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ANL-2422; No. of Pages 7
ARTICLE IN PRESS
Auris Nasus Larynx xxx (2018) xxx–xxx
Contents lists available at ScienceDirect
Auris Nasus Larynx
journal homepage: www.elsevier.com/locate/anl

Effects of nasal septum perforation repair on nasal airflow: An analysis using computational fluid dynamics on preoperative and postoperative three-dimensional models

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ARTICLE INFO

Article history:
Received 23 December 2017
Accepted 27 February 2018
Available online xxx

Keywords:
Nasal septal perforation
Airflow evaluation
Numerical simulation

ABSTRACT

Objective: The purpose of this research is to examine the changes in nasal airflow dynamics before and after the nasal perforation repair.
Methods: Three dimensional (3D) models of the nasal cavity before and after septal perforation repair was reconstructed using preoperative and postoperative computed tomography (CT) images of a patient. The numerical simulation was carried out using ANSYS CFX V15.0. Pre- and post-operative models were compared by their velocity, pressure (P), pressure gradient (PG), wall shear (WS), shear strain rate (SSR) and turbulence kinetic energy (TKE) in three plains.
Results: In the post-operative state, the cross flows disappeared. In preoperative state, there were areas showing high PG, WS, SSR at the posterior border of the perforation, which exactly correspond to the area showing erosive mucosa on endoscopic inspection of the patient. In postoperative state, such high PG, WS and SSR areas disappeared. High TKEs also disappeared after surgery.
Conclusion: The effects of septal perforation repair on airflow dynamics were evaluated using computer fluid dynamics (CFD). High WS, PG and SSR observed at the edge of the septal perforation may be related to the clinical symptom such as nasal bleeding and pain. TKE was considered to cause nasal symptom.

1. Introduction

Nasal septal perforation can be caused by septal surgery, hemostat to nasal bleeding, tumor removal in the septal area, excessive nose picking, and cocaine use. Patients may have a variety of symptoms, such as nasal bleeding, crust formation, nasal stuffiness and whistling noise. These symptoms are irritating for the patients and they are sustained until the defect is corrected [1,2]. The mechanisms underlying the nasal symptoms in septal perforation have not been fully elucidated.

Some reports have shown that septal perforation causes abnormal airflow by using a computer simulation of the airway [3–6], but all these simulations were performed using a virtual perforation. We also reported a preliminary study regarding the effects of septal perforation repair on nasal airflow dynamics [7]. In the study, we used pre-operative model from real CT but post-operative model with a virtual repair on the computer, because of the technical difficulty to compare two 3D taken in the different times.

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https://doi.org/10.1016/j.anl.2018.02.006
0385-8146/

Please cite this article in press as: Nomura T, et al. Effects of nasal septum perforation repair on nasal airflow: An analysis using computational fluid dynamics on preoperative and postoperative three-dimensional models. Auris Nasus Larynx (2018), https://doi.org/10.1016/j.anl.2018.02.006

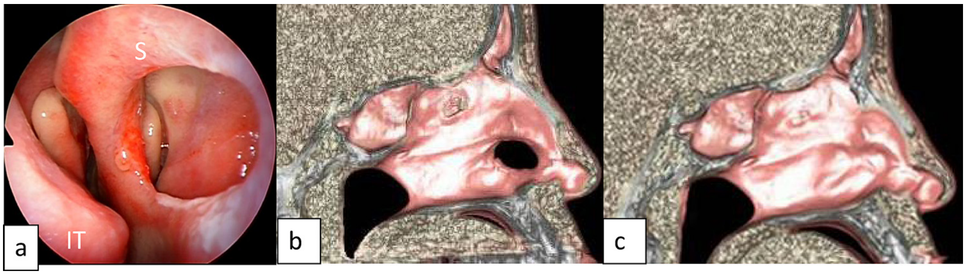

Fig. 1. a: Pre-operative state of nasal septal perforation. S: Septum, IT: inferior turbinate. b: Reconstruction model of preoperative state. c: Reconstruction model of postoperative state. This figure was reprinted from [7] with permission from Springer Nature.

In the current study, we analyzed the effects of nasal septum perforation repair on more precise and real pre- post-operative models.

2. Materials and methods

2.1. Patient

A 51 year-old female patient visited our hospital complaining of repetitive nasal bleeding, nose stuffiness and crust formation. During the nasal examination, a perforation 20 mm in diameter was found in the anterior nasal septum (Fig. 1a, b).

The mucosa of posterior end of perforation was erosive and had crust formation.

All of her symptoms were thought to be related to the septal perforation, and repair surgery was performed. The procedure started with the elevation of bilateral mucosal flaps under an endoscopic view. A releasing incision was made across the nasal floor on one side and across the lateral cartilage on the other side. The flaps were slid up- and down-ward, respectively. The perforation is then sutured. After surgery, all symptoms apparently resolved, given that the patient had no more symptoms when she was evaluated 12 months after surgery. The effect of nasal perforation repair on three-dimensional airflow was evaluated on the model based on CT data from this patient.

2.2. Model generation

A realistic three dimensional (3D) model of the nasal cavity with paranasal sinus of the patient was reconstructed using preoperative and postoperative CT images of 0.5 mm slice thickness. The data was transferred by DICOM data, and the nasal geometry was determined using MIMICS 15.0 (Materialise JAPAN Tokyo, Japan). The geometry was meshed using ICEM-CFD (ANSYS, Inc. Canonsburg, PA, USA), and the numerical simulation was performed using ANSYS CFX V15.0 (ANSYS, Inc. Canonsburg, PA, USA). For the ICEM-CFD simulation, the flow was assumed to be incompressible, in a quasi-state and at a temperature of 25 °C. To account for the possible existence of turbulence, κ–ε (kappa–epsilon) model was used. This model comprised about two million tetrahedral grids.

As of boundary conditions, the nasal walls were assumed to be a non-slip, rigid model. A velocity of 2 m/s airflow was applied to the outlet surface, and zero gauge pressure was applied to the pressure inlet as atmospheric pressure (Fig. 2).

2.3. Analysis

Pre- and post-operative models were compared for the stream line velocity, pressure (P), pressure gradient (PG), and wall shear (WS), shear stress transport (SSR) and turbulence kinetic energy (TKE) in three planes.

3. Results

The velocity of pre- and post-operative state in the stream line view is shown in Fig. 3. In the pre-operative state, air flow passes through across the septal perforation to another side. The maximum speed was recorded 5.5 m/s at the right nostril. In the post-operative state, the cross flow disappeared. The maximum post-operative speed was 4.5 m/s, which was recorded at the left nostril. As outlet size of our model is 6 cm^2, 5.5 m/s is equal to 33 cm^3/s.

Stream lines bound to the olfactory cleft area were found same manner in both state.

The pressure level is shown in Fig. 4. High pressure point was found in posterior wall of perforation in pre-operative

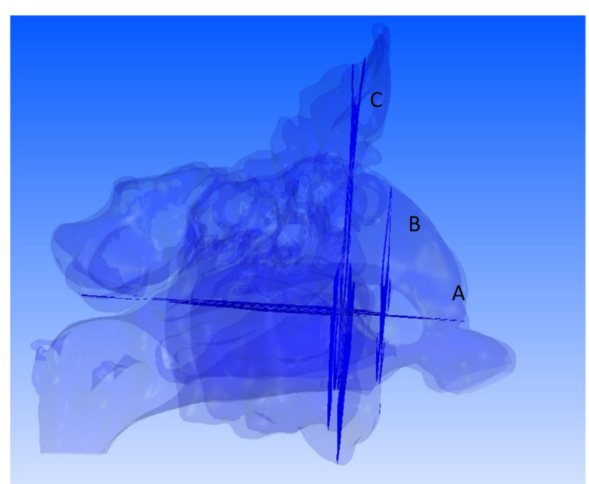

Fig. 2. The three planes that were evaluated. a: Parallel plane to Frankfurt plane crossing center of septal perforation. b: Perpendicular plane to Frankfurt plane crossing center of septal perforation. c: Perpendicular plane to Frankfurt plane crossing the olfactory area.

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