Obstructive Sleep Apnea (OSA), a repetitive closure of the upper airway during sleep associated with attention deficit, increased accident frequency, and cardiovascular disease, affects 2% of children and over 4% of adults. OSA is treated successfully by continuous positive airway pressure (CPAP) in adults, and by surgery in most children, but a successful surgical approach to adult OSA remains elusive. OSA is fundamentally a problem of soft tissue mechanics, fluid mechanics, and feedback control in a biological system – a perfect subject for mechanical engineers! Our research objective is to develop new image-based modeling techniques that relate airway performance to anatomy and motion, to study the pathophysiology and improve diagnosis and treatment of OSA.

Three related studies will be reviewed. (1) Image-based computational fluid dynamics (CFD) models were used to study the effect of anatomical restriction on pharyngeal pressure in children and adults. Flow resistance was an order of magnitude higher in children with OSA compared to controls, higher than nasal resistance, and typically associated with the region where tonsils and adenoids overlap. In adults resistance was also higher in OSA than controls, but not higher than nasal resistance. Results were consistent with the relatively high success of surgery in children compared to adults. (2) Finite element modeling with fluid-structure interaction was used to explore the relative impacts of anatomical restriction and collapsibility during flow-limited respiration in a child. Maximum flow was a strong function of both area restriction and collapsibility, suggesting that surgical approaches that reduce area restriction can reduce apnea severity by raising maximum flow rate, without improving collapse pressure. (3) A new soft tissue mechanics model of the upper airway of a rat was developed, using advanced magnetic resonance imaging methods. SPAMM imaging, a method for tracking material points in a deforming tissue, was used to measure tissue displacement between positive and negative airway pressures. A finite element model with interactive tongue, soft palate, and other tissues was developed, and the inverse mechanics problem was approximately solved to find the elastic modulus for each tissue region. The model has been used to calculate collapse pressure and its sensitivity to tissue properties, and is currently being developed as a method to extract muscle fiber stress in stimulated airway experiments.

The methods that we are developing will allow researchers and clinicians to use detailed noninvasive images to better understand OSA in individual subjects. These mechanics models may be used in lumped parameter and hybrid models of the dynamics and control of the respiratory system. OSA is also a rich source of material for design and research projects, and may be used in teaching lab experiments on pressure measurement, Bernoulli’s principle, and the choked flow.