Functional model of the diaphragm for computer assisted medical interventions

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Abstract

Computer assisted medical interventions of the heart, liver, digestive or urinary system have underlined the need for a reliable, non-invasive three-dimensional technique to assess the respiratory movements, and more particularly the diaphragm displacements.

In this context, we present a 3D functional model of the diaphragm muscle based on a discrete biomechanical model. In this model soft tissues are considered as three-dimensional elastic bodies. Elastic properties are modeled using a shape memory function. Bones are considered as three-dimensional rigid bodies. All these objects are dynamically moving in a viscous medium and are submitted both to internal cohesive forces and to external attractive or interaction forces. Muscles are elastic bodies where explicit directions are used by an activation function to generate contraction forces. It is possible to add a global incompressibility constraint.

A dynamic MRI study, where the subject respiratory volumes were strictly controlled using a ventilator, was used to extract the diaphragm shapes and deformations in relation with the corresponding lung volumes.

A generic 3D diaphragm model was built according to anatomical references (shape, muscle attachments, fiber directions and central tendon). Abdominal content was modeled as an elastic incompressible body. Lungs and rib cage were not considered as active bodies, but their volume was measured. The diaphragm activation function was set to mimic the phrenic nerve activation.

The generic model was then registered to the segmented data and simulations of a respiratory cycle were made.

The resulting simulations were confronted with the real data. We compared the diaphragm deformation and movements as well as the ventilation volumes. The simulations were accurately simulating the diaphragm piston motion and lung volumes variations.

Keywords : 3D modelling, simulation, discrete physical model, breathing, medical imaging, dynamic MRI.