Preliminary Analysis of Temperature Changes Through Tracheobronchial Airway

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Abstract

The temperature changes of air through the tracheobronchial airway to second degree bronchial bifurcation were examined for a reconstructed subject-specific lung airway model using medical image processing and post processing software. Currently, there is no analysis of temperature changes through the tracheobronchial airway. In this study, temperature changes were evaluated using CT images of one healthy human subject and standard data of the human body including body temperature, density of tissue, conductivity of tissue, and thickness of tissue. It was found that exit temperature changes with different mass flow rates; therefore, it is recommended that mass flow rates be considered with the analysis of the inhalation of aerosol-related drugs.

Introduction

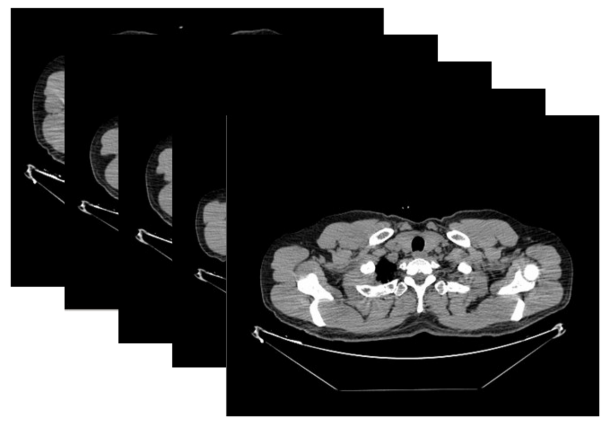
- Asthma affects an estimated 20 million Americans
- It is estimated that 11 people die from asthma related deaths each day with many being preventable with proper treatment or care
- Inhalers and nebulizers introduce medicine via aerosol and are currently the most common day-to-day treatments for patients with asthma
- No analysis has ever been performed on tracheobronchial airway temperature changes

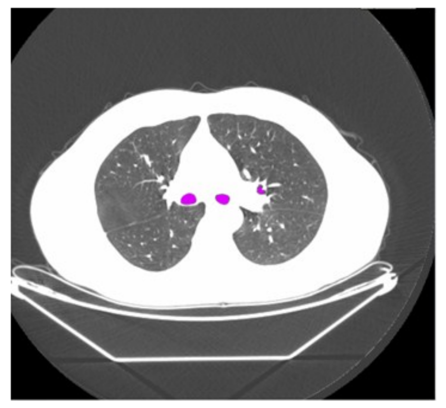
Purpose

- Investigate temperature changes through tracheobronchial airway
- Temperature changes associated with mass flow rate may change the characteristics of an aerosol drug related delivery system
- Apply results to future airway temperature analysis

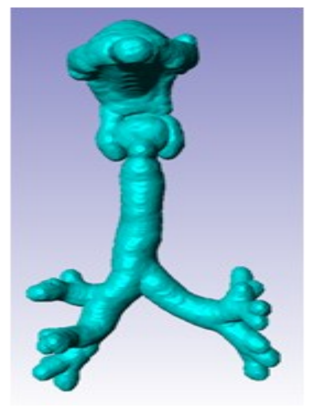
Methods

Subject-Specific Image Processing

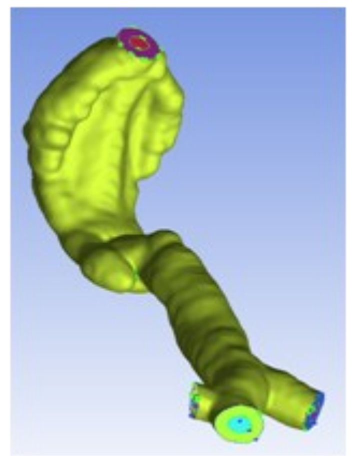

Several slices of raw images

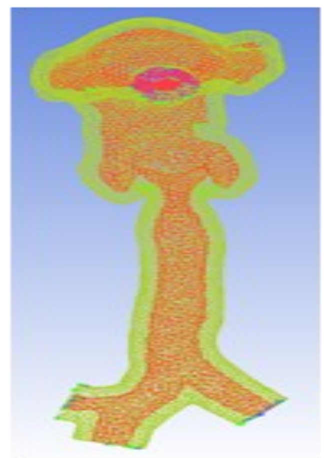

Raw image with selected areas of interest


Interior tissue model


Exterior tissue model

- Import dicom images with appropriate contrast
- Create mask of interior and exterior airway Systems
  - ⇒ Select areas of interest— remove extra parts
  - ⇒ Floodfill— merge until continuous mask
  - ⇒ Copy mask and expand new mask to tissue diameter
  - ⇒ specificationss
- Smooth mask using filters
  - ⇒ Recursive Gaussian filter
- Cut desired airways


Airway with inlet and exit cuts


Airway with mesh

Governing Equation

$$\rho C_p \frac{\delta T}{\delta t} = \frac{\delta}{\delta x}\left(k\frac{\delta T}{\delta x}\right) + \frac{\delta}{\delta y}\left(k\frac{\delta T}{\delta y}\right) + \frac{\delta}{\delta z}\left(k\frac{\delta}{\delta z}\right)$$

Assumptions

- No metabolic heat flux
- No blood perfusion

Properties

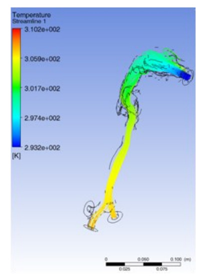
- Tissue:
  - ⇒ Density: 2702 kg/m^3
  - ⇒ Molar Mass: 26.98 kg/kmol
  - ⇒ Specific Heat Capacity: 903 J/kgK

Boundary Conditions

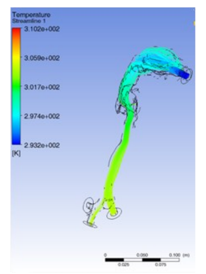
- Airway domain
  - ⇒ Domain type: Fluid
  - ⇒ Reference Temperature: 25 degrees Celsius
  - ⇒ Motion: Stationary
  - ⇒ Reference Pressure: 1 atm
- Tissue domain
  - ⇒ Domain type: Solid
  - ⇒ Reference Temperature: 37 degrees Celsius
  - ⇒ Motion: Stationary
  - ⇒ Morphology: Continuous Solid

Results

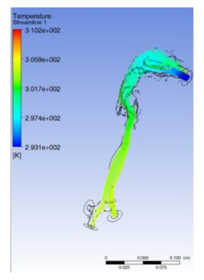
3000 mL/s flow rate Streamline



6000 mL/s flow rate Streamline

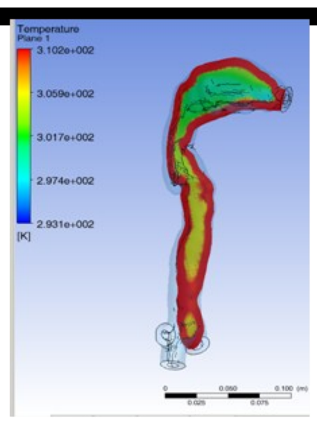


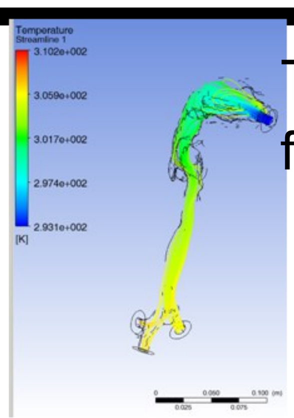
9000 mL/s flow rate Streamline



- Steady-state analysis revealed more temperature change from the mouth to exits performed with slower mass flow rates

Cross-sectional temperature distribution

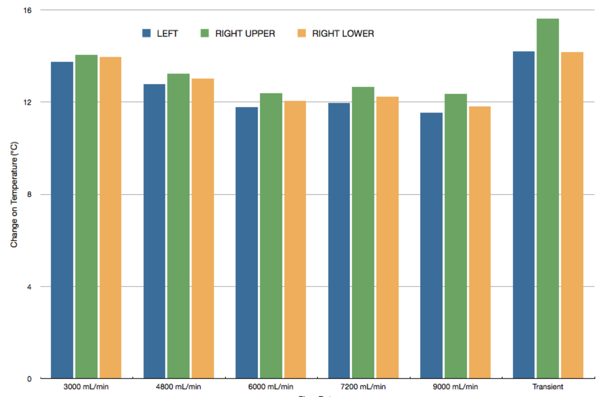




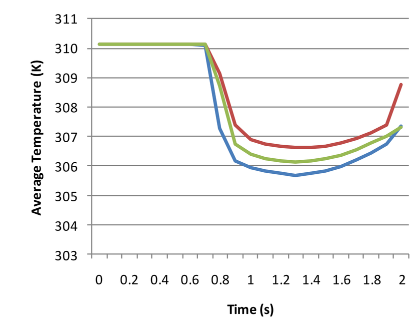
Transient flow rate

- Transient analysis demonstrated the greatest temperature changes
- The greatest temperature changes occurred from mouth to trachea interface

Temperature comparison



Time-Temperature Comparison



- The greatest
- temperature difference occurred from inlet to upper right exit
- The least occurred from inlet to left exit
- There is significant a difference in temperature changes in mass flow rates occurring below 6000 mL/s
- The greatest average temperature occurred from inlet to right upper exit

Conclusion

- There is a significant difference in temperature of the different mass flow rates through the tracheobronchial airway
- More rapid breathing causes less of a temperature change through the airway system

Future Work

- Expand the number of subjects and bronchial bifurcations in order to develop a more complete analysis
- Use results in a 3-D model application incorporating cartilage and mucus variables
- Explore the effect of humidity on temperature distribution through the tracheobronchial airway