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TOWARD PATIENT-SPECIFIC SIMULATIONS OF AIRWAY COLLAPSE IN OBSTRUCTIVE SLEEP APNEA

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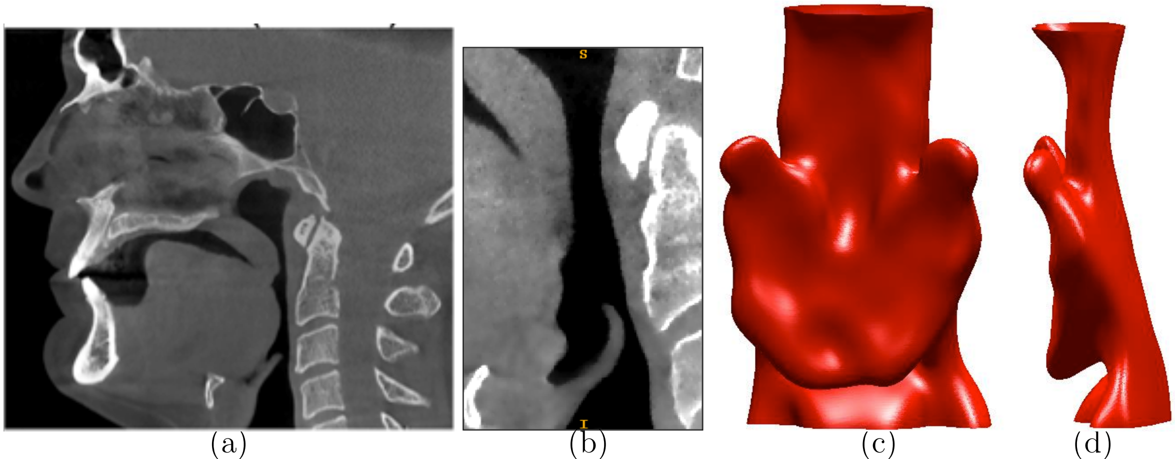
Obstructive sleep apnea (OSA) is a chronic sleep-breathing disorder characterized by partial or complete obstruction of the pharyngeal airway during sleep. It is estimated that the disorder affects between 3 to 7 percent of men and 2 to 5 percent of women in the general population. The pathophysiology of OSA is not fully understood. However, there is strong evidence that OSA patients have anatomical variations that predispose their airways to collapse. In clinical practice, diagnostic imaging is used to examine the airway geometry in order to identify sites of airway narrowing and obstruction. However, these static images are insufficient for reliably predicting the likelihood of collapse or the efficacy of treatments. Sleep studies are the current standard for diagnosis.

Computational fluid dynamics can potentially serve as a powerful tool with which to augment diagnostic imaging of the airway. In the past decade, several research groups have performed computational studies of the pharyngeal airflow in geometry obtained from medical imaging of specific patients. Nearly all of these studies were performed with Reynolds-averaged Navier-Stokes (RANS) simulations of the flow in a rigid-walled airway with static inflow conditions. However, under the simplifying assumption of a rigid airway, one can only postulate loci of minimum pressure as sites of potential collapse. Furthermore, RANS turbulence models are generally inadequate for predicting the separated flow behavior in the transitional or mildly turbulent flow in the airway; airway collapse may be sensitive to the details of this flow behavior.

In this work, we will discuss our progress in developing a computational tool to predict—and to investigate the factors of and treatments for—airway collapse in OSA. The computational tool is designed to resolve the fluid-structure interaction, based on patient-specific geometry from medical imaging and generic material properties of the surrounding soft tissues. In order to reduce the complexity of grid generation, both the fluid and structure solvers rely on Cartesian grids. The fluid solver uses a staggered-grid finite difference method in conjunction with the embedded boundary method of Yang and Balaras to enforce the kinematic constraints at the fluid-structure interface. The structural solver makes use of weighted residuals in the computational elements (Cartesian in their reference configuration), with a cut-cell modification in elements transected by the interface. Both solvers rely on an implicit description of the interface via the level-set method.

The geometry is reconstructed from de-identified images obtained from cone-beam CT scans of patients at the UCLA School of Dentistry. The open-source software ITK-SNAP is used for edge detection of the DICOM images, and the subsequent reconstructed geometry is exported as a level set. Currently, an additional post-processing step is used to filter the images and generate a true signed distance field. Figure 1 demonstrates the original image and the result of the reconstruction process.

The discretized fluid and elastic equations, as well as the dynamic and kinematic conditions at the interface, are assembled into a global system with the form of a saddle-point problem. Various computational treatments of this system are explored and demonstrated on benchmark fluid-structure interaction problems, including a vibrating elastic disk in a viscous fluid and two- and three-dimensional versions of the Starling resistor. Preliminary results of the patient-specific airway flow will also be presented.



(a) (b) (c) (d)

Figure 1: Original cone-beam CT scan: single slice (a) and region of interest (b). Anterior (c) and anteroposterior (d) views of reconstructed level set.