

Computational Biofluid and Particle Dynamics in Respiratory Systems

ゲン, ダン コア

<https://hdl.handle.net/2324/7182519>

出版情報 : Kyushu University, 2023, 博士 (工学) , 課程博士
バージョン :
権利関係 :



氏 名 : Nguyen Dang Khoa

Name

論文名 Title : Computational Biofluid and Particle Dynamics in Respiratory Systems

(呼吸器系モデルを対象とした計算生体流体解析)

区 分 : 甲

Category

論文内容の要旨

Thesis Summary

Dissertation was established aiming to propose the insights about the fluid physics and transportation/deposition of airborne particles, as well as the emission of viral copy-laden droplets during the inhalation or coughing processes. The primary focus of this dissertation encompasses the respiratory systems of both humans and mammals. In order to implement the dissertation, the Computational Fluid – Particle Dynamics (CFPD) technique was employed in several topics, such as (i) simulating the fluid physics in the human/mammal airways, (ii) investigating airborne particle transportation/deposition in the human/mammal airways, and (iii) delivering a seamless analysis from exposure phase to re-emission phase of pathogens. Brief introduction to each chapter of the dissertation to fulfill the mentioned objectives is conveyed as follows:

Chapter 1 outlines the motivation context of the dissertation and introduces the main objectives that are achieved at the dissertation completed.

Chapter 2 theoretically expands the primary techniques employing in the dissertation including (i) medical image processing to re-construct the 3D numerical models of mammal and human airways, and (ii) Computational Fluid Dynamics - CFD method.

Chapter 3 visually presents the numerical 3D model and mesh design. The main 3D numerical models used in this dissertation comprising the airway systems of human and mammals.

Chapter 4 initiates the main results and discussion with the virtual de-congestion trials in the French bulldog airway with severe Brachycephalic Obstructive Airway Syndrome – BOAS. The effects of the decongested airways on the breathing functions of a patient bulldog were quantified by benchmarking against a clinically healthy bulldog using CFD method. The findings demonstrated a promising improvement in breathing function, which is a viable tool providing visual and quantitative insight into new unexplored surgical techniques.

Chapter 5 explores the inhalation toxicology study in the upper airway of monkey. Herein, the CFPD method was employed to investigate the flow field and deposition patterns. The simulated airflow patterns were validated against the PIV experiment, which confirmed the accuracy of the simulation. Particle transportation/deposition terms were visually and quantitatively elucidated in the monkey airway. These results placed a foundation for an application of CFPD technique in the inhalation toxicology targeting human airway, and provided the data for extrapolation analyses between inter-species.

Chapter 6 unveils the transportation/deposition of non – spherical particle (cylindrical fiber) in the human upper airway, and compares with the results with spherical particle. As the results, the nasal deposition efficiencies of the two drag models agreed well with experimental data. Comparatively, asbestos deposition was independent of fiber length, while CF deposition increased in proportion to fiber length. Meanwhile, a comparison of fiber and spherical particle indicates a higher deposition rate of the spherical particles. Comparison studies involving the deposition rates in the upper airway of monkey and human established semi-empirical equations to facilitate extrapolation across species.

Chapter 7 continuously expresses the deposition of airborne particle in the lower airway region down to the bronchial terminal using RANS and LES techniques. Firstly, this Chapter reports reliable results of airflow patterns and particle deposition efficiency in the lower airway. Total and local deposition patterns were explicitly delivered indicating the significant impacts of individual features. As compared between the RANS and LES techniques, profound discrepancies in terms of quantitative and spatial deposition were observed. From the results, the developed human lower airway delivers the accurate prediction of a wide range of particles in terms of particle dosimetry and visualization of site-specific.

Chapter 8 commences analysis about the mechanism behind the droplet generation during coughing epoch. In this chapter, the droplet generation process during a coughing event was reproduced using the EWF model, and the droplet behavior was tracked using the DPM technique in an oral-airway model. Origin site analyses represented the hot-spot of droplet release located in the oral cavity. The size of the expelled droplets was 0.25–24 μm , with the peak concentration at 4–8 μm . In addition, a combination technique by inheriting the results obtained by the HCD model elucidated the viral RNA copies contained in the escaped droplets during coughing epoch. This study significantly contributes to the realm on the site of origin and localized number concentration, and viral density of droplets after a coughing episode.

Finally, highlights are delivered in the Chapter 9 with relevant limitations of the current studies. Accordingly, future research endeavors are outlined to enhance the conclusions derived from this dissertation.