MCB, vol. 16, supplemental 1, pp.83-84, 2019

Numerical Simulation of the Granulation Tissue Resection Operation in Human Trachea

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Abstract: To quantitatively analyze the aerodynamic changes in patient's trachea after the resection operation of hyperplastic granulation tissue, computational fluid dynamic (CFD) method was utilized to perform the simulation. Firstly, three dimensional finite element model of the patient's trachea before and after surgery were reconstructed based on CT images; secondly, the numerical simulation based on CFD method was performed to investigate the changes in aerodynamic changes in patient's trachea after excision. Results indicated that the dyspnea symptom was largely alleviated after the removal surgery, the abnormal morphology was obviously improved and the resistance of trachea was decreased significantly. Present research also demonstrates that CFD methods can be used to quantitatively evaluate the postoperative effects of the granulation tissue resection operation.

Keywords: Trachea, granulation tissue, resection operation, computational fluid dynamics.

1 Introduction

The hyperplasia of granulation tissue is one of the most common complications of airway incision surgeries. It can lead to the suffocation of patients or even death [Grillo, Donahue and Mathisen (1995)]. So far, the granulation tissue is clinically removed mainly by means of laser elimination or radiofrequency burning. However, the quantitative evaluation method before resection operation is still lacking for the reason of limited factors such as examination methods [Mukhopadhyay, Farver, Vaszar et al. (2012)].

2 Material and method

2.1 Geometry and meshes

Firstly, CT scan was performed and the images were imported into Mimics17.0 to reconstruct the 3D numerical model of the patient's trachea. Secondly, the numerical model was imported into ANSYS ICEM for meshing. Finally, the ANSYS-FLUENT was used to solve the problem.

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2.2 Governing equations

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho\overline{u_i})}{\partial x_i}=0 \quad (1)$$

$$\frac{\partial\ (\rho\overline{u_i})}{\partial t}+\frac{\partial(\rho\overline{u_i}\,\overline{u_j})}{\partial x_j}+\frac{\partial\overline{p}}{\partial x_i}=\frac{\partial}{\partial x_j}[\mu_{eff}\overline{S_{ij}}] \quad (2)$$

Where $i, j = 1, 2, 3,\ \rho,\ t, \overline{u},\ \bar{p},\ \bar{S}_{ij}$ and μ_{eff} represents the air density, time, airflow velocity, pressure, rate tensor of turbulent viscosity strain and effective viscosity coefficient, individually. $\mu_{eff} = \mu + \mu_t$, $\mu_t$is the turbulent viscosity:

$$\mu_t=[C_S(\prod_{i=1}^{3}\Delta x_i)^{1/3}]^2\sqrt{2\overline{S}_{ij}\overline{S}_{ij}},\overline{S}_{ij}=\frac{\partial\overline{u}_i}{\partial x_j}+\frac{\partial\overline{u}_j}{\partial x_i} \quad (3)$$

where Δx is the mesh size, C_S is the Smagorinsky constant.

2.3 Boundary conditions

Air is assumed to be an incompressible Newtonian fluid ($\rho = 1.205\, kg/m^3,\ \mu = 1.83 \times 10^{-5}\, kg/m \cdot s$) and the flow is assumed to be turbulent. The airflow velocity variations were used as the inlet boundary condition and the zero pressure was used as the outlet boundary condition.

3 Results

The flow field of the patient's trachea changed significantly after the resection operation. High pressure areas were formed on the inflow surface of the granulation tissue with the low pressure areas on both sides before resection. However, the local negative pressure areas were obvious and the pressure gradient tended to be flat after resection.

4 Discussion

In general, numerical simulation based on CFD methods can provide more theoretical basis for surgical plan and evaluate the postoperative effect of the resection operation quantitatively.

Acknowledgement: We acknowledge the National Natural Science Foundation of China for supporting the project via the grant number 11472062 and 11002034.

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