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Computer Fluid Dynamics Analysis for Aerosol Transport Phenomena During Exhalation Through Nose

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Abstract

Aerosol medicine exhalation through the nose (ETN) is one of promising and comprehensive treatment methods for Eosinophilic Chronic Rhinosinusitis (ECRS) with asthma. In this treatment, the patient inhales aerosol of inhaled corticosteroid (ICS) medicine from mouth using portable inhaler. Then a part of the aerosol still floats and remains in upper airway. When the patient exhales inhaled air through the nose, the aerosol is effectively transported on the walls of middle meatus and olfactory fissure. The mechanism of how ETN improves ECRS with asthma is still controversial even though ETN gets a lot of attention as a treatment method for ECRS with asthma. This study performed Computational Fluid Dynamics (CFD) analysis for the transport phenomena of aerosol medicine during exhalation period in order to evaluate the curative effect of ETN numerically. As a result of CFD analysis, ETN formed impinging flow toward upper wall of nasopharynx, subsequently complex swirl and circulation flow in the nasopharynx region. In addition, main flow of ETN passed upper region of nasal cavity. Such the tendencies affected on aerosol transport characteristics; a part of aerosol particles moved into ethmoindal sinuses. Total aerosol deposition amount during ETN depended on flow rate of exhalation. This tendency was more remarkable on the upper wall of nasopharynx.

Keywords: eosinophilic chronic rhinosinusitis, computational fluid dynamics, exhalation through nose

1. Introduction

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Aerosol medicine exhalation through the nose (ETN) is one of promising and comprehensive treatment methods for Eosinophilic Chronic Rhinosinusitis (ECRS) with asthma [1,2]. In this treatment, the patient inhales aerosol of inhaled corticosteroid (ICS) medicine from mouth using portable inhaler. Then a part of the aerosol still floats and remains in upper airway. When the patient exhales inhaled air through the nose, the aerosol is effectively transported on the walls of middle meatus and olfactory fissure [3,4]. Many patients with ECRS are able to obtain the efficacy of ETN. On the other hand, there are some patients who could not obtain the efficacy. The mechanism of how ETN improves ECRS with asthma is still controversial even though ETN gets a lot of attention as a treatment method for ECRS with asthma. According recent clinical practice research, the authors have elucidate exhalation conditions, expiratory flow velocity and exhalation period, has strongly correlation with the efficacy [4].

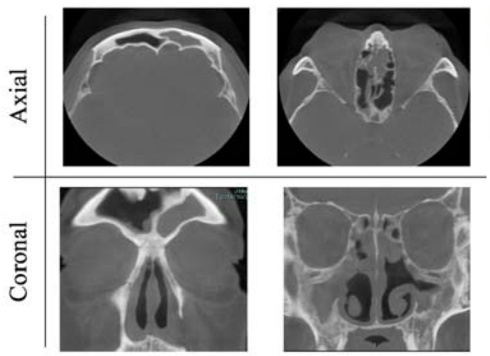

Fig. 1: CT images of a patient who suffers Eosinophilic Chronic Rhinosinusitis

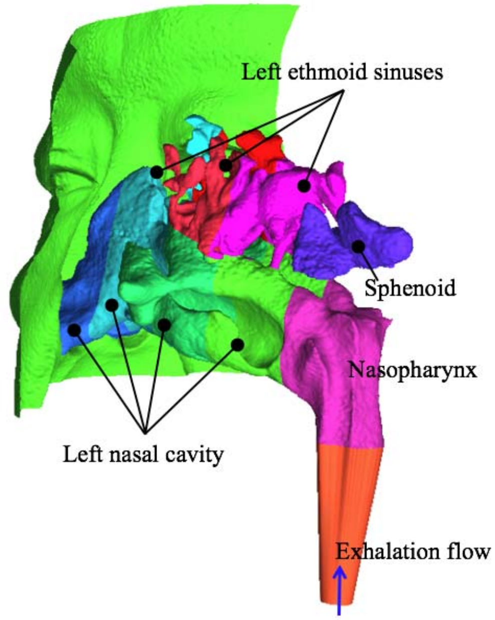

Fig.2 3D model of nasal cavity and nasopharynx airway: this model is divided by six regions; nasal cavities, nasopharynx, ethomoidal and sphenoidal sinuses.

This study performed Computational Fluid Dynamics (CFD) analysis for the transport phenomena of aerosol medicine during exhalation period in order to evaluate the curative effect of ETN numerically.

2. Case Data

A 75-years-old male, who had ECRS with asthma and a history of endoscopic sinus surgery, was selected

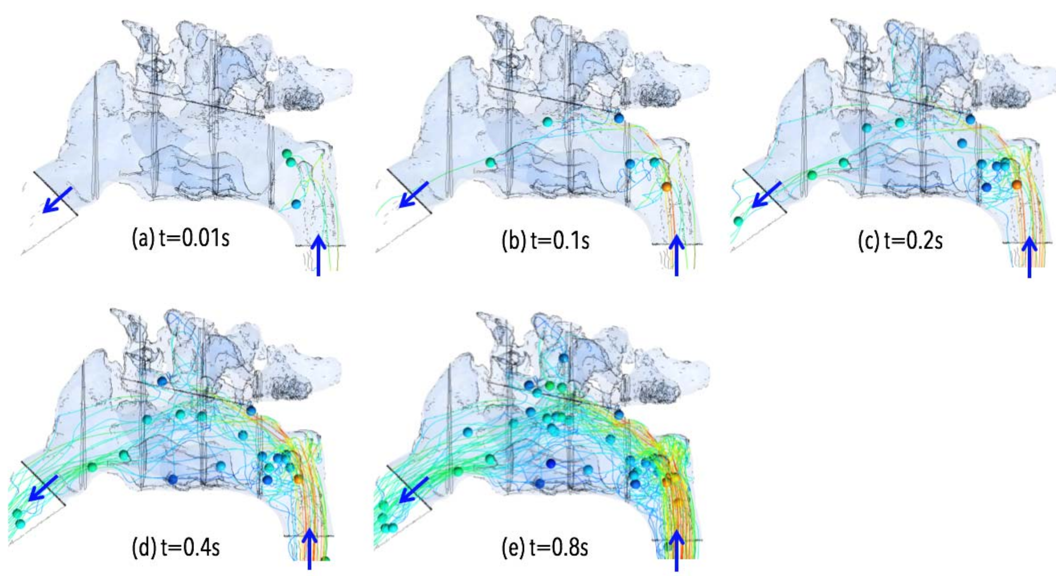

Fig. 3 Trajectories of aerosol particles in exhalation through nose; exhalation flow rate 15L/min

as an analysis case in this study. Figure 1 shows the CT images of the patient which were scanning using a multi-detector CT (Discovery ST, GE). In this case, endoscopic sinus surgery had operated and his ostium of ethomoidal sinus had been enlarged. These morphology of the patient's nasal cavity elucidate aerosol transport phenomena in nasal-pharynx region. A 3D anatomically accurate patient-specific model was reconstructed from the data obtained using multi-detector CT scanner with medical imaging software package, Mimics (Materialise Co.) [5]. The entire series was loaded into the software, and then the nasal-pharynx airway was identified in each of the axial images based on predefined threshold of 500 Housfield units relative to the surrounding tissue. Fig.2 is 3D model of the nasal-pharynx airway. This model is composed by six parts; left and right nasal cavities, nasopharynx, left and right ethomoidal and sphenoidal sinuses.

3. Computational Fluid Dynamics Analysis

The nasal-pharynx airway model was exported into CFD meshing software package, ICEM-CFD (ANSYS Co.) to generate discrete volume cells [6]. This study used both a Euler-Lagrange particle transport model for aerosol transport and a Large Eddy Simulation model for complex intranasal turbulent flow, which are able to account for the transient transport of mass and turbulent energy, and consequently, provides highly accurate predictions of the amount of flow separation under adverse pressure gradients (CFX ver.16, ANSYS) [7-9]. This study assumed that the condition of exhaling flow rate through nose set at 15 l/min and 30 l/min, respectively. These inflow condition was adopted on the pharynx. Nostrils were outlet boundary and Dirichlet pressure conditions were adopted.

4. Result and Discussion

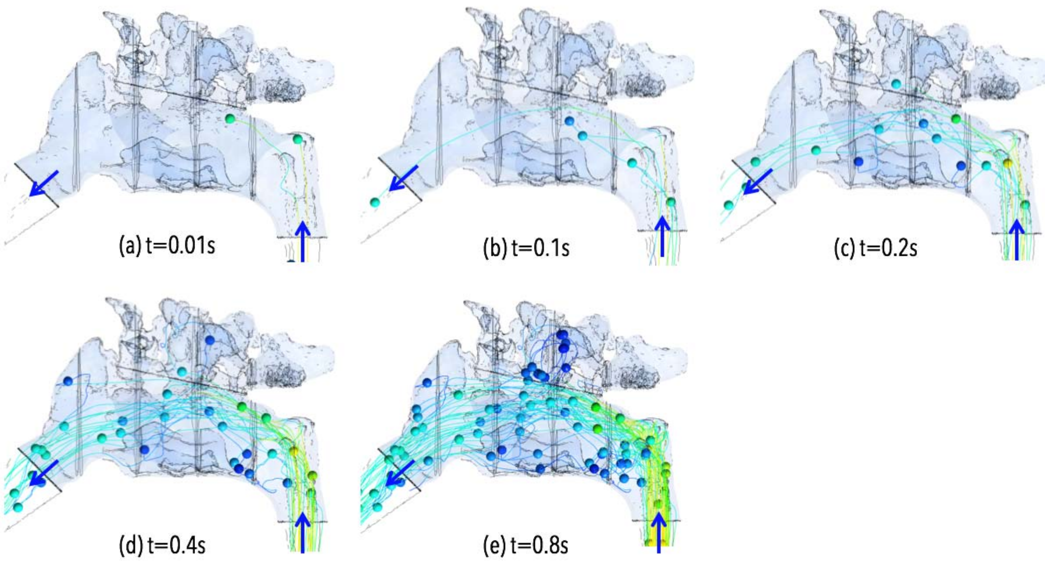

Fig. 4 Trajectories of aerosol particles in exhalation through nose; exhalation flow rate 30L/min

Figures 3 and 4 show the results of CFD analysis, trajectories of aerosol particle during ETN. From the results, ETN formed impinging flow toward upper wall of nasopharynx, subsequently complex swirl and circulation flow in the nasopharynx region. In addition, main flow of ETN passed upper region of nasal cavity.

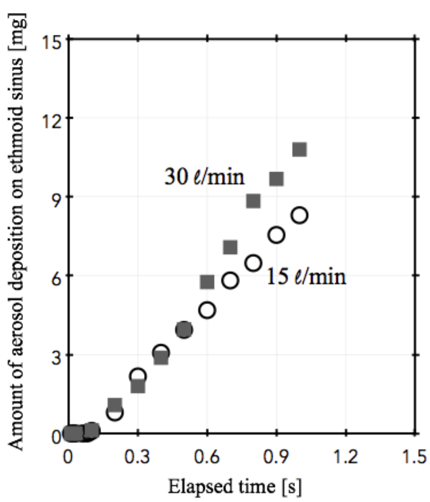

Fig. 5 Transient deposition rate in exhalation through nose.

Table 1 Distribution of aerosol particle deposition in nasal cavity and nasopharynx airway

Exhalation flow rate	Nasal cavity	Ethmoid sinus	Nasopharynx	Overall
15 l/min	9.3 %	2.3 %	6.1 %	17.7 %
30 l/min	10.3 %	3.9 %	9.2 %	23.5 %

Such the tendencies affected on aerosol transport characteristics; a part of aerosol particles moved into ethmoindal sinuses. Table 1 shows total aerosol deposition amount during ETN. The deposition characteristics depended on flow rate of exhalation. This tendency was more remarkable on the upper wall of nasopharynx. On the other hand, according with a result of transient deposition rate shown in Fig. 5, the deposition rate of aerosol on the ethmoidal sinuses did not appear strong correlation with flow rate of exhalation. These results imply that the phenomena of aerosol transport and deposition during ETN has non-stationary characteristics. In past researches concerning CFD analysis for intranasal aerosol transport, steady-state turbulent flow model had been applied as CFD model [10-13]. New finding of this study is that unsteady turbulent model, similar to the LES turbulent model adopted in this study, is needed in the further investigation for ETN.

5. Conclusion

This study performed CFD analysis for the transport phenomena of aerosol medicine during exhalation period in order to evaluate the curative effect of ETN numerically. As a result, ETN formed impinging flow toward upper wall of nasopharynx, subsequently complex swirl and circulation flow in the nasopharynx region. In addition, main flow of ETN passed upper region of nasal cavity. Such the tendencies affected on aerosol transport characteristics; a part of aerosol particles moved into ethmoindal sinuses. Total aerosol deposition amount during ETN depended on flow rate of exhalation. This tendency was more remarkable on the upper wall of nasopharynx.

6. Acknowledgement

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7. References

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