Development of a Three Dimensional In Silico Model of the Human Respiratory System for Dosimetric Use

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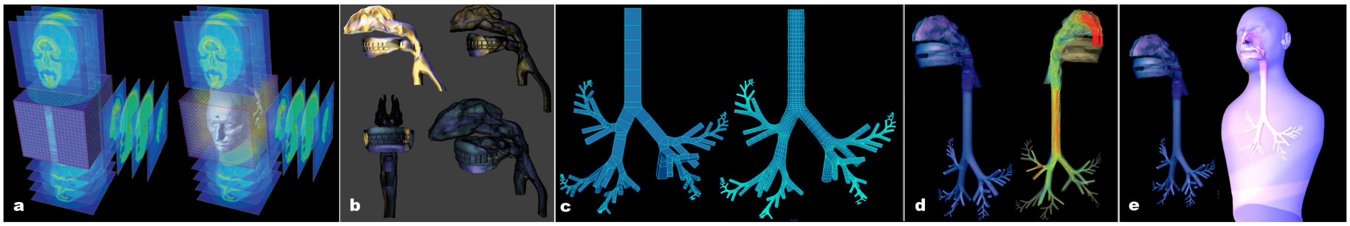

Figure 1: *A volumetric data set created from combining a series of MRI images. The image shows how a surface is created by extracting a particular threshold value, called an isosurface, from the volume data (a). Extrathoracic airways combined with the nasal and oral cavity (b). Bifurcation model combines the pharynx showing one complete 23 generation path in each of five lobes (c). Complete contiguous typical path model, including nasal and oral cavities, traces of the velocity magnitude (cm/s) are shown for an inhalation laminar flow study (d). Complete contiguous internal and external typical path model, including nasal and oral, cavities, larynx, and 24 generations with a single bifurcating path into each of the five lobes of the lung. (e).*

ABSTRACT

The homeland security community requires a unique solution to the challenges of studying exposure to aerosol-based contaminants. The goal of this work is to create a comprehensive computational, morphologically-realistic model of the human respiratory system that can be used to study the inhalation, deposition, and clearance of contaminants, while making the model adaptable for age, race, sex, and health.

Keywords: homeland security, biomedical and genomic, aerosol contaminants.

1 Introduction and Motivation

The homeland security and public health community are confronted with research challenges when studying inhaled anthrax, ricin toxin, or other aerosol-based contaminants due to their toxicity. Computational studies of aerosol-based hazardous contaminants and particle-transport within the human respiratory system therefore have a critical role to play in this research. To aid in studying exposure and risk assessment, we are developing a comprehensive morphologically-realistic model of the human respiratory system from nares to alveoli that will respond to the dynamic changes of respiratory mechanics and abnormal pathologies. The project's goal is to develop a comprehensive morphologically-realistic model of the human respiratory system that can be used to study the inhalation, deposition, and clearance of aerosol-based contaminants.

2 Technical Approach

We started by using magnetic resonance imaging (MRI) slices from the Visible Human Project's (VHP) Brigham and Women's Hospital (BWH) to create a volumetric data set. A threshold value was used to extract an isosurface of the head and nasal cavity, which are soft tissues. The upper and lower gums with teeth were combined to form a complete oral cavity. The tongue was added to the oral model and the upper airway models were then aligned and combined into a single morphology model, including sides and uvula. The branching airways were created using an algorithmic method that generates a single path to each of the five lobes, 23 generations down. From that model, we use subdivision surfaces to create a smoothed, watertight mesh, removing holes and imperfections from the original model. We then combine the nasal, oral, and bifurcations models into a contiguous typical path model. The internal structure of the respiratory system was combined to create a three-dimensional morphologically realistic model of the human respiratory tract from the nares to the alveoli. To confirm the model was free from surface imperfections we prepared a computational mesh, a process which requires a watertight surface and performed a trial CFD run. Traces of velocity magnitude are shown for inhalation laminar flow. The external surface representing the facial structure obtained from the volumetric data and the internal structure including the nasal and oral cavities along with the five lobe typical path bifurcation model was combined to form a three-dimensional morphologically realistic model of the human respiratory system.

3 Future Work

Upcoming work includes parameterizing the models to allow for manipulation of such features as age, gender, race, disease states, as well as fine controls for the shape of specific features, such as the nasal turbinates.

The model will also feature a dynamic morphology that mimics the changes in the airway structures during a typical breathing cycle. The model will therefore allow for any variation of airway geometries and disease states. The model's flexibility and adaptability could help researchers predict dose from exposure to hazardous contaminants, such as anthrax and ricin, and assist in estimating thresholds and the need for prophylactic measures.

References

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