Numeric Simulation of the Upper Airway Structure and Airflow Dynamic Characteristics After Unilateral Complete Maxillary Resection

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This study investigated upper airway aerodynamic characteristics of patients who underwent maxillectomy using three-dimensional reconstruction and computational fluid dynamics. The results revealed the generation of low-velocity vortices throughout the entire maxillary defect during respiration. The nasal structure on the nonsurgical side changed postsurgically, possibly due to the pressure gradient between the defective and healthy side. The bilateral disturbed airflow patterns are believed to be the cause of common symptoms. The numeric simulation technique could be used as a potential method to understand upper airway morphology changes and respiratory functions, thus guiding the fabrication of prostheses. *Int J Prosthodont 2013;26:268–271. doi: 10.11607/ijp2970*

Nasal dryness and crusting are common complaints from patients with maxillectomy defects. These symptoms are attributed to changes of upper airway structures and airflow dynamics.[1] However, there are few studies on postoperative airflow dynamics patterns. Research in this area revealed that computational fluid dynamics (CFD) can be a useful tool for evaluating nasal airflow patterns during respiration.[2] The objective of this study was to analyze the influence of postoperative upper airway structures on airflow patterns by means of numeric simulation of the airway using CFD on a three-dimensional (3D) reconstructed upper airway model.

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Materials and Methods

A 60-year-old woman with a history of maxillary right inflammatory myofibroblastic sarcoma was enrolled in the study after a complete maxillary right resection. Preoperative and 1-year postoperative computed tomography images were obtained and imported into MIMICS software (Materialise) to generate the 3D models of the upper airway (Fig 1).

Numeric simulation was performed using CFD software (ANSYS12.0–CFX, ANSYS). The airflow was assumed to be incompressible and viscous.[2,3] The RNG-based turbulence model was used in the study. The boundary conditions were defined as follows: the pressure at nostrils was defined as atmospheric and airflow was defined at the level of larynx. The authors assumed the volume was 350 mL and the respiratory rate was 15 per minute. The airflow with time-dependent variance was defined by the sine wave function.[4]

Results

Airflow separation occurred on the defective side, forming a series of spacious vortices of low velocities during both inspiration and expiration (Figs 2 and 3). The peak flow velocity was located along the upper third of the defect, and the lower velocity at the lower two-thirds (Figs 2c and 3c). The airflow in the intact nasal cavity and preoperative nasal cavity was relatively constant and followed the middle meatus. This was consistent with the results of previous studies.[2,3]

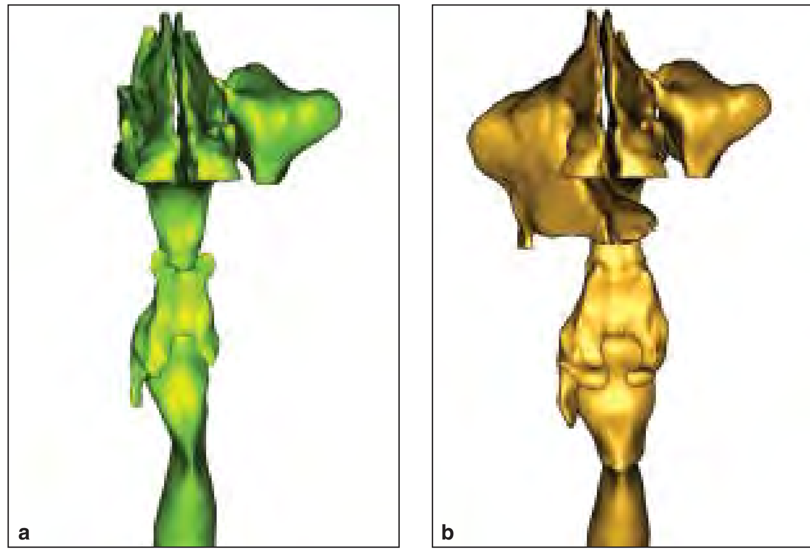

Fig 1 3D reconstruction of the patient's upper airway. **(a)** Preoperative model, **(b)** postoperative model.

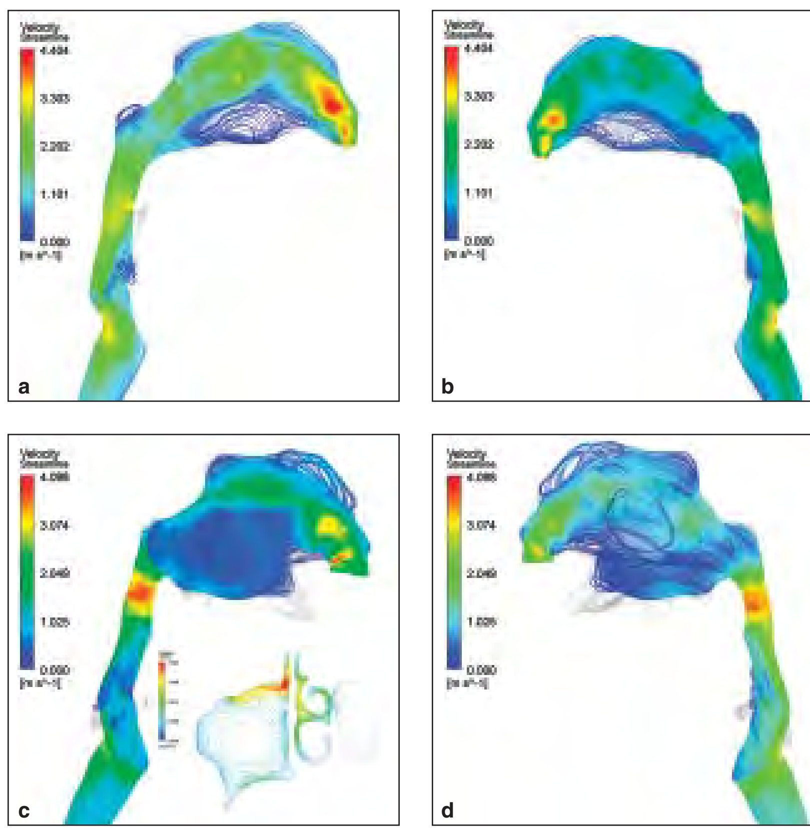

Fig 2 Inspiration period. **(a)** Right and **(b)** left nasal flow prior to surgery; note that the airflow is relatively laminar between the nostril and trachea. **(c)** Right and **(d)** left side after surgery; note the change in flow pattern preventing effective mixing with the center of the air stream.

The mean pressure in the postoperative nasal area was significantly less compared with before surgery (Fig 4). Postoperative pressure distribution at the coronal cross section demonstrated slightly higher pressure at the nonsurgical site (Fig 4a) and a return of balance toward the nasopharynx (Fig 4c).

The surface area and volume of the patient's nasal cavity before and after resection are presented in Table 1.

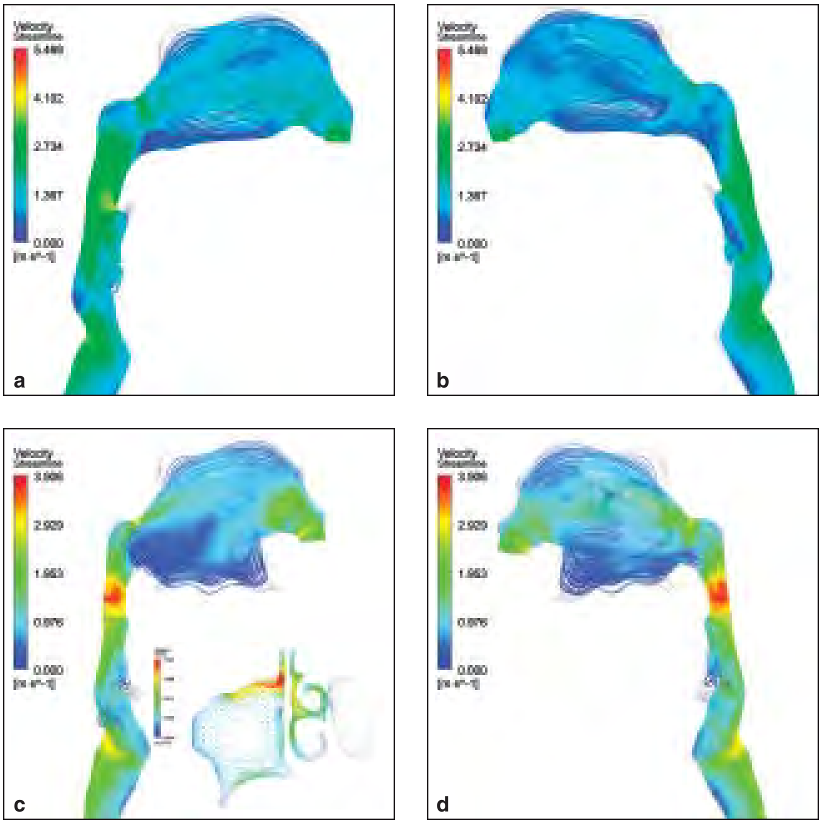

Fig 3 Expiration period. **(a)** Right and **(b)** left nasal flow prior to surgery. As with inspiration, the airflow is relatively laminar between the nostril and trachea. **(c)** Right and **(d)** left side after surgery. As with inspiration, there is a change in flow pattern preventing effective mixing with the center of the air stream.

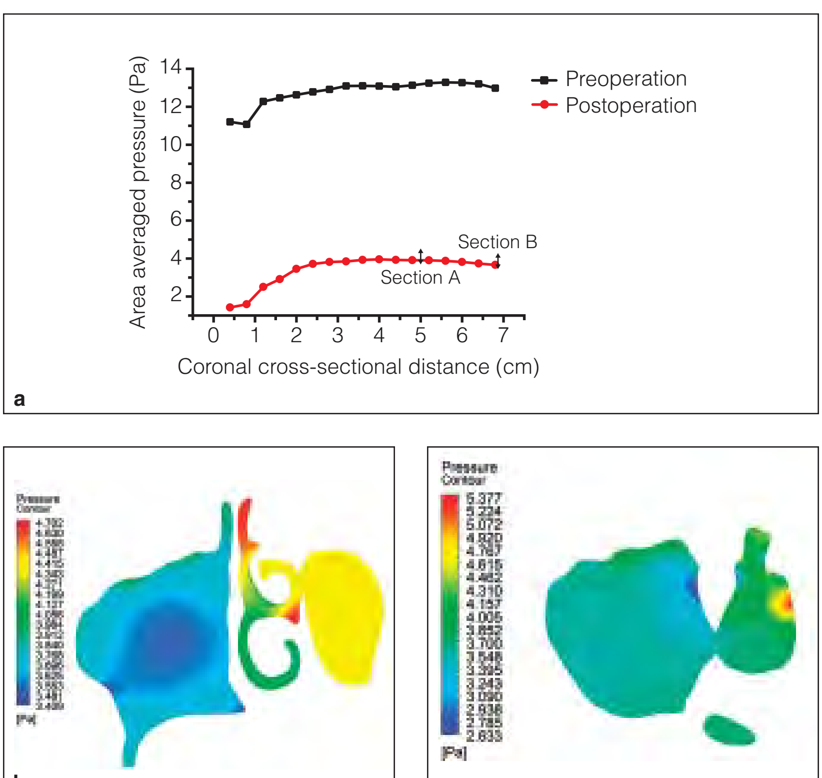

Fig 4 **(a)** Mean nasal area pressure comparison at cross-section plane 4 mm before and after surgery. Pressure contours were presented in coronal sections 50 mm from **(b)** the anterior nostril (section A) and **(c)** the beginning of the nasopharynx (section B) after surgery.

Table 1 Pre- and Postoperative Surface Area and Volume of the Nasal Cavity

Nasal cavity	Surface area (cm^2)	Volume (cm^3)
Left		
Presurgical	85.01	10.91
Postsurgical	85.75	12.69
Right		
Presurgical	83.01	10.45
Postsurgical	101.35	39.74

Discussion

An increase in nasal volume leads to an abrupt decrease of pressure on the defective side. Postoperatively, under the influence of the pressure gradient between the defective and healthy sides, the surface area and volume of the healthy nasal cavity may change so that the pressure can equilibrate between the two sides.

The enlarged nasal cavity on the defective side results in spacious vortices of low velocities, thus preventing the effective mixing of air within the center of the air stream. The removal of turbinates disturbs effective airflow distribution in the defective side. Laminar flow is prevalent, preventing strong contact between air and the sounding nasal wall. These factors result in compromised cooling and a lowering of humidity values in respiratory mucosa and of the temperature and humidity values of these patients, leading to the symptoms of nasal drying and crusting.

Given the physiologic changes after surgery, rehabilitations of patients with maxillectomy defects require considerations for functional improvement of nasal airways. Obturators have been recommended as reliable prostheses for postmaxillectomy patients; however, the height, shape, and open vs closed position of the obturator remain controversial. The CFD results in this study display higher velocity airflow along the top third of the surgical defect and lower velocity airflow along the bottom two thirds. Therefore, it is suggested that the height of the obturator does not engage the top third of the lateral wall of the maxillectomy defect and does not extend superior to the middle turbinate along the nasal septum.

Conclusions

Changes in airway structure and physiology require reconstruction with sophisticated and individualized designs, which may be facilitated by using 3D reconstruction combined with the computer-aided design/computer-assisted manufacture (CAD/CAM) technique. Further studies need to involve airflow mitigation or aggravation patterns with obturators of different heights and shapes and sound conduction patterns with and without an obturator by means of the numeric acoustics technique. With the increase in surgical reconstruction with a vascular free flap based on CAD/CAM and implants for the maxillectomy patient,[5] the influence of vascular flap position and size and shape of grafted tissue on nasal airway function needs to be further investigated. Multiple approaches may be helpful for analyzing the pathophysiologic changes in these patients in order to guide their prosthesis fabrication and reconstruction.

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