Construction of an anthropomorphic thorax phantom using CT scan segmentation and 3D printing

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ABSTRACT

To fabricate an individualised anthropomorphic thorax phantom using a three- dimensional (3D) printing technique. Based on human chest CT images, the phantom contained a 3D- printed tissue shell filled with tissue equivalent materials. This phantom mimics the human thorax and designed to provide the ground truth to find out the actual source of adventitious sound coming from the lungs. As it is not possible to find out the actual location of source producing the cracking, wheezing sounds inside the human lungs. So a phantom is designed which mimics a human thorax so that on applying various stethoscopes, microphones inside it so as to obtain an estimated value or location of the particular source.

Keywords: 3D Printing, Thorax phantom, Segmentation

1. INTRODUCTION

Phantoms are widely used to provide a ground truth for testing and quality assurance of medical imaging devices. However, although commercial phantoms often consist of materials with realistic tissue densities, they commonly have simple generic forms and sizes that do not closely resemble real patients, making it difficult to extrapolate the performance of an imaging system in phantoms to humans. Affordable 3D printing is increasingly available and offers new opportunities to tailor phantoms for specific clinical and research purposes. To design robust imaging solutions for different clinical scenarios, a patient-like phantom that mimics the real size, anatomy would, therefore, be desired. 3D printing may make this possible, allowing for better optimisation of image acquisition parameters and validation of matching software. The phantom consisted of tissues which act as a mould and was printed hollow.

2. MATERIALS AND METHODS

2. A. Imaging data for manufacturing of the 3D model

A computed tomography (CT) scan of a person was selected to create the 3D model for printing. The selection criteria was the presence of good quality of bones and a CT scan without artefacts. The DICOM (Digital Imaging and Communication in Medicine) images in the NRRD format were imported into 3D Slicer software. The thorax phantom was divided into lungs, bones and tissues. Based on the image in Axial, Sagittal and Coronal regions, each part of the bones, lungs and tissues were segmented and 3D reconstructed.

The models were created from the CT images in the software 3D Slicer. The model of tissue shell was transformed into Ultimaker S5 (Figure 1) and processed with solid generation (Figure 2).

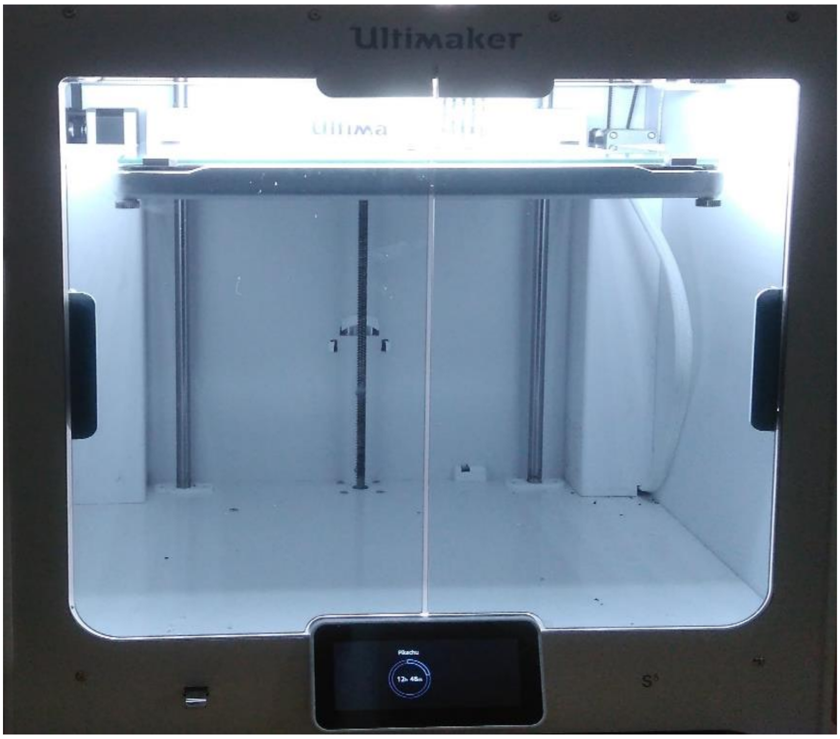

Figure 1: Ultimaker S5

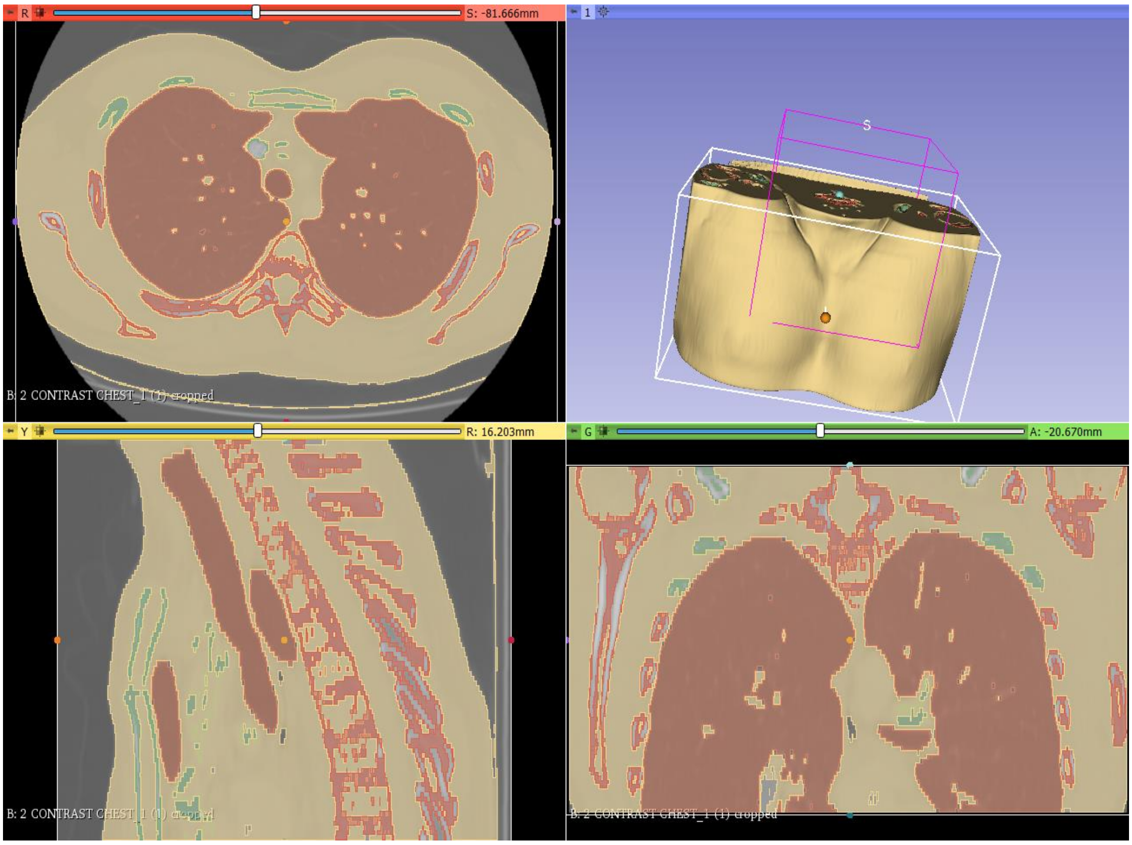

Figure 2 Illustration of Axial region, sagittal region, Coronal region, 3D Reconstruction

2. B Segmentation of Regions of Interest

The data acquired from CT scan was segmented according to regions of interest i.e., lungs, tissues and bones separately in the software 3D Slicer with the help of algorithms Grow from seeds, Editable intensity range which basically selects the regions particularly which falls under the similar intensity range.

3D Slicer is a free, cross-operating system, open-source piece of extensible software, built off of VTK and ITK that specializes in medical image visualization and computation. It serves as a platform to facilitate development of clinical-oriented image analytic tools for clinical research applications. It is capable of using Digital Imaging and Communications in Medicine data from low-dose CT scans and is still able to construct acceptable models.

Grow from seeds is a feature of Segment Editor which can be used for segmenting objects that cannot be easily separated because they have similar image intensity and they are very close to each other (or even fused together in some places). It uses a ‘FastGrowcut’ and similar region growing algorithms.

The algorithm then grows the seeds until it reaches the edge of the anatomy or a different growing seed. There is then a back and forth until it stabilizes on what the edge really is. The result is a 'label' file which has all the voxels labelled as background or one of the entities of interest. Once everything is segmented to the level, then applied volumetric smoothing of each entity before creating the surface models.

The other technique which used as a common segmentation technique is Thresholding. This typically involves applying a threshold then going in and cleaning up the model until the desired output is obtained. But it is suitable for quickly viewing data or creating rough models and not for creating high quality models to be printed.

2. B. 1 Lung segmentation

The HU mean values of lung module were measured to be -1347.82 – 195.95HU. The segmentation was done with the Grow from Seeds by using paint and selected the seeds and hence got separated with an assigned Yellow colour.

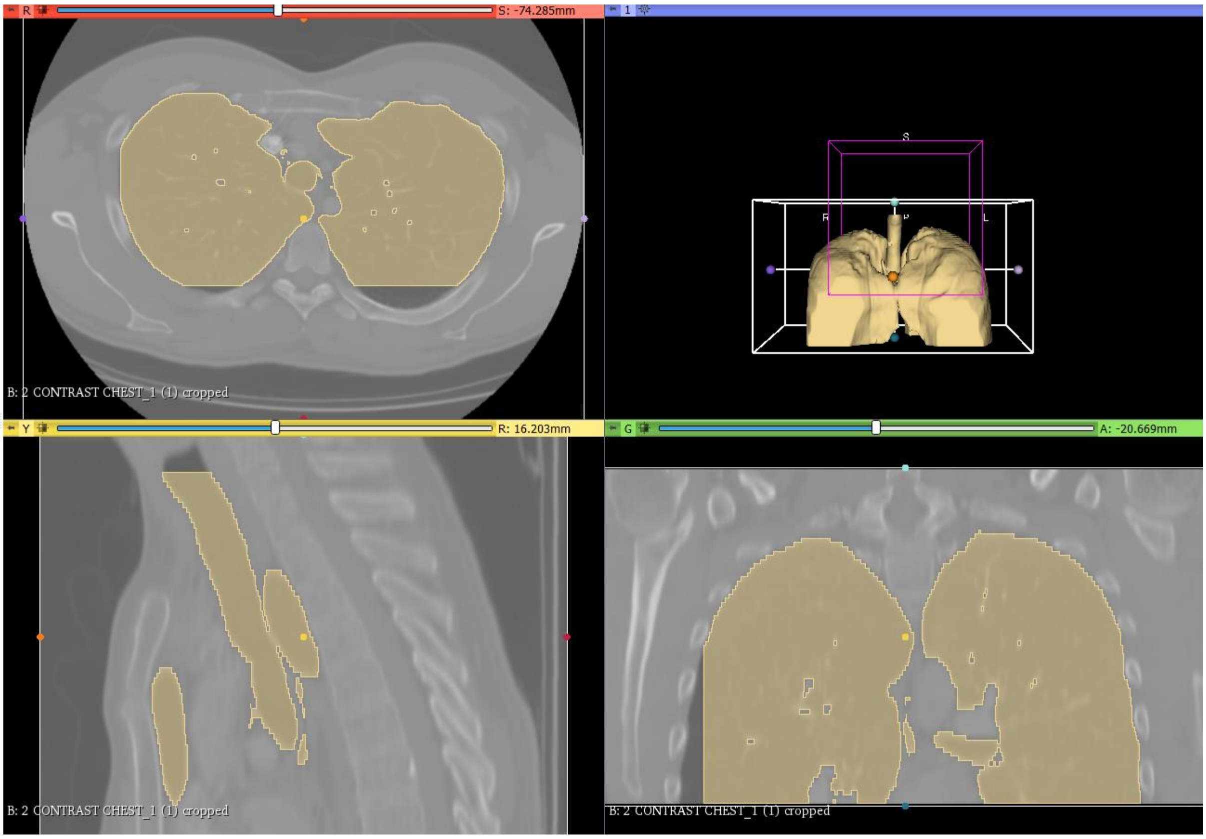

Figure 3: Segmentation of Lungs.

2. B. 2 Bones segmentation

The HU mean values of bones module were measured to be 169.82 – 1736.13Hu. The segmentation was done with the algorithm Grow from seeds by using paint and selected the seeds and hence got separated with an assigned Green colour.

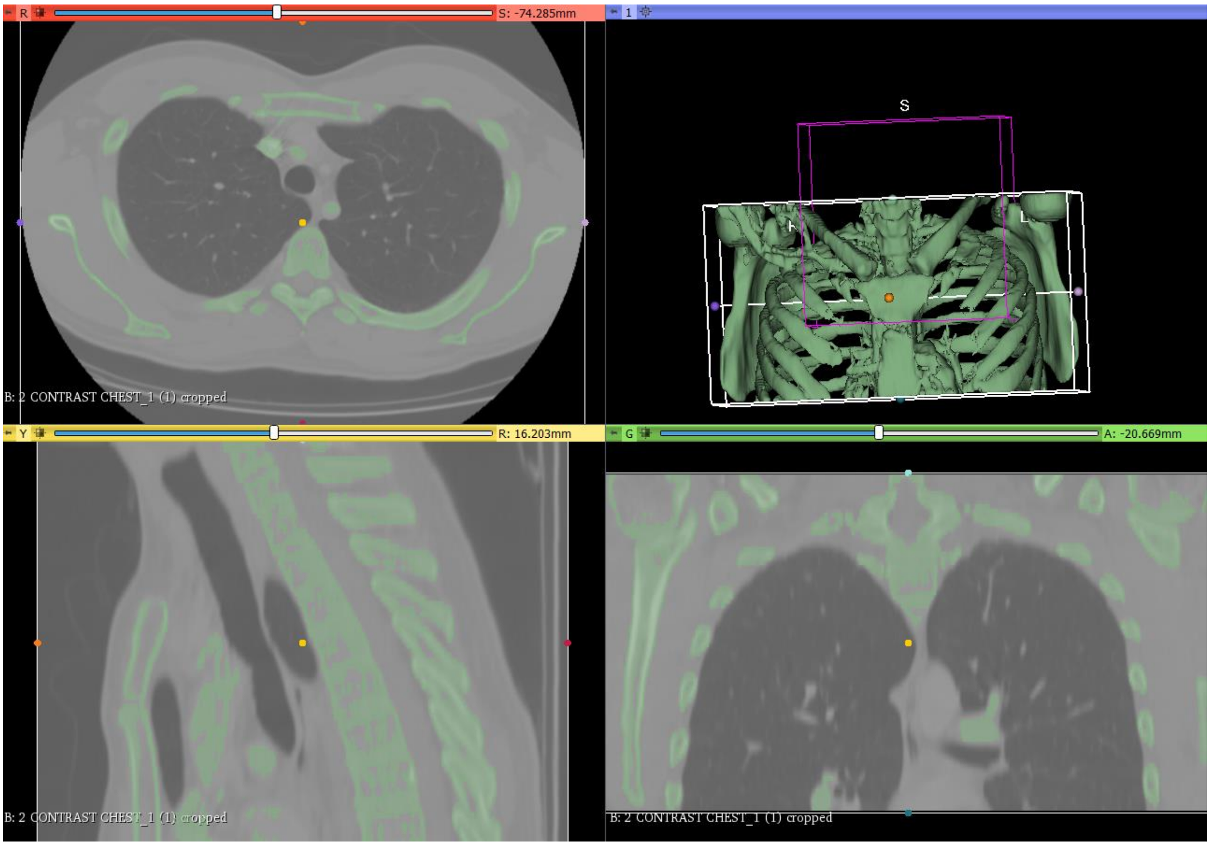

Figure 4: Segmentation of Bones

2. B. 3 Tissues segmentation

The HU mean values of tissues module were measured to be -768.84 + 224.62HU. The segmentation was done with the algorithm Grow from seeds by using paint and selected the seeds and hence got separated with an assigned Brown colour.

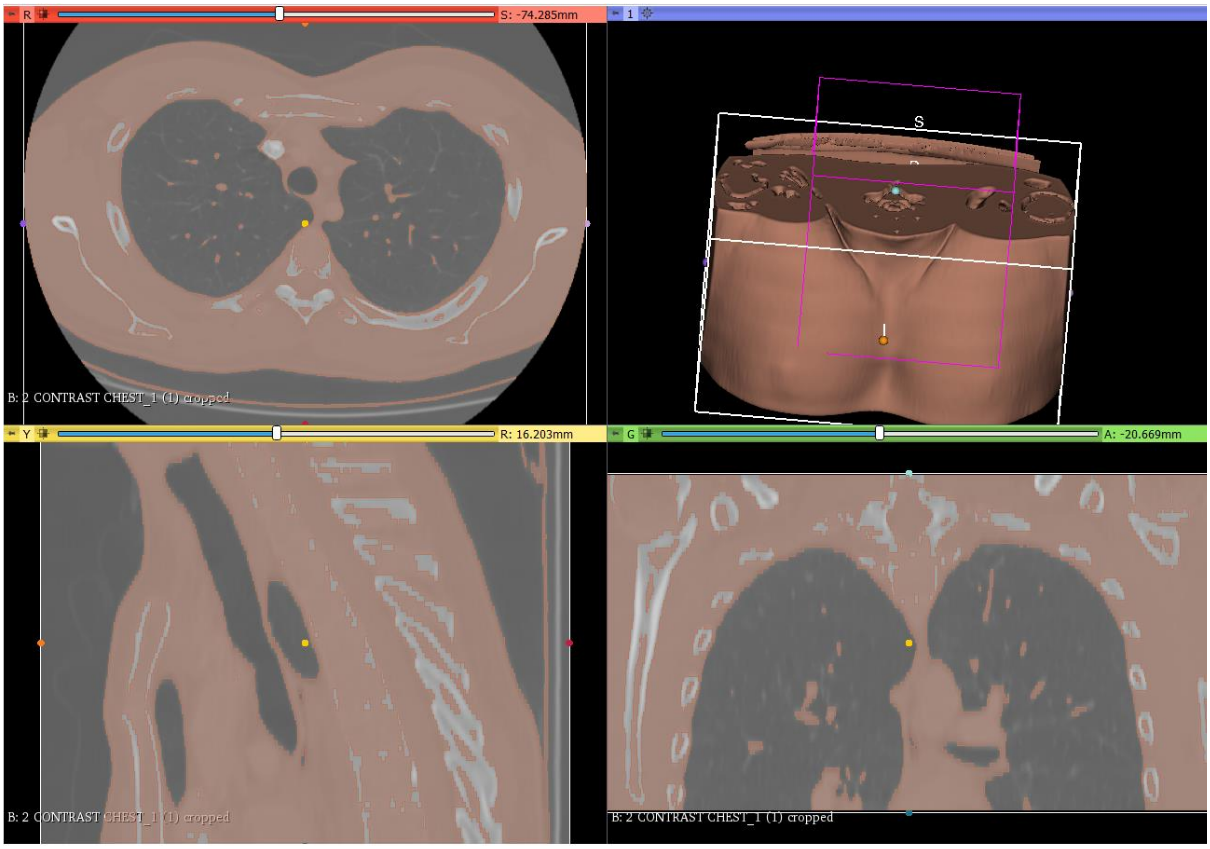

Figure 5: Segmentation of Tissues

2. C 3D printing models and materials

The segmented mesh files for the chest wall were converted into the Standard Tessellation Language (STL) format for 3D printing. This file format is widely used for rapid prototyping, 3D printing and Computer- Aided manufacturing. STL files describe only the surface geometry of a three-dimensional object without any representation of colour, texture or other common CAD model attributes. An STL file describes a raw, unstructured triangulated surface by the unit normal and vertices of the triangles using a three-dimensional Cartesian coordinate system.

The material used in printing the thorax is Co-Polyester (CPE). CPE is a chemically resistant material and has strong mechanical properties and temperature resistance (75°C to 110°C) provides tough and durable printed parts. Hence plays a major role in 3D printing for its low fine particle emission.

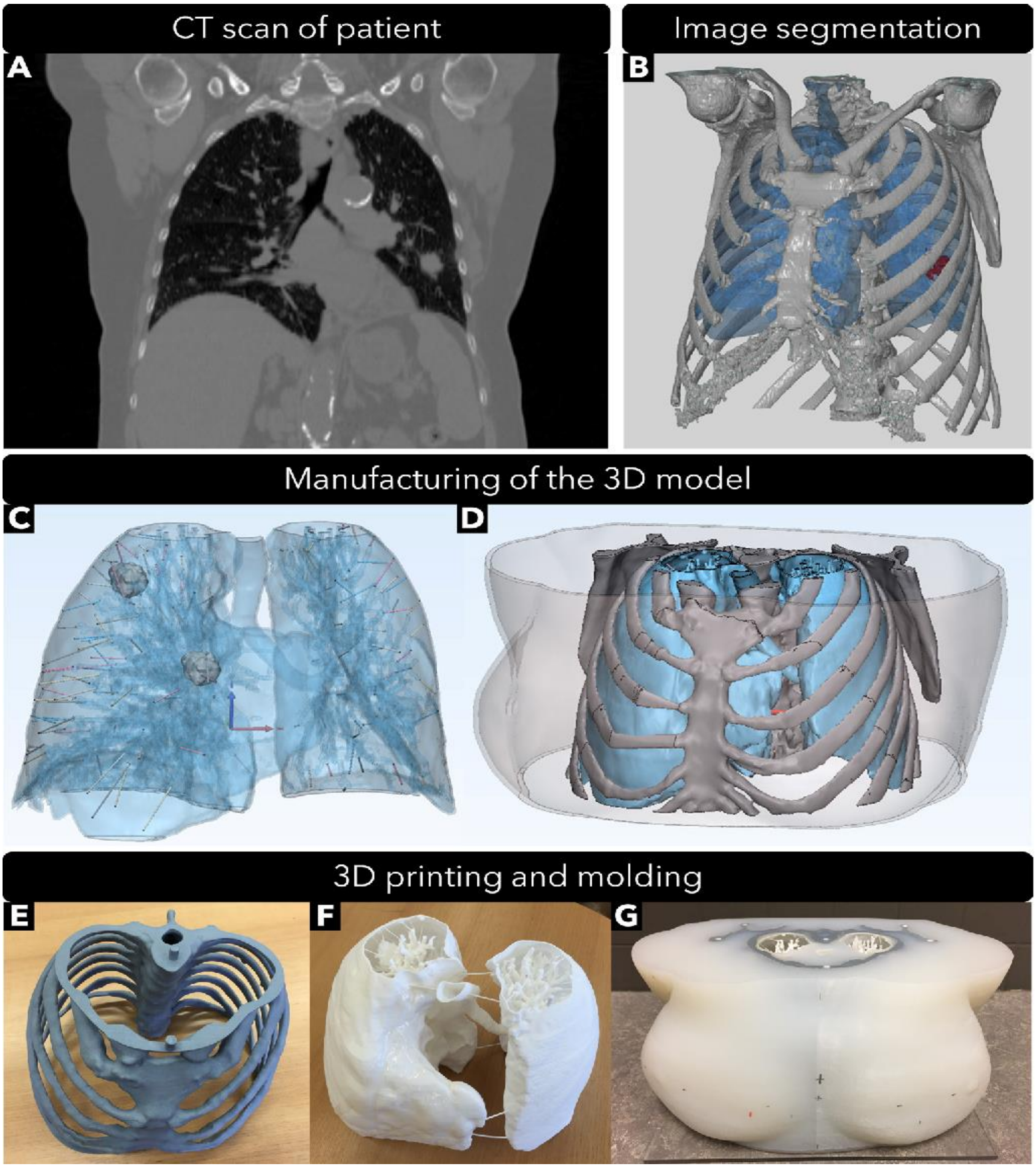

Figure 6: An example of an image of an anthropomorphic thorax phantom through 3D printing

3. RESULTS

The total printing time was 25 hours and phantom preparation time, for example, removing support materials, assembling all parts of the phantom was 23 hours.

Before printing the phantom, some STL files of objects like Cone, Prism, Cylinder, and Cube were printed with the material Polylactic acid (PLA) which took 24 hours to print. These objects were printed to understand the basic concept of Standard Tessellation Language (STL) and 3D printing.

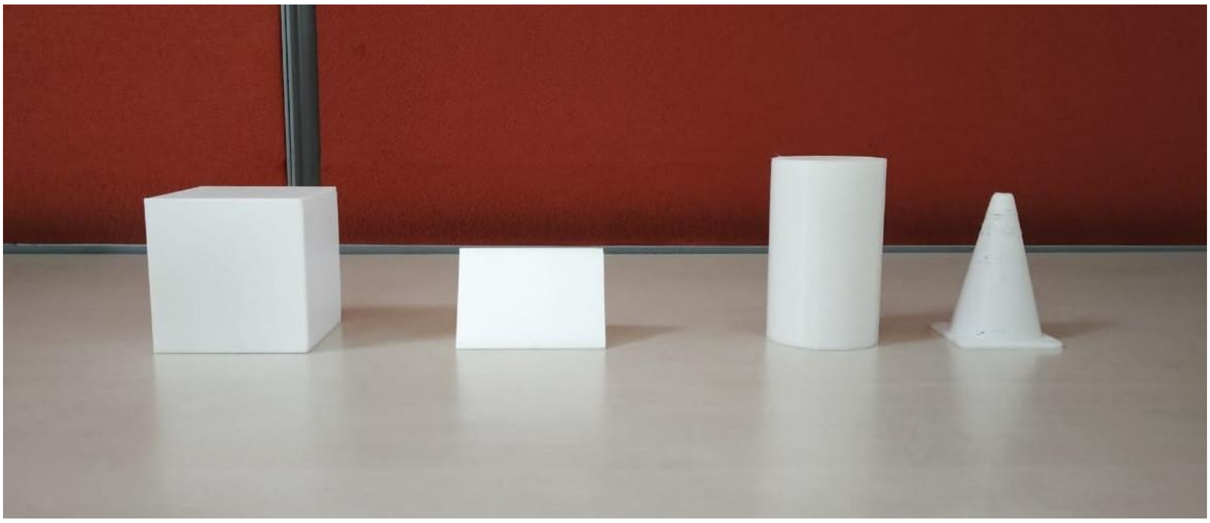

Figure 7: Illustration of 3D Printed objects like Cube, Prism, Cylinder, and Cone respectively.

4. DISCUSSION

With the development of 3D printing technology, anthropomorphic phantom can be manufactured in a simple and fast manner. In this experiment, this thorax phantom provides a ground truth for localisation of signals and will find out the actual location of the cracking and wheezing sounds coming from the lungs. With this methodology, by applying multiple sensors and digital stethoscopes, the localisation of signals will be obtained and will play a major role in Healthcare.

The advantage of this phantom is that it acts as a mould and hence allows bones and lungs to be inserted for further experimental research. Additionally, this design was successfully developed by using a CAD software program, hence making it possible for others to redesign and reproduce new phantom models. In fact, numerous other open sources software programs are also available on the internet for the users to download and use to build their phantom designs.

The primary challenge of 3D printing had been seeking the most apt printing methodology, which is inclusive of selecting suitable printable materials, determining the correct temperature settings of the extruders, and choosing the most appropriate printer protocols. Another problem that was experienced had been during the printing process of the removable inserts due to the surface intricacy and the size of subtle diameters.

5. CONCLUSION

In conclusion, this study demonstrates that a 3D printed modular, anthropomorphic thorax phantom can be produced from volumetric CT images. The phantom consists of tissue module enclosed by Co-Polyester (CPE). It was shown that the CT parameters of the different modules can be adjusted by adjusting the threshold ranges. The organs like bones and lungs can also be added to this phantom for further research purposes.

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