Use of Computational Fluid Dynamics Nasal Airflow Measurement to Design Septoplasty: A Pilot Study

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Deviation in the nasal septum that obstructs airflow is a source of discomfort to patients. Areas of nasal malformation then, need to be identified before performing surgery. In the present study, the authors introduce the computational fluid dynamic (CFD) technique to predict regions of limited airflow based on CT scan reconstruction of the nasal cavity. The present study proposes to use CFD to identify regions of obstructed airflow and design a surgical procedure to correct them. The authors report three cases with obstructed nasal airflow together with CFD measurements before and after the surgery. Results indicate that CFD is useful to verify the areas of airflow abnormality and conform with the results obtained using other methods.

Keywords: *Computational fluid dynamics, Septoplasty, Deviated septum, Nasal obstruction, Nasal airflow*

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Deviated nasal septum (DNS) is the most common cause of anatomical nose obstruction. Clinical symptoms and the degree of complaints depends on air-unflow through the nose due to DNS vary in individual patients(1). Up to now, the physiology of nasal airflow is not clearly understood. However, the balancing function between airway patency and warm/ moist inspired air is not known. Several combination methods have been used to evaluate of the degree of DNS. The simplest method to determine which side of nose has a blockage is by performing rhinohygrometry or spatula misting test, which consist of exhaling over metallic tongue depressor. Rhinomanometry is used to measure airflow and pressure difference(2). Acoustic rhinometry is used to describe the minimal cross-sectional area of the nasal cavity. High resolution imaging studies such as computerized tomography or magnetic resonance are used to demonstrate the details of anatomical defects. Another advanced method used to explain the quality of nasal airflow is computational fluid dynamics (CFD). The present study proposes to utilize CFD measurement to design septoplasty and evaluate the patient's clinical aspects before and after septoplasty to compare it with conventional methods.

Material and Method

Patients were recruited at Otolaryngology unit, HRH Princess Maha Chakri Sirindhorn Medical Center, Faculty of Medicine, Srinakharinwirot University from January 2010-December 2011. Everyone was consented to septoplasty with the main indication being nose obstruction and difficulty breathing. All patients underwent medical treatment for least 3 month, their symptoms did not improve. Patients' characteristics are shown in Table 1. All cases had never been operated nose or paranasal sinus. Data collected from patients included Nasal Obstruction Septoplasty Effectiveness scores (NOSE), nasal endoscopic examination and spatula misting test, rhinomanometry, acoustic rhinometry, computerized tomography scan of the paranasal sinus and CFD data. NOSE is a clinical symptoms score comprising five items (nasal congestion, nasal blockage, trouble breathing through the nose, trouble sleeping, unable to get enough air through the nose during exertion)(3). The author planned the surgical operation based on pre-operative patients' subjective and objective information. Routine

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Table 1. Patients' characteristics

Case	Age	Sex	Weight (kg)	Chief complaint
1	23 years old	Male	58.9	Nose block 1 year with epitaxis 2 months
2	33 years old	Male	55.4	Nose block 1 year
3	30 years old	Male	53.1	Nose block 1 year

intranasal post-operative care was done without any complication. Three months after surgery, NOSE scores and total objective evaluations were repeated. CFD were measured in 5 coronal planes according to Fig. 1: 1) nasal valve, 2) Plane 1 = 0.5 cm behind anterior end of inferior turbinate, 3) Plane 2 = 0.5 cm behind anterior end of middle turbinate, 4) Plane 3 = the middle of inferior turbinate, 5) Plane 4 = 0.5 cm in front of posterior end of inferior turbinate.

Equipment

Rhinomanometry: software RhinoStream®, hardware SRE2000 Interacoustics AS Assens Denmark.

Acoustic Rhinometry: software RhinoScan®, hardware SRE2000 Interacoustics AS Assens Denmark.

Computerized Tomography: SOMATOM® Volume access, Version A20A Siemens AG Erlangen Germany.

CFD analysis using continuity equation, conservation energy equation and Navier-Stokes equation base on CT data for numerical fluid computations by second author.

Results

The NOSE scores for cases 1, 2, 3 before the operation were 12, 13 and 12, respectively and decreased to 2, 6, 4 after the operation. According to Table 2, the results show that the minimal cross-sectional area of both values (MCA1 and MCA2) provided by acoustic rhinometry. All of pre-operate MCA1 values are much lower than male Asian's average 0.61 $\pm$ 0.60 cm^2[(4)]. After surgery all showed improvement except for MCA 2 in the left nostril of patient case 1 being the same. According to Table 3 the results show that the difference pressure of airflow values provided by rhinomanometry give good results in almost all parameters show improvement, particularly in the congested side. According to Table 4, the results from CFD peak flow show improvement in all planes except for the left nostril in planes 3 and 4 for cases 2 and 3 in which it was found that the airflow was faster. According to Fig. 2-4 the post-operative results show that there is a decrease in airflow speed in all obstructed areas except for the posterior left nostril in cases 2 and 3, in which it was found that airflow speed had increased.

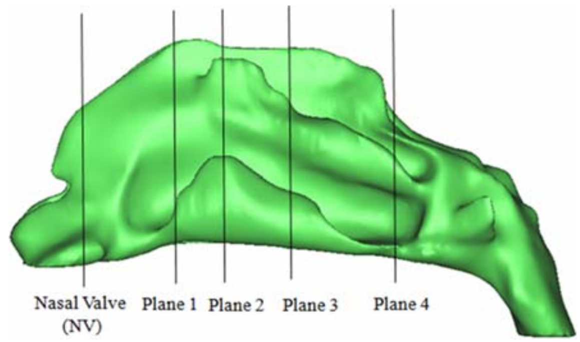

Fig. 1 Demonstrate lines of each coronal plane as same as table 4 , left is anterior nose, right is nasopharynx

NV = nasal valve, Plane 1 = 0.5 cm behind anterior end of inferior turbinate, Plane 2 = 0.5 cm behind anterior end of middle turbinate, Plane 3 = the middle of inferior turbinate, Plane 4 = 0.5 cm in front of posterior end of inferior turbinate

The CFD technique were used to visualize velocity contour of airflow in coronal cross-section in pre-operative as Fig. 2. The data obtained from CFD show the local flow velocity vary as a multicolor scale at left side of Fig. 2. Blue represents regions of slow air flow and red represents areas of air stagnation. Yellow represent areas where the air velocity has a moderate magnitude, and pink and red represent areas of high flow. The air move faster in narrow areas and slower in wider ones. To analyse the air flow, the authors examined first a coronal cross section because the authors noticed that it is easier to spot narrow passages. Then the authors compare the flow profile with sections in different planes going from anterior to posterior side of the nasal cavity. Then, the authors examined the axial (horizontal) cross sections in order to verify the location and shape of the narrow passage and to plan for the surgery. From examining the coronal section in case 1, a pink region indicated a obstructed area is pointed by the arrowhead in planes 1, 2 and 3. In the second case, the obstructed area is shown in orange in planes 1 and

Table 2. Minimal cross-sectional area evaluation; cm^2 (Acoustic rhinometry)

	MCA1		MCA2	
	Left	Right	Left	Right
Case 1 before, after	0.50, 0.53	0.59, 0.69	0.57, 0.57	0.61, 0.83
Case 2 before, after	0.14, 0.49	0.36, 0.47	0.20, 0.41	0.30, 0.52
Case 3 before, after	0.16, 0.52	0.62, 0.75	0.15, 0.45	0.47, 0.59

MCA1 = minimal cross-sectional area from 0-2.2 cm of nasal cavity, MCA2 = minimal cross-sectional area from 2.2-5 cm of nasal cavity. Asian's average 0.61 ± 0.60 cm^2[4]

Table 3. Difference pressure of Airflow ; $Pa/cm^3/s$ (Rhinomanometry)

	Expire		Inspire	
	Left	Right	Left	Right
Case 1 before, after	2.23, 1.12	0.70, 1.36	4.37, 0.95	0.68, 1.19
Case 2 before, after	161.29, 1.07	0.78, 0.78	5.22, 0.69	0.59, 0.56
Case 3 before, after	8.28, 0.58	0.84, 0.93	3.31, 0.78	0.73, 1.07

Asian's average 0.51 ± 0.22 $Pa/cm^3/s$[5]

Table 4. CFD peak velocity of airflow in each coronal plane (m/s)

	NV	Plane 1	Plane 2	Plane 3	Plane 4
Case 1 left before, after	2.375, 1.888	2.638, 1.760	2.366, 1.674	2.209, 1.566	1.791, 1.650
right before, after	2.230, 1.888	1.900, 1.650	1.650, 1.260	1.650, 1.260	1.450, 1.260
Case 2 left before, after	2.524, 2.192	2.655, 2.083	2.389, 1.960	1.650, 1.840	1.840, 2.131
right before, after	2.524, 2.192	2.655, 2.083	2.230, 1.650	2.067, 2.015	2.577, 2.131
Case 3 left before, after	3.113, 2.129	2.910, 2.323	2.604, 2.129	1.270, 1.549	1.000, 1.549
right before, after	2.550, 1.742	2.655, 1.936	2.604, 1.549	2.003, 1.161	1.860, 1.161

Each plane corresponds with demonstrated line in Fig. 1

2. In the third case, the obstructed area is shown in plane 2 and 3. When the authors analysed the corresponding axial cross sections as Fig. 4, the authors were able to identify the area to be enlarged by surgery. The examination of CFD after the surgery shows that pink and orange areas have disappeared in all three cases as Fig. 3.

Discussion

In the past, before performing a septoplasty to correct the obstructed nasal airway, the surgeon would examine the nasal cavity with an endoscope, or perform an additional CT or MRI scan before planning for the surgery. Rhinometry and acoustic rhinometry are additional techniques used to verify areas of nasal obstruction. But surgical treatment with nasal septoplasty may not always be adequate in alleviating the patient's symptoms. Research involving use of CFD may be employed to determine the area that needs correction using a physiological model. The author brings this test to analyze the data of both before and after nasal septoplasty to compare with the others. Clinical outcome of surgery is excellent due to all symptoms were clear up. NOSE score also become lower. Objective data from rhinomanometry, acoustic rhinometry and CFD peak velocity show improvement. Patient case 1 has anterior misshapen septum to left side that causes the air passage to become tortuous, which causes high airflow at left nasal valve. Then it causes difficult breathing and stimulates nose bleeding

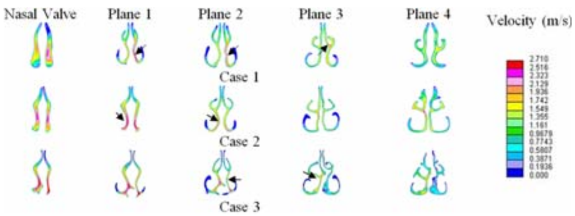

Fig. 2 Velocity contour of airflow in coronal cross-section in pre-operative

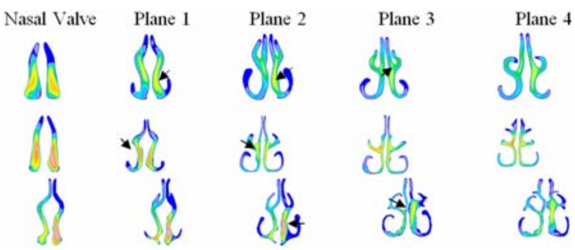

Fig. 3 Velocity contour of airflow in coronal cross-section in post-operative case 1-3, respectively

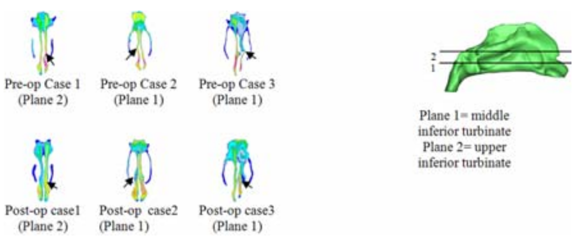

Fig. 4 Velocity contour of airflow in axial cross-section. In the figure the upper part correspond to the nasopharyngeal side, and the lower part correspond to the anterior portion of the nose

at the prominent area of the deviated septum that close to inferior turbinate which relate to high velocity in plane 1, 2, 3 (arrow). Post-operatively this issue was no longer present at 18 months follow-up. For case 2, CFD determined that at the inferior area the results were good according to plane 1 and 2. But the superior and posterior area in plane 4 presents some obstruction evidence, although did not correlate to the patient's clinical symptoms. Case 3 had severe DNS and distort left lateral nasal wall. After operation, In spite of the distribution of air in the left side of nasal passage was not broadly dispersed, reshaping septum improves the regularity of the air distribution in the right side. And current management is waiting for the left middle and inferior turbinate remodeling itself in order to make the left nostril more balanced in terms of air distribution. Therefore, for this patient, CFD is planned for re-evaluation again.

Rhinomanometry measures transnasal pressure and flow[6] which reports total patency of each nostrils. Acoustic rhinometry determines minimal cross-section areas (MCA) at anterior part of nose[7] and valuable for evaluation of nasal patency[8,9]. MCA1 values are correlated to CT images[10]. Rhinohygrometry or Spatula misting is the easiest, quickest and cheapest measurement to evaluate nasal patency and quite relevant to rhinomanometry. CT images detail scrupulously anatomic nose obstruction and unveil clogged structure. CFDs elaborate pattern of dynamic airflow[11] and localize peak flow areas in various cross-sectional plane which often flow through medial surface of inferior, middle turbinate and uncinate process[12-14], in addition to show the unflow spaces, nasal roof and inferior meatus. In the present study, CFD give more details that can explain surgical outcome better than others. Velocity contour helps to show the details both before and after the surgery. As for the CFD peak velocity is able to provide accurate data, particularly in the planes NV 1, 2, and 3. Comparison between objective measurements, patency or volume of airflow is better demonstrated with rhinomanometry and CFD. Localizing obstruction is better defined by CT and CFD. And only CFD can show airflow quality regarding velocity contour include pathophysiology.

Patients with DNS will have more narrow nasal passage ways than others and the airflow at the narrow areas which its have increased negative pressure. By the principles of the Bernoulli's effect there will be an increased air force at those narrow areas and often those areas will have air circulating at an increased speed along with turbulent flow which may cause symptoms of nasal obstruction as the air is not circulating in its normal direction. In addition, the nasal epithelium in that area is usually drier than normal which causes frequent epistaxis[15]. After septoplasty the nostrils will be equally wider which will allow laminar flow, which in turns cases the airspeed to be decreased and allow the patient to use less effort in breathing. The decreased airspeed also results in less turbulent flow which results in decreased dryness of the nasal epithelium, resulting in less epistaxis in that area. Accordingly, the patients with concomitant epistaxis along with nasal obstruction are good candidates for septoplasty because the surgery will decrease shearing force pressure on the septal area. The nasal valve which is located at the anterior part of the nose is an area that tends to have the most narrowing, consist with Garcia's work[16]. However, in the patients with contralateral turbinate hypertrophy[17-19], correction of the hypertrophy should also be done simultaneously otherwise it may result in a narrowing of the passages that is more severe than it was before surgery[20], which may cause the patient to feel like their previously good nostril has become obstructed post-operatively. The second important area is the common meatus and the medial wall of the uncinate process, as post-operative left nose of case 3. Future studies will use the CFD model to be able to design a minimal invasive surgery.

Conclusion

In conclusion, CFD is able to provide more data than other objective tests and is able to explain both the pathophysiologic phenomenon and the physics of the nasal passage better than other equipments. The useful information that is provided includes pre-operative evaluations that may enable surgeons to design better methods of septal defect correction, as well as post-operative data that can describe airflow characteristics regarding treatment succession. Further research of this method is future trend to be noted for physicians that specialize in this field.

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Potential conflicts of interest

None.

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การศึกษานำร่อง การใช้วิธีจำลองพลศาสตร์ของไหลช่วยออกแบบการผ่าตัดผนังกั้นจมูก

วิศาล มหาสิทธิวัฒน์, ไขแสง เหมทิวากร, ชูชาติ ปิณฑวิรุจน์

อาการอุดตันของจมูกอาจเกิดจากผนังกั้นจมูกคด ก่อนการผ่าตัดรักษาควรได้รับการตรวจวิเคราะห์ถึงลักษณะที่ผิดปกติของจมูก การศึกษานี้ผู้วิจัยนำเสนอการใช้ข้อมูลจากวิธีจำลองพลศาสตร์ของไหลที่ได้จากภาพถ่ายเอกเรย์คอมพิวเตอร์เพื่อวิเคราะห์การเคลื่อนไหลของลม ที่ผ่านในโพรงจมูกมาหาตำแหน่งที่ก่อให้เกิดการอุดกั้นและช่วยออกแบบการผ่าตัดแก้ไข ในผู้ป่วย 3 ราย ที่ได้ศึกษาพบว่าวิธีการนี้สามารถให้รายละเอียดความผิดปกติของจมูกได้ดีทั้งก่อนและหลังผ่าตัด ตลอดจนสามารถให้ข้อมูลผลการรักษาที่สอดคล้องกับวิธีประเมินชนิดดั้งเดิม