Rapid Prototyping Raw Models on the Basis of High Resolution Computed Tomography Lung Data for Respiratory Flow Dynamics[1]

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Rationale and Objectives. Three-dimensional image reconstruction by volume rendering and rapid prototyping has made it possible to visualize anatomic structures in three dimensions for interventional planning and academic research.

Methods. Volumetric chest computed tomography was performed on a healthy volunteer. Computed tomographic images of the larger bronchial branches were segmented by an extended three-dimensional region-growing algorithm, converted into a stereolithography file, and used for computer-aided design on a laser sintering machine. The injection of gases for respiratory flow modeling and measurements using magnetic resonance imaging were done on a hollow cast.

Results. Manufacturing the rapid prototype took about 40 minutes and included the airway tree from trackea to segmental bronchi (fifth generation). The branching of the airways are clearly visible in the ^{3}He images, and the radial imaging has the potential to elucidate the airway dimensions.

Conclusion. The results for flow patterns in the human bronchial tree using the rapid-prototype model with hyperpolarized helium-3 magnetic resonance imaging show the value of this model for flow phantom studies.

Key Words. Pediatrics; development; congenital malformation; ventricles; 3D visualization

Radiologic imaging provides a noninvasive modality to visualize human organ structures. With the revolutionary technological developments of the past decade, radiology has grown beyond the visualization of two-dimensional structures. Multislice helical computed tomography can handle up to 320 slices within <1 second, recording volumetric data at submillimeter spatial resolution, which has improved quality in diagnostic radiology. Three-dimensional image reconstruction by volume rendering has made it possible to visualize anatomic structures in three dimensions for interventional preoperative planning and procedures. The recently introduced method of rapid prototyping is one modality with a promising future in academic and industrial research.

Rapid prototyping can be used to produce models of living organs from high-resolution in vivo images representing the actual structure in three dimensions. Humans are considered to be the most evolved and complicated organisms, yet we are still uncertain about many human physiologic processes, because in vitro models are used to mimic in vivo processes.

In this work, a rapid-prototype model of the human trachea and bronchial tree was constructed from in vivo human high-resolution computed tomographic (CT) images and remodeled at a 1:1 scale. The resulting model was then used as a flow phantom for gas flow experiments with hyperpolarized

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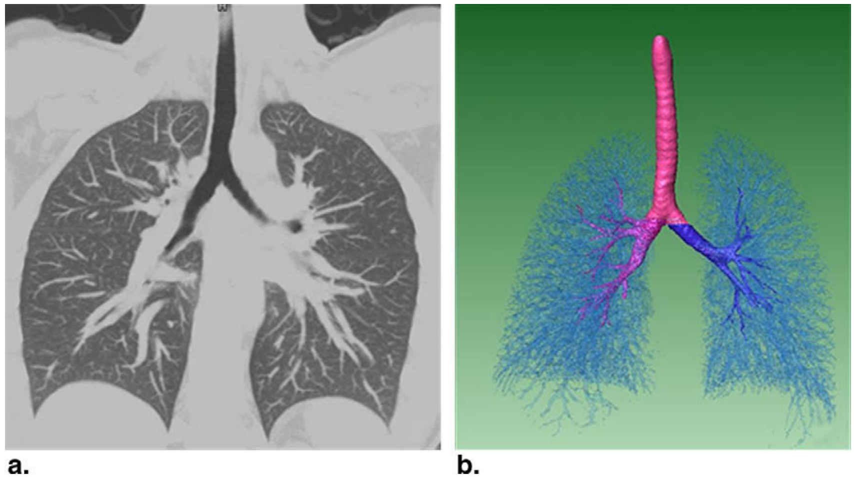

Figure 1. Three-dimensional mesh **(b)** constructed from high-resolution computed tomographic images **(a)**.

helium-3 (^{3}He) magnetic resonance imaging (MRI) to study the flow pattern of gas through the bronchial tree.

MATERIALS AND METHODS

Patient and Imaging

A healthy, 20-year-old, Caucasian female volunteer who had never smoked underwent spirometrically controlled volumetric chest computed tomography at 96% of total lung capacity using a Siemens Sensation 64 (Siemens Medical Systems, Erlangen, Germany) at a slice thickness of 0.4 mm. Imaging was performed with approval from the local ethics committee and according to good clinical practice.

Rapid Prototyping

The CT images were segmented using a hybrid method, the combination of several mathematical methods. Larger bronchial branches were segmented by an extended three-dimensional region-growing algorithm that prevented the segmentation from being affected by leakage. The segmentation of smaller branches was achieved with the level-sets method. Different initialization types were used for the seed points, such as thresholding and colliding fronts. Additionally, the complementary vascular tree of the lungs was also segmented. The images were converted into a stereolithography file and used to provide the base three-dimensional data set for computer-aided design on a laser sintering machine. This technology allows the reproduction of a computer-aided design data set as a cast model from various materials (1). For this experiment, laser sintering was chosen because of the MRI compatibility of the material used. The cast was hollow, thus allowing the injection of gases for respiratory flow modeling and measurements using MRI.

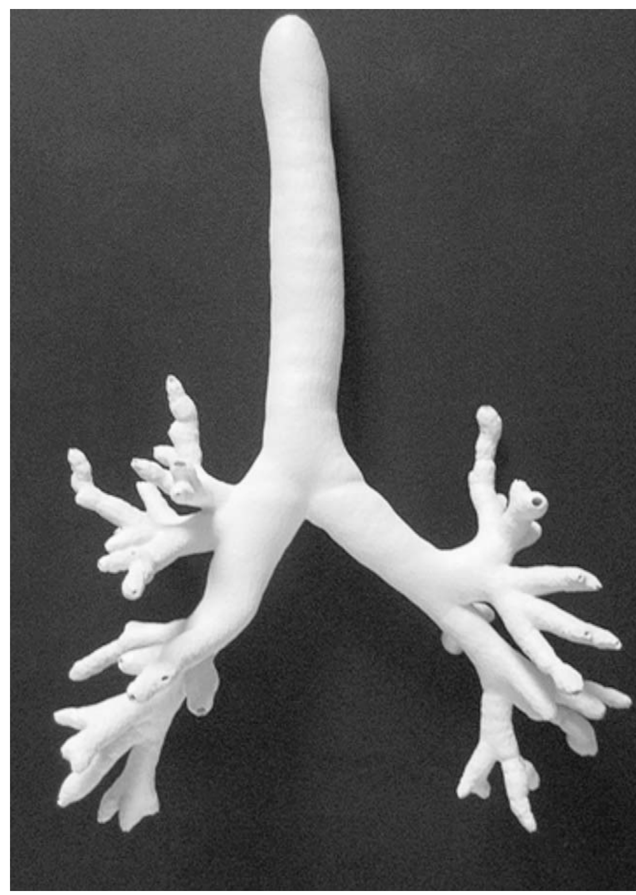

Figure 2. Airway model constructed by rapid prototyping of high-resolution computed tomographic images.

Helium-3 MRI

All ^{3}He MRI work for the flow respiratory analysis was conducted using a 1.5-T whole-body MRI system (Eclipse; Philips Medical Systems, Cleveland, OH). The system was