–23].

In this article, seven articles that used CFD analysis to evaluate nasal septum deviation are reviewed.

Materials and Method

A database search was performed using electronic searching. The electronic databases are MEDLINE (from 1980 to 2020), EMBASE (1980 to 2020) and the Cochrane Database of Systems Review (CDSR) (1980 to 2020). The search terms used in the database were 'septal deviation', 'nasal obstruction' and 'Computational Fluid Dynamics (CFD)'. The inclusion criteria were used for the initial selection of studies from abstracts and titles located through an electronic database search were: human studies, no case reports or conference proceedings and no neonatal studies.

The following exclusion criteria were applied after full-text review: any sino nasal disease that may affect on diagnosis of nasal septal deviation, septal perforation, chronic rhinitis, choanal atresia, turbine hypertrophy, nasal polyps, etc...; Studies with patients with past septal surgery were also excluded.

Results

The chart of the electronic database search and last selection of studies in the review is shown in figure 1. Electronic searches brought about 21 abstracts after expulsion of copies that came from overlap of studies between the electronic databases. 14 studies were excluded concurring to exclusion criteria. This resulted in 7 studies that are discussed in this review article[24-30].

The intention of Sung Kyun Kim et al [24] study is to fing the relationship between CFD parameters and the structure of nasal cavity with NSD using numerical simulation. They produced 6 computational models of nasal cavities with septal deviation from computed tomographic images: three patients had nasal airway obstruction (NAO) and three asymptomatic patients. CFD used to reconstruct inspiratory airflows in each nasal cavity and the fluid dynamic parameters of each were evaluated. In the cases with NAO, the bigger pressure drop from anterior to posterior of the septum was determined and more irregular flow patterns in different parts of nasal cavity were observed. Local maximum velocity and wall shear stress were greater in patients with NAO in comparison to asymptomatic group. The feeling of NAO maybe in relationship to the cross sectional nasal resistance from nostril to nasopharynx than to the total nasal resistance of

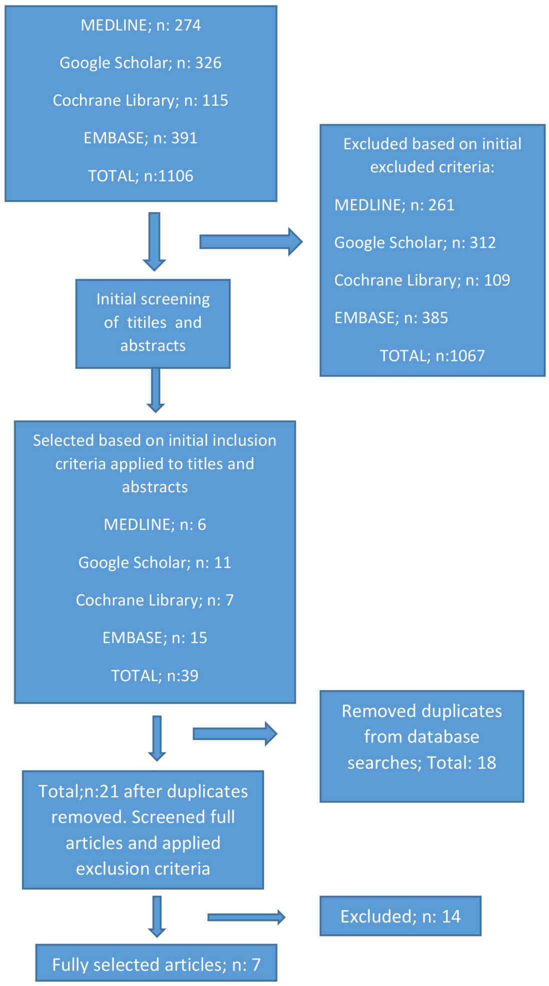

Figure 1. Summery of review article

nasal cavity Figure 2 shows flow partitioninig in normal (N1) and symptomatic (S1) patient.

The study of Natasa Janovic et al included 225 NSD patients [25]. The computed Tomograghic structure of the septum was evaluated utilizing 5 different NSD categories commonly used in clinical practice and research. The NSD angle is also measured. Nasal obstruction was measured by Nasal Obstruction Symptom Evaluation (NOSE) questionnaire. The relationship between Computed Tomograghy (CT) morphology and angle of NSD and NOSE scores were investigated utilizing appropriate regression methods. Patients with NSD found in anterior of septum always have the sensation of nasal obstruction, however patients with posterior NSD do not necessarily have NAO sunjectively, regardless of severity. Regression analysis showed no relationship between NOSE score and CT findings and NSD angle. The spurs of septum were did not statistically influence on obstruction severity.

E. Moreddu et al [26] avaluated nasal nasal airflow in youngsters. According to this in the five youngsters, the consequences of CFD have been concordant with clinical evaluation.

According to the study of Lifeng Li et al [27], NSD is categorized in to 7 types. Type 1 is a one- sided deviated septum that is horizontal to the nasal valve but does not end to the nasal valve. Type 2 may be a one- sided septum that the deviation is placed at the region of valve, decreasing the normal angle of the valve. Type 3 alludes to a "C" type septum found whithin the middle part of the nasal cavity, confronting the middle turbine head. Type 4 is known as a bilateral abnormality including type 2 on one side and type 3 on the other side. The deviation is characterized where the anterior deviation is located. Type 5 is a nearly horizontal septal spur that extends laterally and deeply into the nasal channel. Type 6 is found as a large unilateral intermaxillary bone wing with a ''gutter'' between it and the unilarelal septum. On the other side, there is an anteriorly septal spur. Type 7 maybe a combination of the 1 to 6 types.

The point of this study was to apply CFD to investigate the impacts of different types of NSD on nasal airflow and warming function. Patients with each sort of deviation were selected and person without NSD taken part as a control. By utilizing CFD, modeling of nasal cavity was done. Airflow partitioning, total resistance of nose, velocity and airflow temperature were assessed. Among all NSD types, highest velocity and resistance were significantly higher at types 4 and 7. The flow and velocity partitioning were also different in types 4 and 7 an also types 2 and 6. The airflow in all types of NSDs were totally warmed to a comparative degree. According to CFD analysis, the types of NSD may have relationship to airflow patterns.

In a research by Julia S. Kimbell et al [28] CT and sunjective scores were obtained from the NOSE and Visual analog scale (VAS) in two patients with NAO who were successfully treated with septoplasty. Pre- and post-operative CFD models were made from CT scans. Simulation of steady-state inspiratory airflow was applied to determine nasal resistance using bilateral and unilateral CFD (CFD-NR). In both subjects, NOSE and VAS scores improved after septoplasty. Both bilateral CFD-NR and unilateral CFD-NR showed decreasing resistance on the affected side in post-

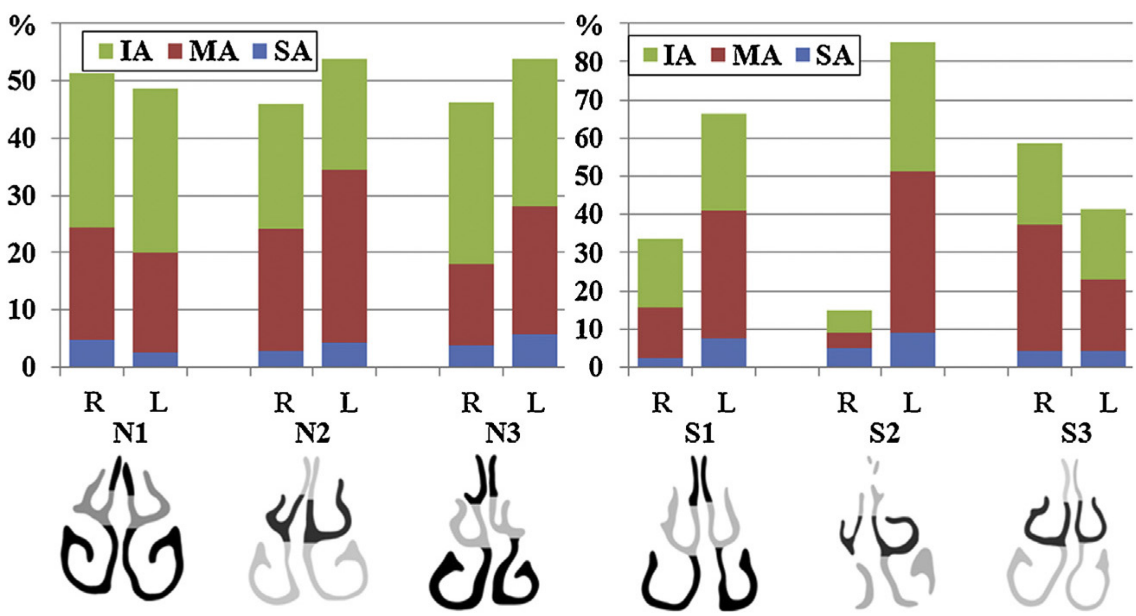

Figure 2. Flow distribution of N1 model (upper) and S1 model (lower). IA: inferior airway, MA: middle airway, SA: superior airway, L: left, R: right [24]

operative model (Figure 3).

Thomas Radulesco et al [29] studied on a group of patients referred for septoplasty. The Age of the patients ranged between 19 to 58 years old. Preoperative CT scan was done. They compared the CFD parameters (total pressure, heat flow, wall shear stress, temperature, nasal velocity and resistance) with the patient's perception score and rhinomanometry results applying the Spearman correlation test (rs). They also made comparison for resistance between CFD and rhinomanometric values.

Twenty-two patients with NSD and NAO were evaluated and 44 analyzes were performed comparing each side to its CFD data. Considering the correlation with the patient's perceived score, the greatest parameter they assessed was the estimation of heat flux (rs = 0.86). Nasal resistance measurement by CFD and rhinomanometry

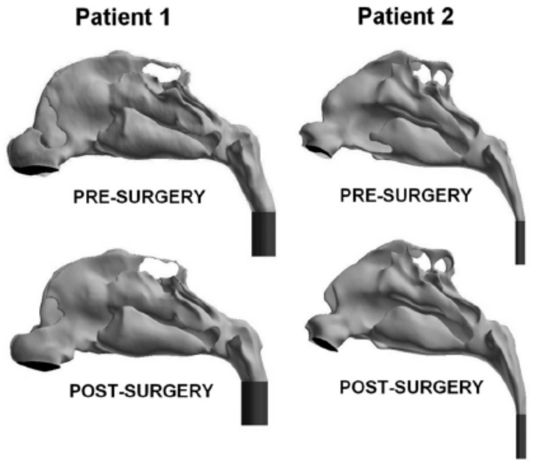

Figure 3. Pre- and post septoplasty CFD models of subjects 1 and 2 with left nares shown in black and channel added to the nasopharynxes to improve simulation convergence in dark gray [28]

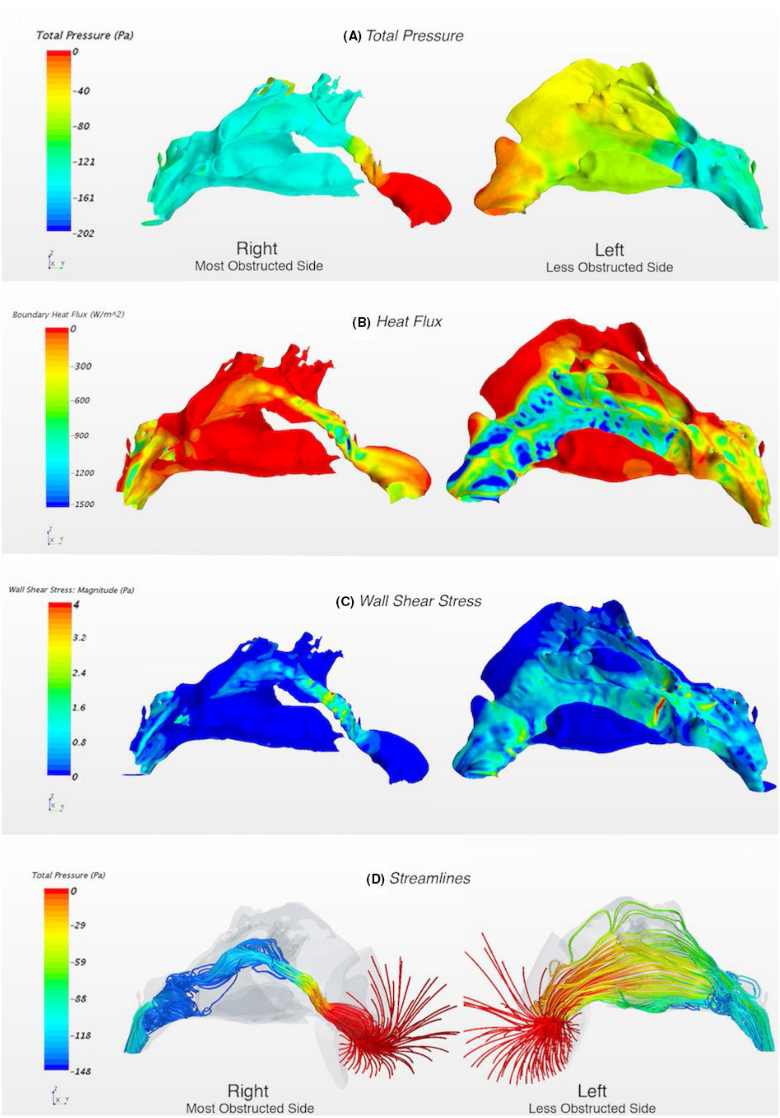

Figure 4. Lateral views of Right side and Left side according to (A) total pressure (Pa), (B) heat flux (W/m2), (C) wall shear stress (Pa) and (D) streamlines. Streamlines are coloured according to total pressure. The patient complained of right side "Total Obstruction" (4/4). On the left side, he reported "No obstruction" (0/4). A strong Pressure drop and decreased Heat Flux. WSS1 and 2 were null and lower, respectively, on the right side [29] revealed a strong correlation with subjective score (rs = 0.75, P < 0.001 and rs = 0.6, P < 0.001, respectively).

This study aimed to improve the interpretability of data calculated by CFD in the upper repiratory tract airways. It emphasizes that heat flux values are strongly correlated with subjective questionnaire in cases with NSD. It also helps to detect the side with obstruction and can help with more research on CFDs. Figure 4 shows the results.

Ting Liu et al [30] utilized commercial software to make a nasal cavity 3D model with the paranasal sinuses from CT of 15 patients with NSD and 4 normal cases. Considering the place of the most curve in nasal septum, patients were classified in to caudal, anterior and media deviation groups.

Airflow showed regular patterns the control group, but in the deviated septum models asymmetry in the bilateral nasal cavities were revealed. Airflow parameters showed difference in terms of convex and concave surfaces in models with NSD. The caudal septum deviation cases had maximum peak velocity, however the minimum peak velocity was in the media deviation patients. An interesting findind was that the peak velocity was not always on the convex side, whereas sometimes it was found at the concave side.

Figure 5 shows the results of the model with caudal septum deviation.

Table 1 provides a summary of the most important points of the mentioned studies.

Discussion

With respect to comparison between subjective nasal obstruction and nasal resistance, some researchers have cocurred that one-sided evaluation is more accurate than bilateral investigation [20]. So, it is essential to center on the narrow side and the other side instead of total airflow or total nasal resistance [22]. The most criticism that can be made against questionnaires (excluding VAs) is that they do locate on the more obstructed side, but CFD analysis focused on unilateral assessment. In most studies, there was a significant widening after operation on narrow side, while patients reported no improvement on feeling obstruction. Therefore, it is important to take in to account the airflow distribution. Assessment of the correlation between CFD and patient perception showed mixed results. Numerous reasons can clarify this issue. To begin with, the feeling of obstruction is not just due to increased nasal resistance. Typically why clinical measurements such as rhinomanometry are discussed [22, 30]. Second, special consideration ought to be paid to the nasal cycle in CFD analysis, because this fact can be a main issue [22]. Third, tissue compliance is not right now considered in CFD studies, which they assume wall rigid and not flexible. It is known that nasal obstruction due to nasal valves can be static or dynamic [22].

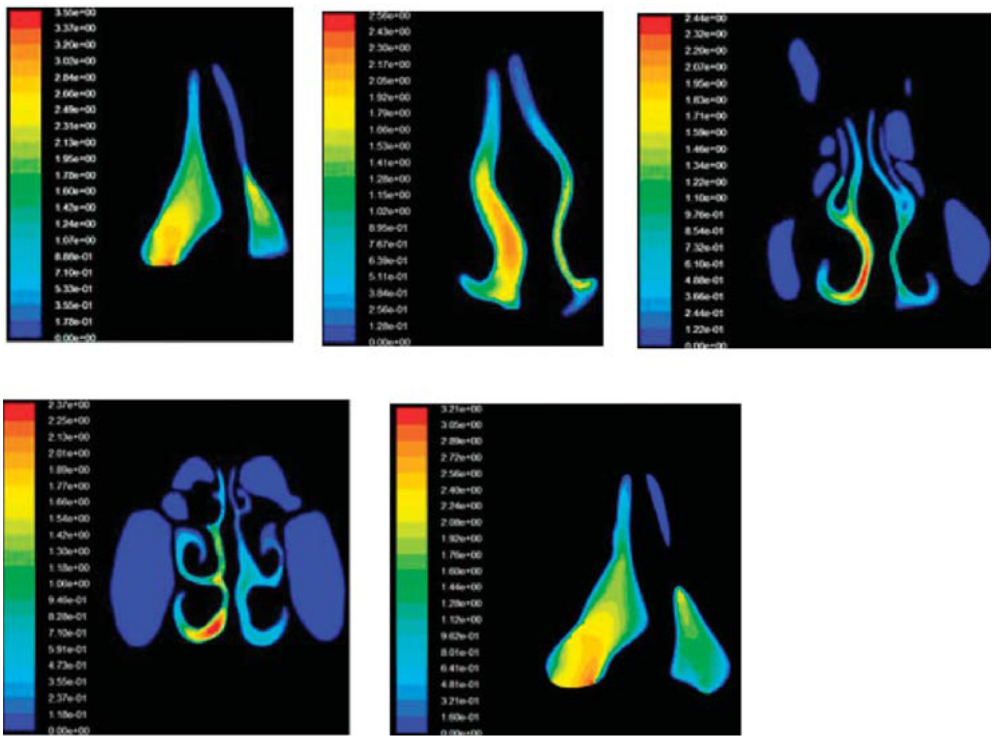

Figure 5. The peak velocity contours at five coronal sections of one caudal deviation case. Plane 1, nasal valve region; plane 2, anterior part of the inferior meatus; plane 3, anterior part of the middle meatus; plane 4, anterior part of the superior meatus; and plane 5, coronal section placed in the most curved part of septum [30]

Table 1. Summary of mentioned studies

Study	Study group	Control group	Results	Conclusion
Sung Kyun Kim et al. [24]	3 patients with nasal airway obstruction	3 patients without nasal airway obstruction	In patients with nasal obstruction pressure drop was greater and more irregular flow distribution was found. Local peak velocity and wall shear stress were higher in the group with nasal obstruction	The feeling of nasal obstruction may be related more to the level of nasal resistance than to the total nasal resistance
Natasa Janovic et al. [25]	225 patients with NSD	No control group	Regression analysis did not show any relationship between NOSE scores and CT morphology and the angle of NSD. The presence of spurs have no effect on the degree of obstruction significantly	The CT morphology and the angle of the NSD could not determine severity of the nasal obstruction. Requesting CT to confirm nasal obstruction is not mandatory.
E. Moreddu et al. [26]	Five patients aged 8 to 15 years, with nasal obstruction	No control group	The results of CFD correlated to clinical practice	CFD simulation can be utilized for children rhinologic pathologies
Study	**Study group**	**Control group**	**Results**	**Conclusion**
Lifeng Li, et al. [27]	8 patients with 7 types of NSD	8 normal participants	The peak velocity and total nasal resistance were greater in types 4 and 7. Airflow in all categories of NSD was fully warmed to a similar degree	The type of septal deviation may allow to disturb airflow characteristics. but, warming function was not different in types of NSD
Julia S. Kimbell et al. [28]	2 cases with NAO	No control group	In both subjects, NOSE and VAS scores improved in post septoplasty models and was correlated to CFD data.	CFD and subjective data was correlated with eatch other.
Thomas Radulesco et al. [29]	22 NSD cases with nasal obstruction	No control group	heat flux rhinomanometric and CFD resistances had correlations with subjective scores.	Heat flux measures are closely correlated to nasal obstruction due to septal deviation.
Ting Liu et al. [30]	15 patients with septal deviation	4 controls	with deviation in caudal had the highest peak velocity The peak velocity was sometimes in the concave side	Different types of septal deviation can alter nasal airflow. The location of septal deviation and the inferior turbinate hypertrophy in the concave side may affect on airflow patterns

If they are static (structural), CFD can solve the problem, however simulating the collapse of the nasal valve that occurs during breathing would be complex and have bios.

The nasal entry would be an important region in the feeling of nasal obstruction, where pressure and velocity measurments are related to the perception of nasal obstruction [24, 29]. Assessing pressure and velocity can be done frequently when performing CFDs.

WSS gets higher with NSD or collapse of the nasal valve and decreases in the absence of obstruction [24]. However the results mentioned above seem interesting, the major limitation of the WSS is that it is not reliable in the presence of complete nasal obstruction. So, in cases of a septal deformity, the outcome is often reliable, whereas in the absence of airflow, the WSS is zero and therefore difficult to correlate with clinical assessments.

Regarding the partitioning of nasal airflow, some authors have reported a strong correlation between the sensation of obstruction and the nasal airflow: patients with reduced airflow in the middle meatus revealed more perception of obstruction [21]. However, in otorhinolaryngology patients, flow in the middle meatus increases after surgery [31, 45]. Therefore, modulating nasal airflow, even without degrading nasal resistance, modulates patient perception and may lead to perception of nasal obstruction.

We did not discover a major contrast between NOSE and VAS in their relationship to CFD, with their correlation varying across different investigations. We suggest using both, as well as more detailed questionnaires like the ENS6Q.

Conclusion

More and more research on CFD related to the nasal cavity is helping to move forward our understanding about nasal obstruction. The correlation between NSD and nasal obstruction is best understood using the CFD model.

Conflict of interest

Acknowledgments

No potential conflicts of interest were disclosed

References

1. Cummings CW, Fredrickson JM, Harker LA, Krause CJ, Richardson MA, Schuller DE: Otolaryngology, Head & Neck Surgery. St Louis, Missouri: Mosby-Yearbook; 1998.
2. Neskey D, Eloy JA, Casiano RR: Nasal, septal, and turbinate anatomy and embryology. Otolarygngol Clin N Amer 2009, 42(2):193-205.
3. Van Egmond MM, Rovers MM, Hendriks CT, van Heerbeek N. Effectiveness of septoplasty versus non-surgical management for nasal obstruction due to a deviated nasal septum in adults: study protocol for a randomized controlled trial. Trials. 2015;16:500.
4. Moor M, Eccles R. Objective evidence for the efficacy of surgical management of the deviated septum as a treatment for chronic nasal obstruction: a systematic review. Clin Otolaryngol. 2011; 36(2):106-113
5. Gandomi B, Bayat A, Kazemei T. Outcomes of septoplasty in young adults: the nasal obstruction septoplasty effectiveness study. Am J Otolaryngol. 2010;31(3):189-192.
6. Bauman I. Quality of life before and after septoplasty and rhinoplasty [in German]. Laryngorhinootologie. 2010;89(suppl 1): S35-S45.
7. Thomas A, Alt J, Gale C, et al. Surgeon and hospital cost variability for septoplasty and inferior turbinate reduction. Int Forum Allergy Rhinol. 2016;6(10):1069-1074.
8. Bhattacharyya N. Ambulatory sinus and nasal surgery in the United States: demographic and perioperative outcomes. Laryngoscope. 2010;120:635-638.
9. Nasal Septal Surgery. ENTUK position paper 2010. ENT UK (the British Academic Conference in Otolaryngology (BACO) and the British Association of Otorhinolaryngology-Head and Neck Surgery (BAO-HNS)). Nasal Septal Surgeryth ed. London, England: ENT United Kingdom; 2010
10. Lin CL, Tawhai MH, McLennan G, Hoffman EA. Computational fluid dynamics. IEEE Eng Med Biol Mag 2009;28:25-33
11. Elad D, Liebenthal R, Wenig BL, Einav S. Analysis of air flow patterns in the human nose. Med Biol Eng Comput 1993;31:585-92
12. Keyhani K, Scherer PW, Mozell MM. Numerical simulation of airflow in the human nasal cavity. J Biomech Eng 1995;117:429-41.
13. Wen J, Inthavong K, Tu J, Wang S. Numerical simulations for detailed airflow dynamics in a human nasal cavity. Respir Physiol Neurobiol 2008;161:125-35.
14. Xiong GX, Zhan JM,Jiang HY, LiJF, Rong LW,Xu G. Computationalfluid dynamics simulation of airflow in the normal nasal cavity and paranasal sinuses. Am J Rhinol 2008;22:477-82.
15. Mosges R, Buchner B, Kleiner M, Freitas R, Horschler I, Schroder W. Computational fluid dynamics analysis of nasal flow. B-ENT 2010;6:161-5.
16. Kim SK, Na Y, Kim JI, Chung SK. Patient specific CFD models of nasal airflow: overview of methods and challenges. J Biomech 2013;46: 299-306.
17. Wang de Y, Lee HP, Gordon BR. Impacts of fluid dynamics simulation in study of nasal airflow physiology and pathophysiology in realistic human threedimensional nose models. Clin Exp Otorhinolaryngol 2012;5:181-7.
18. Li C, Farag AA, Maza G, et al. Investigation of the abnormal nasal aerodynamics and trigeminal functions among empty nose syndrome patients. Int Forum Allergy Rhinol 2017;8:444-52.
19. Balakin BV, Farbu E, Kosinski P. Aerodynamic evaluation ofthe empty nose syndrome by means of computational fluid dynamics. Comput Methods Biomech Biomed Eng 2017;20:1554-61.
20. Chen XB, Lee HP, Chong VF, Wang de Y. Assessment of septal deviation effects on nasal air flow: a computational fluid dynamics model. Laryngoscope 2009;119:1730-6.
21. Garcia GJ, Rhee JS, Senior BA, Kimbell JS. Septal deviation and nasal resistance: an investigation using virtual surgery and computational fluid dynamics. Am J Rhinol Allergy 2010;24:e46-53.
22. Segal RA, Kepler GM, Kimbell JS. Effects of differences in nasal anatomy on airflow distributi: a comparison of four individuals at rest. Ann Biomed Eng 2008;36:1870-82.
23. Chen XB, Leong SC, Lee HP, Chong VF, Wang DY. Aerodynamic effects of inferior turbinate surgery on nasal airflow-A computational fluid dynamics model. Rhinology 2010;48:394-400
24. Sung Kyun Kima, Go Eun Heoa, Anna Seob, Yang Naa, Seung-Kyu Chungc. Correlation between nasal airflow characteristics and clinicalrelevance of nasal septal deviation to nasal airway obstruction: Respiratory Physiology & Neurobiology 2014: 95- 101
25. Natasa Janovic, Aleksa Janovic, Biljana Milicic, Marija Djuric. Is Computed Tomography Imaging of Deviated Nasal Septum Justified for Obstruction Confirmation? Ear, Nose & Throat Journal 2019: 1-6
26. E. Moreddua,b, L. Meistera, C. Philip-Alliez, J.-M. Triglia, M. Medalea, R. Nicollasa. Computational Fluid Dynamics in the assessment of nasal obstruction in children. European Annals of Otorhinolaryngology, Head and Neck diseases 2019 : 87-92
27. Lifeng Li, Hongrui Zang, Demin Han, Nyall R. London Jr. Impact of Varying Types of Nasal Septal Deviation on Nasal Airflow Pattern and Warming Function: A Computational Fluid Dynamics Analysis. Ear, Nose & Throat Journal. 2019: 1-7
28. Julia S. Kimbell, Guilherme J. M. Garcia, Dennis O.

Frank, Daniel E. Cannon, Sachin S. Pawar, John S. Rhee. Computed nasal resistance compared with patient-reported symptoms in surgically treated nasal airway passages: A preliminary report. Am J Rhinol Allergy 2012:94-97

29. Thomas Radulesco, Lionel Meister, Gilles Bouchet, Arthur Varoquaux, Jérome Giordano, Julien Mancini, Patrick Dessi, Pierre Perrier, Justin Michel. Correlations between computational fluid dynamics and clinical evaluation of nasal airway obstruction due to septal deviation: An observational study. Clinical Otolaryngology. 2019: 603 - 611
30. Ting Liu, Demin Han, Jie Wang, Jie Tan, Hongrui Zang, Tong Wang,Yunchuan Li & Shunjiu Cui. Effects of septal deviation on the airflow characteristics: Using computational fluid dynamics models. Acta Oto-Laryngologica. 2012: 290-298