Simulating the human respiratory pump

Background and relevance

The breathing of a human being is directed by respiratory muscles such as the diaphragm. In case of serious injuries and other life threatening circumstances, a patient in intensive care often needs to be placed in a mechanical ventilator. This so called mechanical ventilation works contrary to the normal muscle action, thereby, in times as short as few days, causing substantial damage to the respiratory system. The loss of structure and function of the diaphragm, the main respiratory muscle, delays and complicates the weaning process from the mechanical ventilator, increasing the morbidity and mortality rate, in addition to the costs of care.

![Diagram of diaphragm and ventilation](image)

**Figure 1:** To the left, the location of the diaphragm in the body is indicated. To the right we see a mass-spring model of the diaphragm, constructed as two connected surfaces [1].

Aims

This project aims to construct a quantitative model of the mechanical component of the respiratory function, which can replicate the properties both of normal breathing and of mechanical ventilation. The model will be used for

- learning about the respiratory function and which components are most critical to model accurately,
- developing a simulation tool that can be used by medical doctors for a variety of investigations regarding the respiratory system,
- in a longer perspective, to apply the model to test the efficacy of specific preventive and therapeutical interventions aimed to preserve the respiratory pump’s power during and after mechanical ventilation.

Methods

As a pilot study, a simulation method based on a mass-spring model of the diaphragm was implemented, see [1]. This basic model is able to reproduce the movement of the diaphragm during respiration in a qualitative way. The next step, which is currently under way is to include more elements in the model such as the abdominal pressure (from below) and the lung pressure (from above) as well as the movement of the rib cage.
The mass-spring model is computationally expensive and provides a rather crude representation of the diaphragm. More sophisticated modeling is employed in [3, 2, 4], where a finite element method is used to represent the diaphragm as a continuum. In this project, we propose to use a meshfree method, radial basis function (RBF) approximation, to model the diaphragm and other components of the thorax region. The advantage of a meshfree method is that it is easy to represent any geometry and furthermore RBF methods are highly accurate (potentially) leading to computationally efficient methods. This is especially important when studying damage to the diaphragm, which is a process that happens over time, and needs to be simulated over a large number of respiration cycles.

To start with, synthetic data can be used for developing methods, but at a later stage, it can also become important to have patient specific data, in which case interaction with experts in image analysis will be needed in order to transform image data into three-dimensional objects.

People

Elisabeth Larsson is a senior lecturer at the division of Scientific Computing at the department of Information Technology. She is an expert in numerical simulation methods, in particular RBF approximation and will be the main advisor in the project.

Nicola Cacciani is an MD, specialist on Anesthesiology and Critical Care, PhD, postdoc at the Neurosciences department (Basic and clinical muscle research laboratory). He will be the co-advisor and be in charge of medical and biophysical issues linking this project to the experimental results and the clinical investigation.

Professor Pierre Frédérique Villard, who is an author of [3, 2, 4] has also agreed to discuss the details of the method and share his experience.

Contact

Elisabeth Larsson, bette@it.uu.se
Nicola Cacciani, nicola.cacciani@neuro.uu.se

References