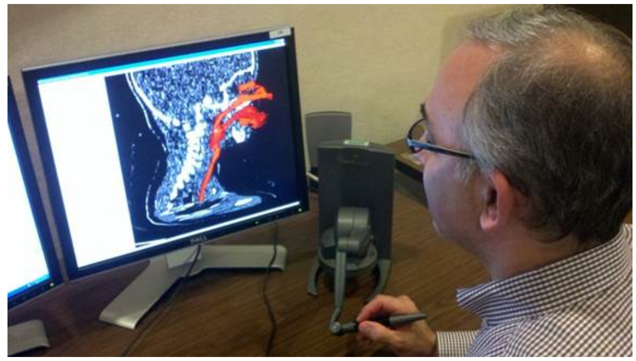
Virtual Workbench for Planning Treatments of Airway Problems in Young Children

Department of Computer Science **University of North Carolina at Chapel Hill** **March 2012**

Highlights

- **Integrated environment for intervention planning in pediatric patients with breathing problems caused by constricted airways**
- **Interactive geometry editing provided by a force-feedback device delivers a fast, intuitive method to describe desired airway shape outcomes from clinical intervention**
- **Stereo display for enhanced shape perception**
- **Coupled to GPU-accelerated simulation for fast feedback on intervention impact**



The Virtual Pediatric Airways Workbench (VPAW) is a software application enabling segmentation, interactive anatomical shape editing, flow simulation, visualization, and analysis.

The Challenge

Upper airway problems in young children may lead to life threatening respiratory difficulties, poor growth, aspiration, delay in speech development and long-term illness. Two common upper airway anomalies are Pierre Robin sequence (small jaw, cleft palate, downward displacement of the tongue) and subglottic stenosis (narrowing of the airway below the vocal cords). Treatment of these children is typically directed by the clinician’s experience and preference, rather than by published protocols or quantitative measures of airway physiology and anatomy. Improved methods of evaluating and determining best treatment options would benefit clinical care and outcomes. Novel research tools that measure structure and airflow and essentially create a virtual model of the airway would significantly improve care of these children. These computational models are now possible and can be modified to reflect medical or surgical intervention as well as normal growth and development.

Improved quantitative measurements through computational modeling have enormous potential to significantly improve care in children with complicated upper airways. The researchers in this study hypothesize that a functional computational model may be developed that is similar to the mechanical and aerodynamic behavior of the upper airway in infants with complicated upper airways. The researchers also hypothesize that this model could be used as an effective diagnostic/treatment planning tool; thereby, reducing failed treatment and avoiding unnecessary future complications or interventions.

The Approach

We are building the Virtual Pediatric Airways Workbench (VPAW) as a unified interface to tie airway segmentation algorithms, geometric modeling, and fluid dynamics simulations together into one system. The end goal is to provide a tool for use by physicians to make more informed decisions about clinical interventions.

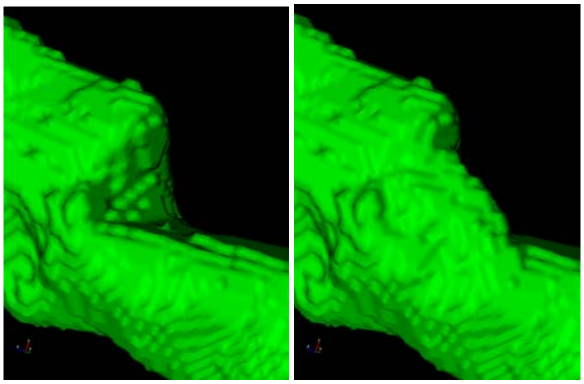
VPAW consists of four main components: segmentation, geometry editing, simulation, and visualization.

Segmentation

CT scanners produce images with high contrast between air and tissue, making segmentation of the airway structure fairly straightforward. VPAW provides two segmentation algorithms, an automated method that uses morphological operations to limit the segmentation to the nostrils and a faster threshold-based algorithm that requires user input to specify a point within the airway and the location of the nostrils. Segmentations produced by external programs may also be imported.

Fast, threshold-based segmentation of the airway. This segmentation includes portions of the lungs.

Geometry Editing
Once an airway has been segmented, a physician can create different airway geometries by using VPAW's 3D interactive editing capabilities to modify the original geometry. A 6 degree-of-freedom force feedback device is used to provide an editing experience similar to molding clay.



Left: a subglottic stenosis is a narrowing of the airway below the vocal cords. Right: one possible modification of the airway created with VPAW's Geometric Editing component

Simulation
From the VPAW interface, a physician can send the modified airway geometries to a computational fluid dynamics (CFD) program to determine how the modified geometry affects airflow and pressure on the airway walls. Results from either a highly accurate CFD program or an integrated near-real-time GPU-accelerated lattice-Boltzmann simulation can be produced.

Visualization
Results from the flow simulation can be visualized within VPAW using arrow glyphs to show the direction and magnitude of flow and pseudocoloring of the airway surface to show pressure. 3D stereo visualization enhances depth perception for greater understanding of airway geometry and fluid flow. In the future, comparative visualizations of different airway geometries and simulation results will be added.

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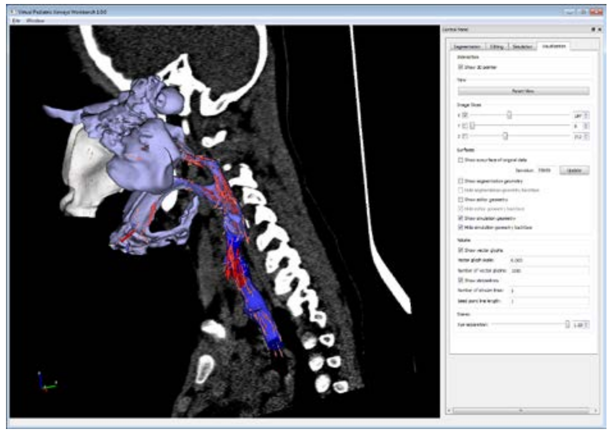

Flow simulation visualization in VPAW. The red arrows indicate flow direction (size is proportional to speed). The surface is colored by five different shades of blue with the lightest shade corresponding to the highest pressure in the dataset and the darkest shade corresponding to the lowest pressure. Increased flow velocity and decreased pressure is visible near the subglottic stenosis.

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Keywords

Pediatrics; treatment planning; haptics; visualization; computational fluid dynamics; medical image analysis

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