A Biomathematical Model for Pre-Operative Visualization of COPD and Associated Dyspnea

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Chronic obstructive pulmonary disorder (COPD), which includes emphysema and chronic bronchitis, has been identified as the 4th leading cause of death in the United States. [1] Dyspnea, which is a subjective experience of breathing discomfort, is one of the major symptoms reported by persons with various cardiopulmonary diseases including COPD. During normal at rest breathing, there is a balance between muscular tension and the length of the associated muscles. The relationship between muscle tension and length is perceived as respiratory effort by peripheral mechanoreceptors in the airways, lungs, and chest wall. [4] A leading theory as to the cause of Dyspnea is the consciously perceived mismatch between the efferent signals sent from the medulla (central respiratory processor) and the afferent feedback provided by the peripheral mechanoreceptors. [2] The theory takes into account physiological changes in respiratory structures due to COPD such as shortening of the respiratory muscles, loss of elasticity in the parenchyma of the lungs, and altered breathing patterns. These physiological changes may be quantitatively modeled by the pressure-volume curve that describes the dynamic process of normal lung breathing from inspiration to exhalation. [2] [3] Given our success at modeling real-time 3D deformation of breathing lungs [4], we are expanding our model to include abnormal breathing patterns such as those found in COPD and associated Dyspnea. [5] In addition to providing a bio-mathematical model of the underlying pathology of COPD associated Dyspnea, the overall scope of the research includes the development of a 3D visualization of the lung pre and post lung volume reduction surgery. Visualizing the breathing pattern of COPD patients pre and post operatively would be an effective diagnostic tool for medical professionals as well as an educational tool for patients.

In our approach, we are developing a bio-mathematical "rhythmogenesis" model that is driven by pressure differences and the neural control of breathing. The neural control is modeled as a step-by-step dynamic process whereby a single inhalation or exhalation is divided into multiple steps and in each step, the tension in the respiratory muscles and the pressure difference seen in the lungs by the receptors are compared in order to detect abnormalities, and compensatory measures are applied.

We consider the symptoms as initial values of the dynamic process and model the subsequent changes in the breathing pattern. The symptoms of Dyspnea includes increase in heart rate, increase in partial pressure of carbon dioxide in blood, and presence of impurities. We classify the symptoms in terms of either resistance to breathing or increase in flow or increase in rate of breathing. The compensatory measures include increase or decrease in hysteresis, local and global changes in the pressure-volume relation, and increase or decrease in lung capacity. This model is dynamic in nature, since any change in symptoms would be reflected immediately in the rhythm of breathing. Additional symptoms could also be easily added, and thus the model is scalable to new scenarios.

Initial results of how Dyspnea may be represented in a biomathematical model for pre-operative visualization will be presented. 3D real-time visualization of both normal versus Dyspnea breathing at rest will be shown using the Visible Human Dataset as the anatomical model. The implementation of the rhythmogenesis model will also demonstrate how a high-density lung model may deform realistically and in real-time under normal and abnormal breathing conditions.

References

1. Adams, F. V. The breathing disorders source book. Los Angeles: Lowell House, p. 89.1998
2. ATS Board of directors. Dyspnea Mechanisms, Assessment and Management: A Consensus Statement July 1998
3. Ripamonti C, Bruera E. Dyspnea: Pathophysiology and Assessment Journal of Pain and Symptom management. 2001

4. Santhanan A, Pattanaik S*,, Rolland JP.* Physiologically accurate deformation of breathing lung models. Proceedings of Pacific Graphics (2003).
5. Brack T Dyspnea and decreased variability of breathing in patients with restrictive lung disease. American Journal of Respiratory Critical Care Medicine (2002).