Effect of Functional Endoscopic Sinus Surgery to the Flow Behaviors in Nasal during Inhalation

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Abstract. Researcher nowadays interested in bio fluid mechanics studies that combine engineering problem solving skills with medical and biological sciences to improve healthcare. The understanding of effect on flow behavior for healthy and post Functional Endoscopic Sinus Surgery (FESS) is improving by the continuously advances technology in imaging modalities, measurement technique and technology. Capability of computational simulations has expanded as the result of the increasing use of such high information can be provided by numerical simulation. FESS is a surgery to restore sufficient sinus ventilation and drainage by removing uncinate process. Nevertheless, FESS have a few cases of side effects such as facial pain, reduction in sense of smell and reoccurrence of infection. This study investigates the effect of uncinate process removal. The models were done through computational technique and flows were then simulated to predict the effect of the removal. Inhalation processes with several flow rates were modeled. The results show that smooth flow was observed at paranasal sinuses area which indicates successful surgical process. The results show that smooth flow was observed at paranasal sinuses area which indicates successful surgical process. The uncinate process removal in both post FESS surgery expose the paranasal sinuses to contaminated inhaled air.

Keywords: **Nasal, Paranasal Sinuses, Air Flow Trajectories, Flow Behavior and Three Dimensional Actual Model.**
PACS: 47.63.-b

INTRODUCTION

FESS is a surgical treatment for patients suffering from chronic sinusitis infection and not cured with medical treatment. In other words, FESS is a minimally invasive surgery to eliminate uncinate process to restore sufficient sinus ventilation. Robert stated that most of study shows 80% to 90% post-surgery success rates. However in the other hand, patients with chronic allergic sinusitis show lower success rate and there were a few cases with side effects such as facial pain, reduction in sense of smell and sinusitis reoccurrence of infection [1].

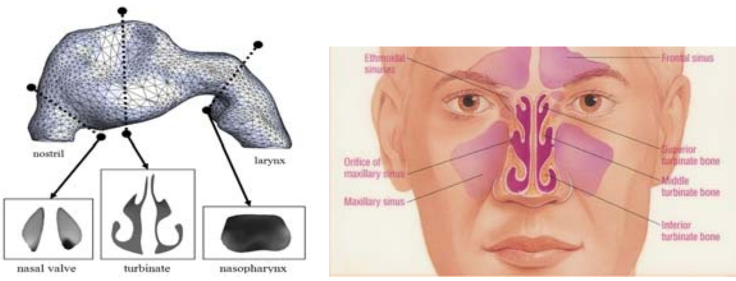
In this study, CFD methods were applied to simulate nasal airflow to increase the understanding of the detailed flow characteristic inside the human nasal cavity without any intervention and clinical risk for the patient. Over the years the airflow field in nasal cavity has been studied by using both experimental and numerical models with either build based on computed tomography (CT) or magnetic resonance imaging (MRI). Even though anatomically precise nasal models can be obtained, it is extremely difficult to obtain measurements from the small and complicated nasal models.

Pressure drop through the nose, particle deposition, exchange processes at the wall, air flow velocity and wall shear stress are important quantities in relation to many physiological processes [2]. *Hahn et al* found that increase in nasal flow velocity at a constant inlet concentration resulted in an increase in total olfactory uptake for all odorants [3]. *J.wen* found that air flow patterns are sensitive to the geometric construction within the human nasal cavity. In this paper a highly automated technique for constructing numerical models of a human nasal including the sinuses from CT scan data. Three numerical models of human nasal cavities and sinuses are developed with this automatic technique, and airflow was simulated with a commercially-available CFD Lab software package.

METHODOLOGY

Nasal Anatomy

Nasal cavity is area between nose tip and throat as shown in **FIGURE 1. (a).** The cross-sectional area of the nasal cavity gradually decreases throughout the nasal valves, up to the internal valve or known as turbinate. Next the flow will enter separate passages where the airflow from left and right rejoin and enter the nasopharynx, the final region of the nasal cavity [1].From fluid mechanics point of view, the airway nasal is designed to reduce airflow resistance in nasal passage to allow easy breathing, the extension of the inferior and middle turbinate with the septum create a large surface area and its curly structure cause swirling and turbulence during breathing, which affects airflow [2]. Paranasal sinuses are air-filled spaces, communicating with the nasal cavity, within the bones of the skull and face as shown in **FIGURE 1. (b).** There are four pairs of sinuses. The sinuses are located on either side of the nose in your cheeks, behind and between the eyes, in the forehead, and at the back of the nasal cavity. Paranasal sinuses are divided into subgroups that are named according to the bones within which the sinuses lie.



(a) (b)

FIGURE 1. Nasal and paranasal Sinuses Anatomy

Three Dimensional Actual Model Reconstruction

The nasal cavity geometry was obtained through a CT scan of a healthy 34-year old, Asian male as shown in **FIGURE 2.** The CT scan was performed using a SIEMEN Body Scanner .The recorded pixel size is 0.6328 while the resolution of the CT scan is 512. The scans captured outlined slices in the *X–Y* plane at different positions along the *Z*-axis from the entrance of the nasal cavity to just anterior of the larynx at intervals of 1–5mm depending on the complexity of the anatomy. The focus area of this study was as in red box in **FIGURE 2** as shown below.

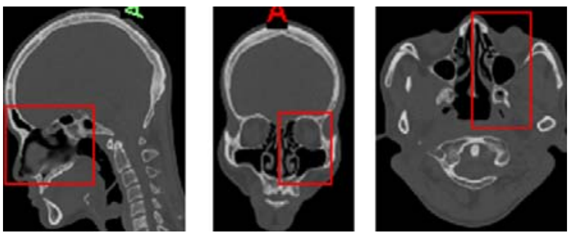


FIGURE 2. CT scan image.

The successful scanned images were transferred electronically to CT scan conversion software called AMIRA 5.2.2. The generated model was then transferred to another software package called MAGICS 13 to make major modification such as holes patching, geometry correction and volume reconstruction. In order to reduce number of faces, the model then transferred back to AMIRA 5.2.2 to fit in the Solid Work 2008. The three-dimensional computer model was saves as STL format for flow analysis purpose. There are three models generated in this study which are healthy, post FESS minor and major as shown in **FIGURE 3**. Post FESS minor model is a model based on FESS surgery with uncinate process removal only, while in post FESS major model the removal process include some part of the paranasal sinuses and uncinate process.

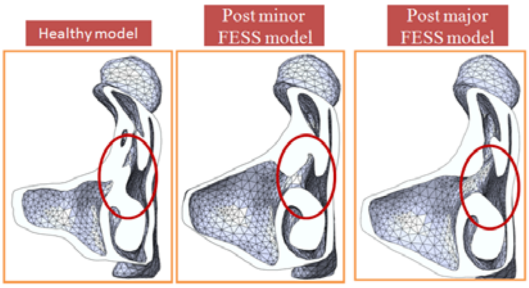


FIGURE 3 Healthy, post FESS minor and post FESS major actual 3D model.

Boundary Condition and Numerical Method

The flow in the nasal cavity and sinuses were assumed in incompressible flow condition as the velocities were less than the speed of sound [4]. In this study, the flow was also considered laminar and turbulent. As for the model exterior wall boundary conditions were assumed to be rigid. While at the interface between air and the surface of the nasal cavity and sinuses, the no-slip boundary condition was defined. The simulation was performed only for inspiration phase, as the structure of the nasal cavity and sinuses are not constant during both inspiration and expiration. The flow rate was set according to adult breathing condition for relax breathing condition (5 L/min), normal breathing condition (12 L/min) and exercise breathing condition 30L/min. The boundary condition at the inlet was set as ambient pressure (1atm). The ambient pressure is assumed to be atmospheric, and for air at 310K. The temperature of the rigid wall of nasal cavity was assumed to be 305K, average of the temperature along the structure of the nasal cavity [5].

All graphical manipulation was done using Solid Works 2008 software and EFD Lab. The processed geometry or 3D model was saved as a Stereo lithography file (.stl) and then was exported to the CFD package EFD, which allows the STL file to be converted from a wall fabricated hollow model into a volume filled with tetrahedral cells, of 0.1mm edge length. The volume mesh is comparable to the numerical solution of the fluid flow. Using EFD, the boundary conditions were applied to both inlet and outlet of the 3D model. By using the same software, flow velocity in the nasal 3D model was calculated by solving the Navies-Strokes equations that govern 3D flow in incompressible fluids assumptions.

RESULT AND DISCUSSION

The 3D nasal model from upper left in **FIGURE 4** indicate the inlet and outlet boundary during inhalation of the nasal airway and shows velocity range for particle fluid trajectory during all flow rate. The velocity range for all flow rates is from 0 m/s to 15.4882 m/s. Velocity fluid particle trajectory in healthy, post minor FESS and post major FESS model for all flow rates (5L/min, 12L/min and 30L/min) were shown in **FIGURE 4.** Generally, air flow velocity for all flow rate decrease as the distance from nostril increase, due to the increment in flow resistance cause by the changes in nasal cavity structure. However as the flow enter turbinate area, air flow velocity in healthy model is higher compared to other models and the lowest was in post major FESS model. At the uncinate process, air flow velocity in post major model was the highest and this happen due to the removal of uncinate process at nasal cavity.

Healthy model at all flow rate in **FIGURE 4** shows inhaled air do not enter the paranasal sinuses which is similar to clinical study done by Nayak(6). However in both post FESS model, the inhaled air enter paranasal sinuses, flow enter maxillary sinuses in post minor FESS. Nevertheless the inhaled flows enter the maxillary sinuses and the frontal sinuses in post major FESS model. In normal and healthy condition, air flow through paranasal sinuses only during exhalation due. During inhalation, uncinate process acts as a border to prevent contaminated air from entering the paranasal sinuses. During exhalation, uncinate process was opened to allow exhaled air into the paranasal sinuses. The uncinate process removal in both post FESS will expose the paranasal sinuses to contaminated inhaled air. Flow percentage through the paranasal sinuses were higher in the post major FESS and the possibilities of sinusitis infection reoccurrence is higher in post major FESS compared to post minor FESS.

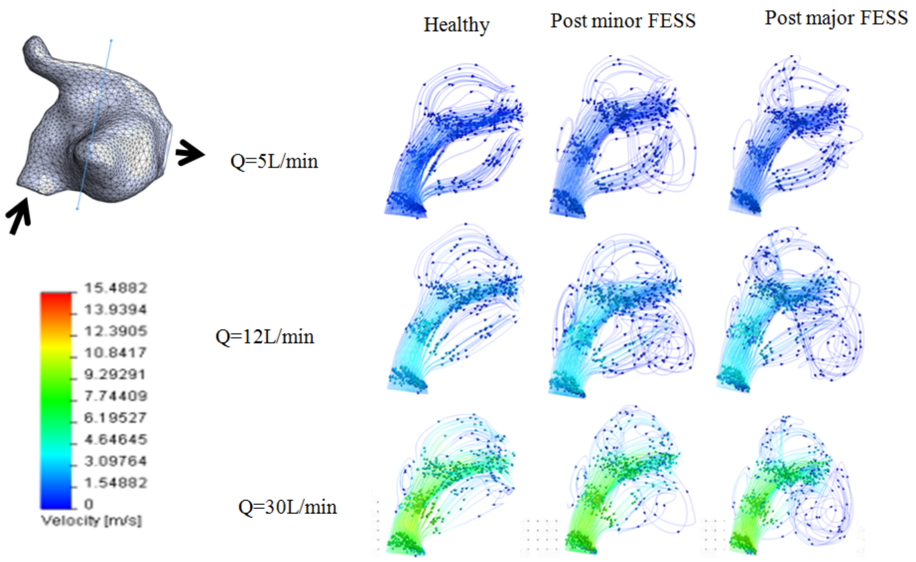


FIGURE 4 Fluid particle trajectory for healthy, post FESS minor and post FESS major actual 3D model.

CONCLUSION

This study investigates the effect of uncinate process removal to fluid flow behavior. The results show that smooth flow was observed at paranasal sinuses area which indicates successful surgical process. The uncinate process removal in both post FESS surgery expose the paranasal sinuses to contaminated inhaled air.

ACKNOWLEDGMENTS

This research was supported by grant number 79415 from the Faculty of Medical Engineering and Health Science of Universiti Teknologi Malaysia

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