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Numerical analysis of the influence of nasal surgery on the nasal heating function

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ABSTRACT

To study the influence of nasal surgery on nasal heating function. Three-dimensional finite element nasal models were based on the computed tomography data of a normal nose and the preoperation and postoperation data of 2 noses (i.e., nose A and nose B) with a deviated nasal septum. Numerical simulations primarily focusing on the airflow distribution and the airflow temperature were used to study the influence of nasal surgery on the nasal heating function of inhaled airflow. The airflow distribution and heating characteristics of these models were obtained by comparing the simulation results of the normal nasal cavity with the results of the diseased nasal cavity and by comparing the preoperative and postoperative nasal cavities. The noses before surgery had a larger surface area and a smaller volume than after surgery. After the operation, the heating effect on the airflow decreased significantly in nose A and remained mostly unchanged in nose B (which had an adhesion between the inferior turbinate and nasal septum). The surface area and the volume of nasal airway are correlated with the nasal heating function. The nasal turbinate should not be resected excessively for treating a nasal obstruction caused by compensatory nasal turbinate hypertrophy. The width of the nasal airway should be maintained within a certain range after surgery. An excessively wide airway could affect the nasal heating function.

KEYWORDS

Finite element method;
Nasal heating function;
Nasal surgery;
Numerical simulation.

INTRODUCTION

The nose acts as an air conditioning device. It primarily performs the functions of warming, humidifying, and removing particulate and gaseous pollutants from inspired air before the air enters the lung. Nasal airway structural changes caused by nasal diseases will affect airflow distribution[1,2] and nasal functions[3] Nasal surgery also changes the nasal structure. It is necessary to explore how nasal structural changes affect the nose in accomplishing its functions. To evaluate changes in clinical symptoms after surgery, Lindemann[4] studied the influence of surgical closure of septal perforations on intranasal temperature. Intranasal temperature was measured at the area of the nasal valve and the anterior turbinate before and after surgical closure. Ten patients with septal perforations were included in this study. The value of the temperature at the anterior turbinate area was significantly higher postoperatively. At different locations in the nasal cavity, Keck[5] measured the temperature of 23 volunteers with a miniaturized thermocouple sensor during respiration. The temperature of the anterior nasal segment airflow was more greatly increased during inspiration. This temperature increase was less prominent in the posterior segment, despite the longer distance. Because of the inaccessibility of the nasal cavity, computational models of nasal transport characteristics were recently developed to compensate for limited *in vivo* data.

The objective of this research is to investigate the influence of nasal surgery on nasal functions such as the heating of inspired air. Three-dimensional models of a normal nasal cavity and 2 nasal cavities with a deviated nasal septum were established before and after the operation. Numerical simulations for inspiratory airflow were performed by using the finite element method under steady-state conditions. Simulation results were analyzed to determine the influence of nasal surgery on the nasal heating function.

METHODS

The computed tomography (CT) scans of the nasal passages of 2 patients' noses (nose A and nose B) were obtained before surgery and 4 months after surgery. This project was approved by the second affiliated hospital of dalian medical university ethics commottee and the patients. Nose A had an atrophic turbinate in the left nasal cavity and a compensatory hypertrophic turbinate in the right nasal cavity. In nose B, the opposite condition was observed. The nasal passageway of nose A was narrow, but had improved 4 months after surgery for a fracture of the inferior turbinate. Nose B had an adhesion between the inferior turbinate and nasal septum; this was improved by inferior turbinectomy surgery.

Three-dimensional nasal models of the normal nasal cavity and the 2 patients' nasal cavities before and after operations were established, based on the 1-mm spacing CT scan images. As Figure 1 shows, the nasal cavity models were meshed and the meshing quality of the tetrahedral elements was good without any distorted elements. Steady-state inspiratory air and heat transport were simulated by using the finite element method (ANSYS). A no-slip flow velocity on the passage surfaces was assumed for the boundary conditions. At the nostril, a pressure condition (P) of 10, 1325 Pa (which equals the standard atmospheric pressure) was specified. At the nasopharynx, the velocity was specified based on a volumetric flow of 600 mL/s and the cross-sectional area of nasopharynx. The volumetric flow of 600 mL/s, which determined the turbulent flow regime, [6-8] is a high but reasonable value that is regarded as the Chinese respiration flowrate value.[9] The k-ω turbulence model was used to simulate the turbulence flow in the nasal cavity.

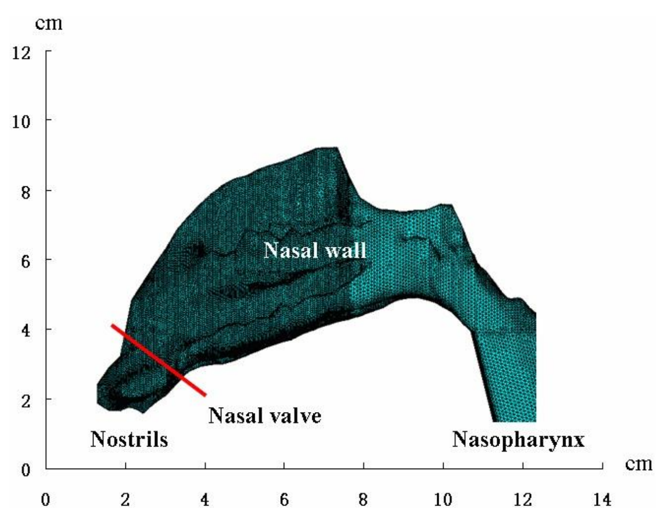

Figure 1 : The three-dimensional finite element model of a normal nasal cavity.

Lindemann[10] measured the mucosal temperature at several intranasal sites in 15 healthy volunteers at room condition (25°C ± 1°C at 30% ± 4% relative humidity). Based on the measurement by Lindemann and on a report by Garcia, [11] the boundary conditions of temperature were defined for the simulation of heat transport in the nasal cavity. The temperature of ambient air was set at 25°C at the nostrils. During inspiration, the mucosal temperature was 32.6°C for the nasal cavity proper and 34.4°C for the nasopharynx. At the end of inspiration and expiration, the measurement by the Lindemann method showed that the temperature values were significantly lower in the nasal valve area and the anterior turbinate area than in the nasal vestibule. Thus, an average value of 33.5°C was adopted for the nasal vestibule.

RESULTS

The volumes and surface areas of the models were calculated for each nasal cavity from the nostrils to the end of the septum (TABLE 1). The noses presurgically had a larger surface area and a smaller volume than they did postsurgically. The surface area and volume of nose B changed slightly, whereas the volume of nose A apparently increased (by approximately 33% in the left cavity and 72% in the right cavity). After the operation, the heating effect on the airflow decreased significantly by a temperature drop of 1.2°C in nose A (especially in the right cavity). After the operation on nose B, the effect on airflow heating also changed (<0.5°C).

the posterior airway (Figure 2). In contrast, the heat flux plot showed a different scenario in the nasal wall of nose B. As Figure 2D shows, the heat flux was higher in the anterior region of cavity and middle nasal meatus. We believe that the adhesion between the anterior region of inferior turbinate and nasal septum obstructed the inferior part of the common nasal meatus, the main airflow passed through the middle nasal meatus in the nasal cavity, the mucous membranes of the middle nasal meatus primarily performed the heating function, and the inferior part of common nasal meatus was ineffective for performing the heating function. This was equivalent that the airflow heating area was reduced. The decreased surface area led to a higher heat flux per unit area in the middle nasal meatus in nose B than in the normal nose. As Figure 3 shows, the increased rate of airflow temperature is higher preoperatively in the posterior part of right cavity of nose B than in the normal nose. After inferior turbinectomy surgery, both sides of the nasal passages in nose B became wider (Figure 4), compared to the normal nose, and the airflow through both sides of the nasal passages was in equilibrium. The percentage of airflow that passed through the right cavity increased from 37% to 55.4%. The postoperative heat flux distribution in nose B was similar to that of nose A (Figure 2). Before the operation, the mucosal surface of the middle nasal meatus and inferior turbinate would simultaneously heat the air when it flowed through the nose. However, the widened nasal passages and increased airflow after the operation would cause the airflow in the center of the airway to have insuffi-

TABLE 1 : Simulation results of heating and humidification in the preoperation and postoperation models of the 2 patients

	T (ΔT) (°C)		Area (cm^2)		Volume (cm^3)		Area/volume	
	Left cavity	Right cavity	Left cavity	Right cavity	Left cavity	Right cavity	Left cavity	Right cavity
Normal	32.1 (7.1)	32.0 (7.0)	75.5	75.3	11.9	12.7	6.3	5.9
Patient A preoperative	32.6 (7.6)	32.6 (7.6)	103.2	99.0	13.2	11.1	7.8	8.9
Patient A postoperative	32.2 (7.2)	31.4 (6.4)	91.2	93.5	17.6	19.1	5.2	4.9
Patient B preoperative	30.4 (5.4)	31.1 (6.1)	87.6	90.2	12.6	13.8	7.0	6.5
Patient B postoperative	30.9 (5.9)	31.2 (6.2)	81.8	84.6	14.9	15.7	5.5	5.4

ΔT = change in temperature; T =temperature.

To examine the effect of structural changes on heat function, we compared heat flux through the nasal wall of noses A and B with heat flux of the normal nose. The heat flux of the normal nose was higher in the anterior region of nasal cavity (Figure 2). This is why airflow temperature increased rapidly in the anterior portion of the nasal cavity (Figure 3). The heat flux distribution on the nasal wall of nose A (Figure 2) was preoperatively similar to the heat flux of the normal nose. However, the preoperative airflow temperature rose higher in nose A than in the normal nose (Figure 3). After the surgery for the fracture of the inferior turbinate, the nasal airway became wider (Figure 4). The high heat flux area on the nasal wall of nose A postoperatively extended to cient time to become heated in the right nasal cavity. In nose B, the postoperative airflow temperature difference was similar and the heat flux per unit area in posterior part of nasal wall was higher than the preoperative values (Figure 2). Figure 3 also shows that the rising trend in the temperature in noses A and B postoperatively was similar to the trend in the normal nose. This finding could also prove recovery of the nasal functio

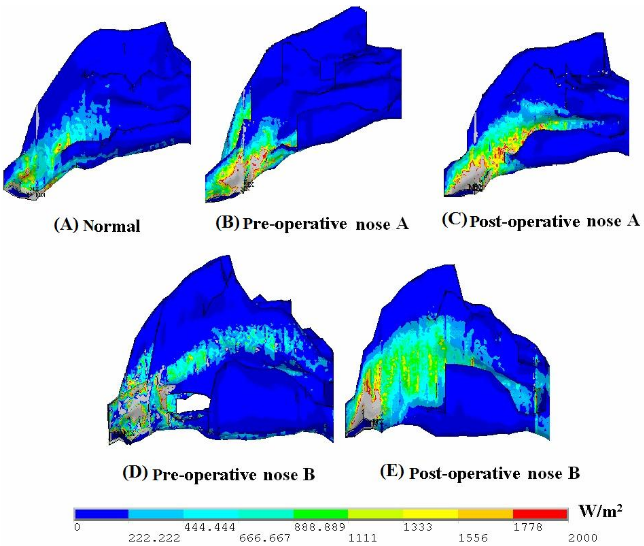

Figure 2 : Heat flux (W/m²) from the nasal wall to the inhaled airflow in (A) the normal nose, (B) nose A, preoperative, (C) nose A, postoperative, (D) nose B, preoperative, and (E) nose B, postoperative.

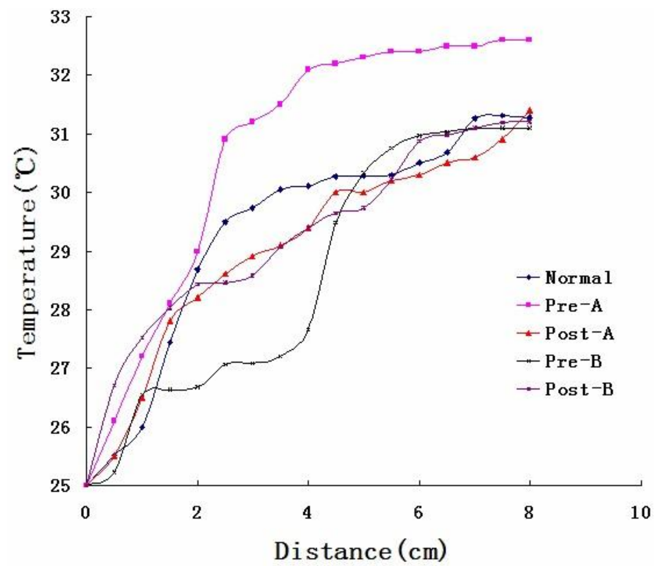

Figure 3 : The warming streamlines in the middle airway of the nasal models.

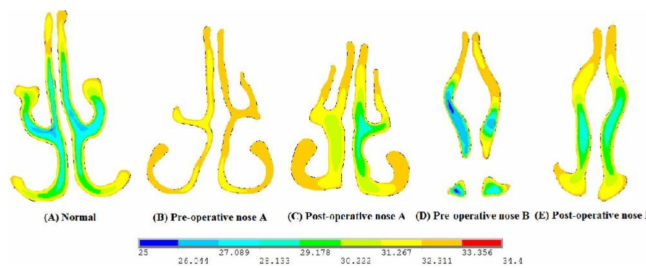

Figure 4 : Temperature (°C) distribution in (A) the normal nose; (B) nose A, preoperative; (C) nose A, postoperative; (D) nose B, preoperative; (E) and nose B, postoperative.

DISCUSSION

The temperature of inhaled air under normal conditions was lower than the temperature of the nasal mucosa. When airflow passes through the nasal cavities, the transportation of heat is inevitable. A significant temperature difference between the mucosal surface and the entering air causes a high heat flux in the anterior portion of the nasal cavity. The exchange of heat occurs primarily in the anterior portion of the cavity in the healthy nose[4,5]. After heat exchange in the anterior portion of the cavity, the temperature difference between the mucosal surface and the air decreases. The exchange of heat per unit area was reduced in the posterior portion of the nasal wall; this trend was consistent with the findings of the study by Garcia[11] The computational result of this normal model showed that the air temperature is 25.3°C in the nasal vestibule, 29.2°C in the nasal valve, and 32.0°C in the nasopharynx during inspiration. These values were close to the measurements of 25°C ± 1.5°C, 29.2°C ± 2.5°C, and 31.9°C ± 0.8°C, respectively, obtained by Keck[5]

The heat exchange occurred at the surface of nasal mucosa. Therefore, a large surface area was beneficial for the nasal heating function. The data also showed a correlation between the nasal cavity volume and the nasal heating function. In general, the area/volume value was larger, the nasal airway was narrower, and the airflow heating effect was greater[11,12] The surgery on nose A increased the left and right cavity volume by 33.3% and 41.7%, respectively, and decreased the surface area by 11.6% and 5.6%, respectively, which then decreased the heating efficiency of the inspired air. Therefore, the airflow temperature at the 2 postnares of nose A was lower before surgery than after surgery.

Nose B was a special case. The nasal cavity volume of nose B increased and the surface area decreased after surgery, but the efficiency of heating the inspired air increased in the left nasal cavity and remained almost unchanged in the right nasal cavity. This was because an obstruction in the inferior nasal passage caused the main airflow to pass through the middle passage, and the effective heating area of the nasal surface for airflow was reduced. The airflow temperature at the postnares was consequently lower than the normal value, despite the area/volume value. After surgery the airway was wider, the volume was larger, and the surface area was only changed slightly (6.6% left and 6.2% right). However, the whole surface area was effectively a heating area. After the operation, the nasal heating function was performed by the whole nasal airway instead of only by the middle nasal airway as it had been before the operation. Therefore, the heating efficiency of nose B after surgery may be higher or similar to that before surgery. From the previous results, it is obvious that a narrow nasal airway—in contrast to a wide nasal airway—is conductive to the nasal heating function, but is not conductive to respiration. Therefore, nasal surgery should maintain the nasal airway at a suitable width.

CONCLUSION

Simulations for heating airflow were performed within several computational fluid dynamics (CFD) nasal models to study the influence of nasal surgery on the nasal heating function of inhaled airflow. The anterior part of nose is the main heating area for inhaled airflow. The parameters of the surface area and the volume of the nasal cavity would affect the performance of the nasal heating function. Nasal surgery would maintain the nasal airway at a suitable width. This study provides some reference data for clinical problems and will contribute to further research on the influence of nasal cavity structure on nasal function.

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