Flexible, Hollow Organs with Inner Structures for Medical Validation and Training

T. Parkel, I. Stergiou, S. Cattaneo

CSEM developed a new process to fabricate hollow and flexible anatomical organs for validation purposes in various domains. By exploiting the advantages of CAD, 3D freeform modeling and additive manufacturing, complex organs with inner structures and inserts can now be realized in a fully digital fashion, replacing the complex and time consuming manual fabrication methods used so far. Cancer treatment experts are using these novel tools to study the radiation planning and radiation delivery under the influence of respiratory motion

Since several years, CSEM has been developing anthropomorphic breathing phantoms, which, in combination with a versatile phantom ventilator, were used to validate proton beam cancer therapies at Paul Scherrer Institute (PSI). In early prototypes, the complex flexible models were designed and manufactured by assembling discrete parts produced by molding and mechanical machining. As each phantom was essentially handcrafted, the reproducibility could not be guaranteed and the integration of more complex inner structures could not be achieved.

To solve these issues, we developed a new generation of validation organs based on the most recent developments in CAD and additive manufacturing techniques. The newly developed processes allow creating hollow and flexible anatomical organs for validation purposes in various domains, along with setting a digital foundation for further development.

Realistic inner structures were created by merging patient data from a bronchial tube and a lung cancer spot into a new generic lung that perfectly fits into the existing Luca Phantom ribcage. The diaphragm is the most flexible interface between the lung (on one side) and the liver and other digestive organs (on the other side), and should move in SI-plane (Superior Inferior) by approximately 20 mm with every breathing cycle. Other non-organ shapes were integrated as a cutout to place ionization chambers from the outside through the diaphragm into the lung (cylinder shape).

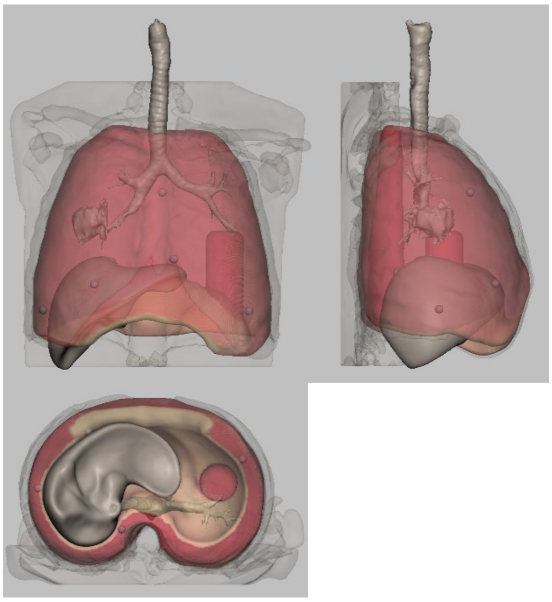

Figure 1: CAD design of generic lung with bronchial tree, tumor spot, CT-MR-markers, diaphragm with tube spacing and connected liver.

.

To enable the anthropomorphic breathing and motion of the entire lung, its inner open-celled structure with irregular patterns was digitally designed to include various sections with different structure designs and varying elastic properties in both contraction and expansion.

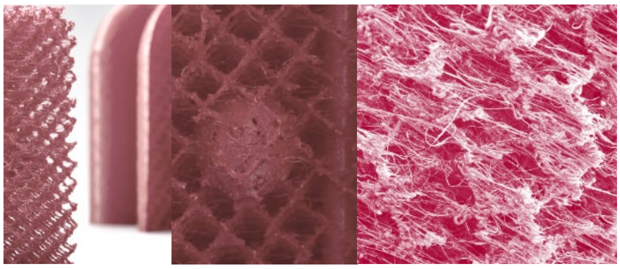

Figure 2: Printed open cell mesh structure with variations between generic tumor sphere and bronchial tube.

A fused deposition modeling (FDM) dual-head 3D printer was mechanically modified to enable printing of TPU soft materials of shore hardness A60. For the support structure a water soluble material (PVA) was chosen. During the printing process 6 CT-MR visual markers were inserted and encapsulated.

In order to make the elastomer materials visible with magnetic resonance imaging (MRI), the entire lung and its inner structure were surface-treated with MR visible material. Since 3D-printed thin flexible walls are known to be permeable to air, the outside of the lung was coated with a thin layer of PUR-skin to make the lung air-tight. The soft tissue displacement under breathing at different locations in the lung is currently being characterized.

With these newly developed processes, CSEM is able to design digital models that can be physically realized with 3D printing to produce various types of flexible, structured and MRI visible hollow anatomical organs. Even multi-organ sections including lung, diaphragm, stomach, liver, bowel with integrated visual markers can be realized, ultimately leading to an entire anatomical validation system. These flexible models will enable the exploration and simulation of soft tissue displacement in complex inner organ structures in a wide range of medical applications.

The future research effort will focus on the development of actuatable, life-like training or validation organs made of even softer material, and on the integration of sensors providing real-time feedback on various medically relevant parameters within the models.