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Numerical Analysis of the Flow and Particle Pattern in a Realistic Human Nasal Cavity

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A numerical study of the dispersion and deposition of liquid drugs sprayed into the nasal airway is presented. A realistic three-dimensional model of the human nasal airway is constructed from computed tomography (CT) scans. Unsteady Eulerian-Lagrangian equations are used to simulate the transitional laminar-turbulent airflow and the micro-particle dispersion and deposition in a realistic human nasal airway. The results of two different numerical volume grids show that the coarse mesh is not suitable to capture the flow characteristics. The simulation shows that most of the particles deposit in the anterior and posterior regions of the nasal cavity, which is due to the changes in flow direction in this area.

1 Introduction

The study of the aerosol dispersion and deposition in the human nasal passage is relevant in controlling the inhalation of toxic particles in the air and administration of therapeutic aerosols for patients suffering chronic rhinosinusitis, asthma, allergies, diabetes, or migraine headaches. Recently, drug delivery via the nasal passage has become an alternative approach to oral drug administration since this approach has advantages such as quick effect, local administration, and minimal side effects. In the present study, the airflow and particle dispersion and deposition in a realistic human nasal cavity is studied numerically.

2 Methodology and Numerical Methods

The CT images in .DICOM format are obtained with a slice thickness of 1 mm. Subsequently, identification of the region of interest, artifacts removal, segmentation, extraction of the .STL file and generation of the triangulated surface are preformed by using the software packages of ImageJ, meshLab, NeuRA2 [1]. The software ICEM-CFD Ansys 11.0 is used to generate the tetrahedral volume grid.

A large eddy simulation (LES) using the solver "pimpleFoam" of OpenFOAM 4.0 with the Smagorinsky sub-grid scale model is coupled to the Lagrangian parcel library in order to solve the incompressible gas-phase equations and the Lagrangian particle equations. The simulations are performed for two volume grids with 0.5 [2] and 15 million tetrahedral grid cells using a moderate steady inhalation rate of 7.5 L/min over 2 s. 10,000 mono-disperse particles with a diameter of 10 µm are injected uniformly at the nostrils with the corresponding gas initial velocity over the first time step. The computations are performed on bwUniCluster using 256 processors with a time step of 10^{-5} s for both gas and particle phases to simulate a real process of two seconds. For the simulations with 0.5 and 15 million grid cells, the clock times are approximately 11 and 60 hours, respectively.

3 Results and Discussion

The study shows that 15 million grid cells resolve the flow characteristics such as vortices and gas velocity which are not captured by the coarser mesh. Figure 1 depicts the contour plots of the gas velocity at different coronal planes between the nasal valve (slice 1) and the nasopharynx (slice 8) for the finer grid. Figure 2 illustrates the right view of the particle deposition pattern. The particle concentration is high in the nasal valve, the nasopharynx, and in parts of the nasal septum.

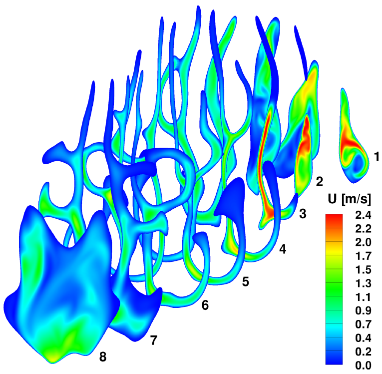

Figure 1: Gas velocity at different cross sections.

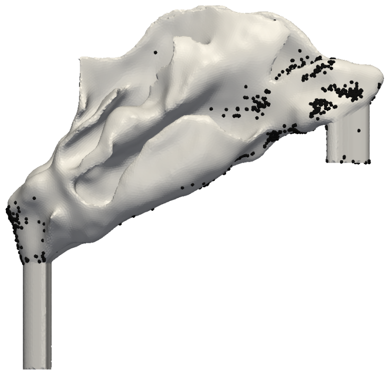

Figure 2: Particle deposition pattern.

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References

[1] Cui, X.G.. "CFD Study of the Flow Field and Particle Dispersion and Deposition in the Upper Human Respiratory System" PhD Dissertation, Heidelberg University (2012).

[2] Farnoud, A., X.G. Cui, I. Baumann, and E. Gutheil. "Numerical Analysis of the Flow and Particle Pattern in the Human Nasal Cavity" 9th International Conference of Multiphase Flow, Florence, Italy (May 2016).