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Aerosol Deposition Characteristics During Exhalation Through Nose Treatment: Relationship between Impaction Parameter and Deposition Ratio

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Abstract. Aerosol medicine exhalation through the nose treatment (ETN) has conducted as an effective treatment for Eosinophilic Chronic Rhinosinusitis (ECRS). In ETN, the patient inhales aerosol of inhaled corticosteroid (ICS) medicine from mouth using portable inhaler. Then a part of the aerosol still floas 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. In this study, computational fluid dynamics (CFD) analysis of aerosol transport phenomena were performed based on patient CT data in order to evaluate the therapeutic effect of ETN numerically. Three cases were selected in this study, one is a patient who had ECRS with asthma and a history of endoscopic sinus surgery and the others are healthy cases. 3D anatomically accurate patient-specific models were reconstructed from the data obtained using multidetector CT scanner with medical imaging software package. 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 -300 Housfield units relative to the surrounding tissue. The nasal-pharynx airway models were exported into a CFD meshing software package to generate discrete volume cells. This study used both a Euler-Lagrange particle transport model for aerosol transport and a model for complex intranasal turbulent flow. This study analyzed both inhaled state and exhaled state, and compared the aerosol deposition characteristics under conditions by changing the particle diameter and flow rate of aerosol. As a result of CFD analysis, amount of aerosol deposition depended on particle diameter and flow rate, and tendency of aerosol deposition was consistent in all cases analyzed in this study.
Furthermore, in the inhaled state, aerosol mainly deposited in nasal meatus areas where not contribute to treatment of ECRS. Exhaled state was more effective treatment for ECRS compared to the inhaled state. The results show advantages of ETN as well as CFD analysis will contribute further development of ENT.

1. Introduction

Aerosol medicine exhalation through the nose treatment (ETN) has conducted as an effective treatment for Eosinophilic Chronic Rhinosinusitis (ECRS) [1,2]. In ETN, 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]. 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. In this study, computational fluid dynamics (CFD) analysis of aerosol transport phenomena were performed based on patient CT data in order to evaluate the therapeutic effect of ETN numerically.

2. Case Data

Three cases were selected in this study, one is a patient who had ECRS with asthma and a history of endoscopic sinus surgery (case 1) and the others are healthy cases (case 2, 3). Figure 1 shows the CT images of the patient (case 1) which were scanning using a multi-detector CT (Discovery ST, GE). 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 -300 Housfield units relative to the surrounding tissue. Figure 2 is 3D nasal model. In the 3D model, NP is the nasopharynx, LETH 0, 1, 2 and RETH 0, 1, 2 are the ethmoid sinus region. LOFT is a region created for both suppressing the backflow phenomenon at the outlet boundary, and consequently stabilizing the convergence of the analysis.

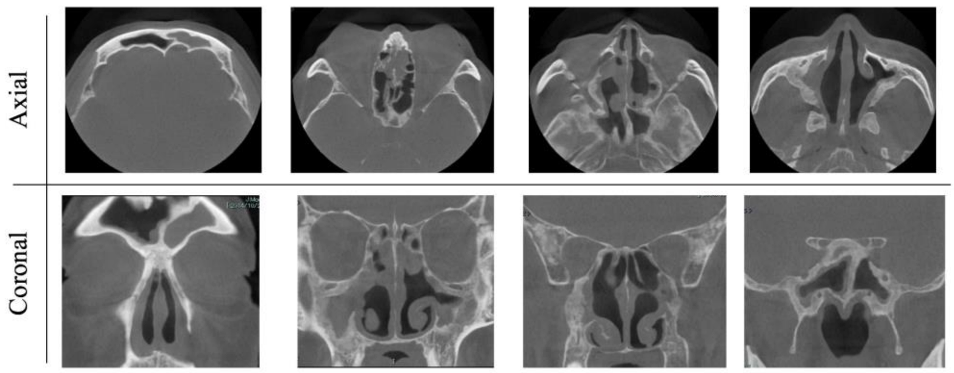
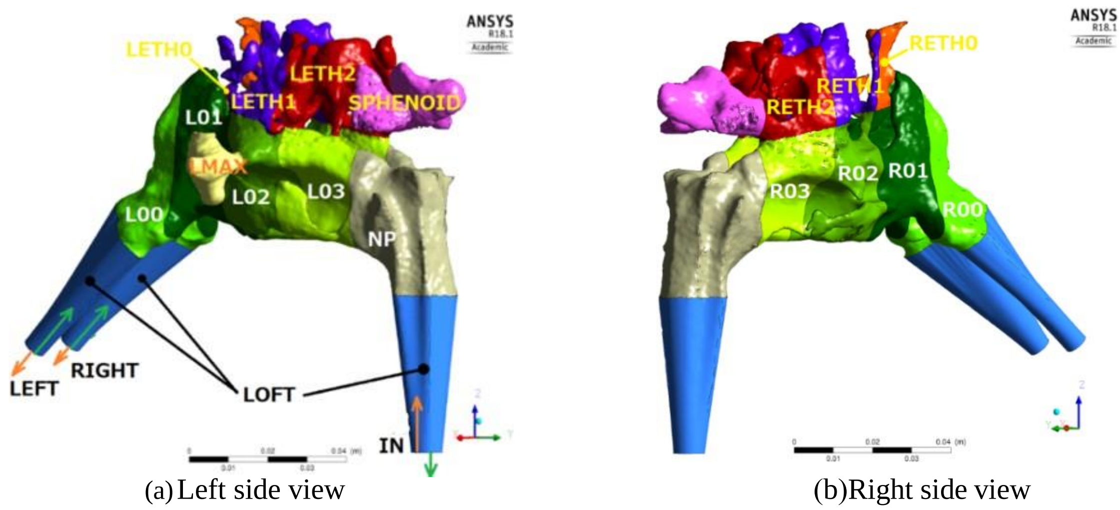


Figure 1. CT images of a patient who suffers Eosinophilic Chronic Rhinosinusitis.



(a) Left side view (b) Right side view

Figure 2. 3D nasal model used in the study.

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 model for complex intranasal turbulent flow. This study analyzed both inhaled state and exhaled state, and compared the aerosol deposition characteristics under conditions by changing the particle diameter and flow rate of aerosol.

The condition of flow rate of through nose set at 10 l/min, 35 l/min, 50 l/min and 70 l/min, respectively. And the condition of particle diameter set at 1μm, 3μm and 10μm, respectively.

4. Evaluation of deposition characteristics of particles

As an index for evaluating the results of this analysis, we define the particle Deposition Efficiency (DE) and the Impaction Parameter (IP). Particle deposition rate is defined as in equation (1).

$$\mathrm{DE} = \frac{C_{dep}}{C_{in}} \tag{1}$$

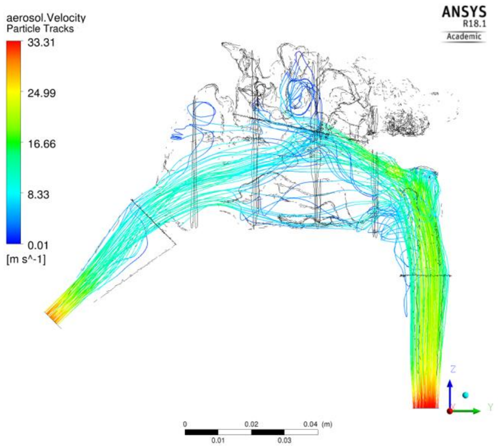
C_{dep} is the total amount of particles deposited on the entire nasal cavity - pharyngeal region or on the surface of each region in the nasal cavity, and C_{in} denotes the total amount of inflowing particles. Collision parameter is defined as in equation (2) [7].

$$\mathrm{IP} = {d_a}^2 \cdot Q \tag{2}$$

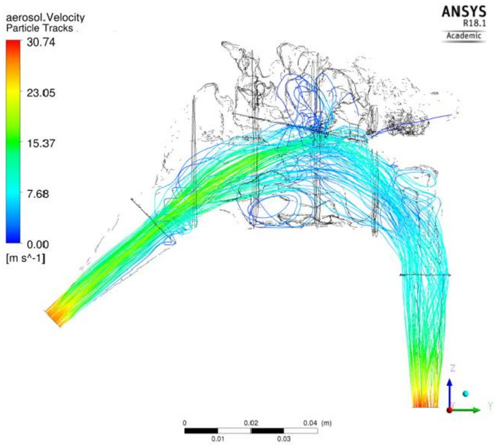
d_a is the aerodynamic diameter and Q is the volumetric flow rate.

5. Result and Discussion

Figure 3 shows the CFD results of aerosol particle trajectory in both exhaled and inhaled states for patient case 1. It shows that the particles collide with each other in the nasopharynx with both exhalation and inhalation, and the particles are meandering. Figure 4 shows the relationship between deposition efficiency and impaction parameter in the whole nose for each case. Furthermore, in each figure, the experimental value of deposition efficiency [8] was compared with the analysis value. The vertical axis shows the particle deposition rate and the horizontal axis shows the impaction parameter. In all conditions, the trends are consistent. From the results, it is considered that the deposition efficiency of the particle depends on the impaction parameter. In addition, it was found that there is a tendency similar to the experimental value of deposition efficiency in all cases. Figure 5 shows the relationship between deposition efficiency and impaction parameter in the nasopharynx, ethmoid and nasal cavities of case 1. At exhalation, as the impaction parameter increases, the inertial collision in the nasopharynx is promoted, whereas in inhalation, particles due to gentle change in direction from the nostrils to the middle nasal passage. In addition to the inertial movement of the flow, peeling of the flow accompanying expansion and contraction of the inside of the nasal cavity acts, and it is presumed that particles gradually deposit before reaching the nasopharynx. As a result, in the inhaled state, it was found that aerosol mainly accumulates in the nasal cavities areas which does not contribute to treatment of ECRS. Therefore, exhaled states are considered more effective as a more effective treatment for ECRS compared to inhaled states.

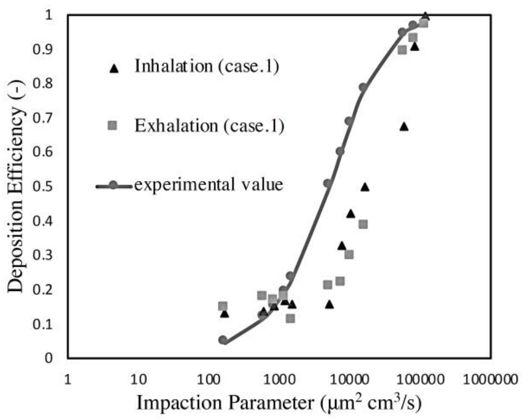


(a) Exhaled states

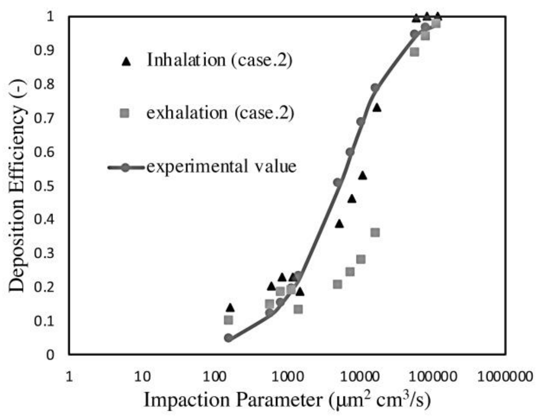


(b) Inhaled states

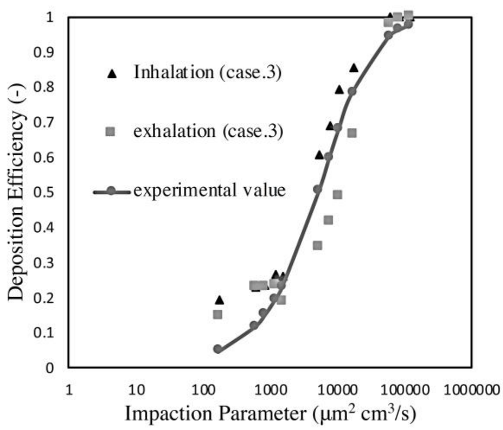
Figure 3. Particle trajectories of analysis nasal model (case 1).



(a) Case 1



(b) Case 2



(c) Case 3

Figure 4. Relationship between deposition efficiency and impaction parameter (each cases).

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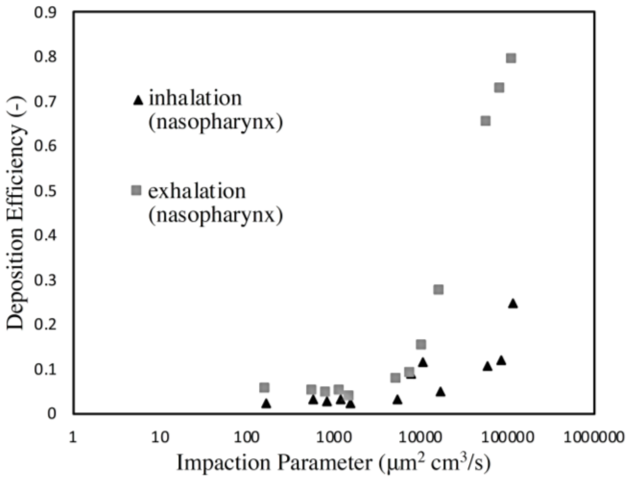
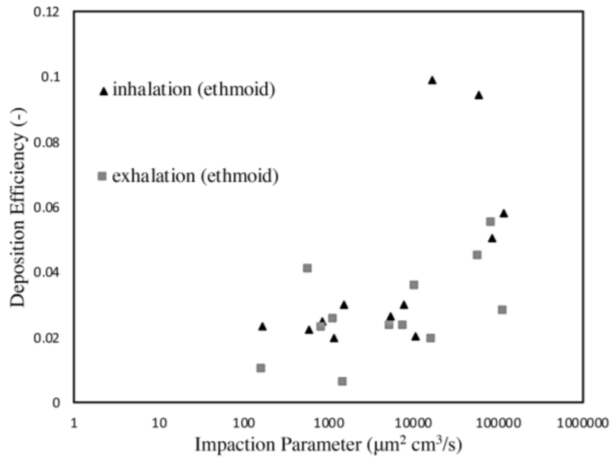
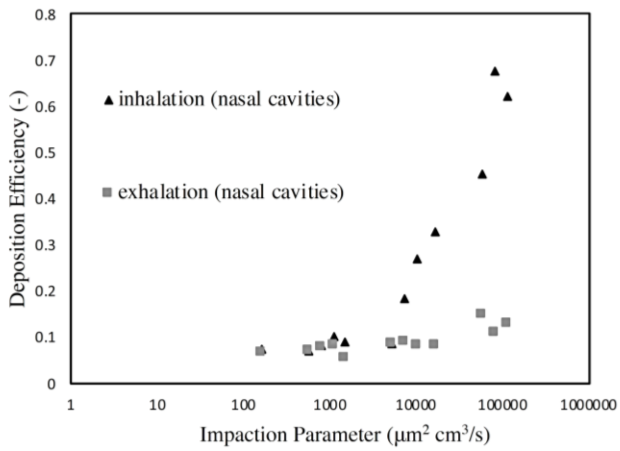


(a) Nasopharynx



(b) Ethmoid



(c) nasal cavities

Figure 5. Relationship between deposition efficiency and impaction parameter (Nasopharynx, Ethmoid and nasal cavities).

6. Conclusion

In this study, computational fluid dynamics (CFD) analysis of aerosol transport phenomena were performed based on patient CT data in order to evaluate the therapeutic effect of ETN numerically. As a result, amount of aerosol deposition depended on particle diameter and flow rate, and tendency of aerosol deposition was consistent in all cases analyzed in this study. Furthermore, in the inhaled state, aerosol mainly deposited in nasal cavities areas where not contribute to treatment of ECRS. Exhaled state was more effective treatment for ECRS compared to the inhaled state.

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