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Rapid Prototyping Method Applied to the Development of Lung Calibration Phantoms from Patient-Specific Anatomical Data

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Introduction

An in-vivo bioassay system is calibrated using physical phantoms that mimic the human body in terms of shape and radiation attenuation characteristics. Existing phantoms have not been revised for decades and do not realistically represent all portions of the population of workers who may be internally contaminated. Furthermore, current phantom fabrication methods are time consuming and expensive. This work proposes a modern approach to phantom design. Our method uses rapid prototyping techniques to develop phantoms from person-specific anatomical images. To demonstrate this method, anatomical images of a virtual phantom known as VIP-Man have been used to develop a physical lung phantom for radiobioassay applications.

Methods And Materials

A lung phantom designed for bioassay applications should have the following characteristics: 1) The geometry of the phantom should be similar to a real human lung; 2) The phantom lung should be made of a material which mimics, as closely as possible, the radiation attenuation properties of real human lung (ICRP 89) over a specified range of gamma-ray energies. This means the phantom lung should have a density of roughly 0.26 g/cm^3 and an effective atomic number of about 7.49. ; 3) A known amount of radioactivity should be spread uniformly throughout the model.

To this end, polygon mesh files were created to describe the lung surface information of the image-based computational model known as VIP-Man (Fig. 1). This VIP-Man vritual phantom was developed by Xu et. al. 2000 using images from the Visible Human Dataset supplied by the U.S. National Library of Medicine. The VIP Man's right lung has a volume of 1771 cm^3. The Rhinoceros 4.0 software (Robert McNeel & Associates, Seattle, WA) was used to edit and convert the mesh file to stereolithography (STL) format ready for rapid prototyping (Fig.2).

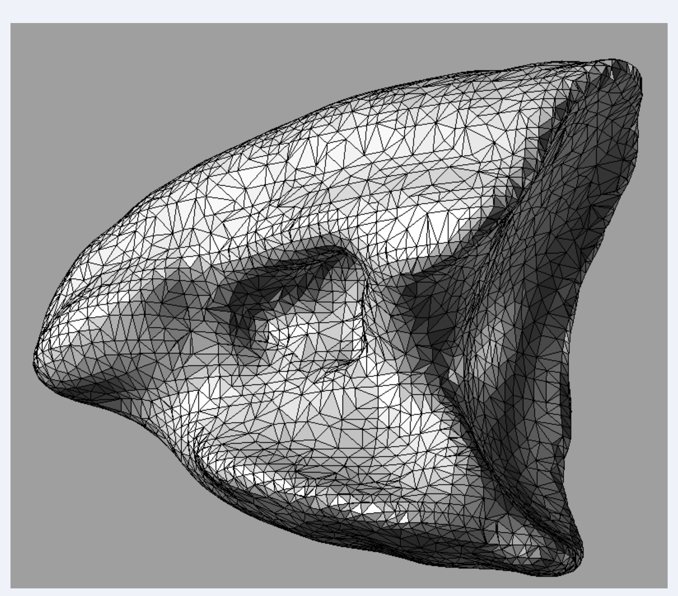

Fig. 1. Polygon mesh file of the VIP-Man's right lung

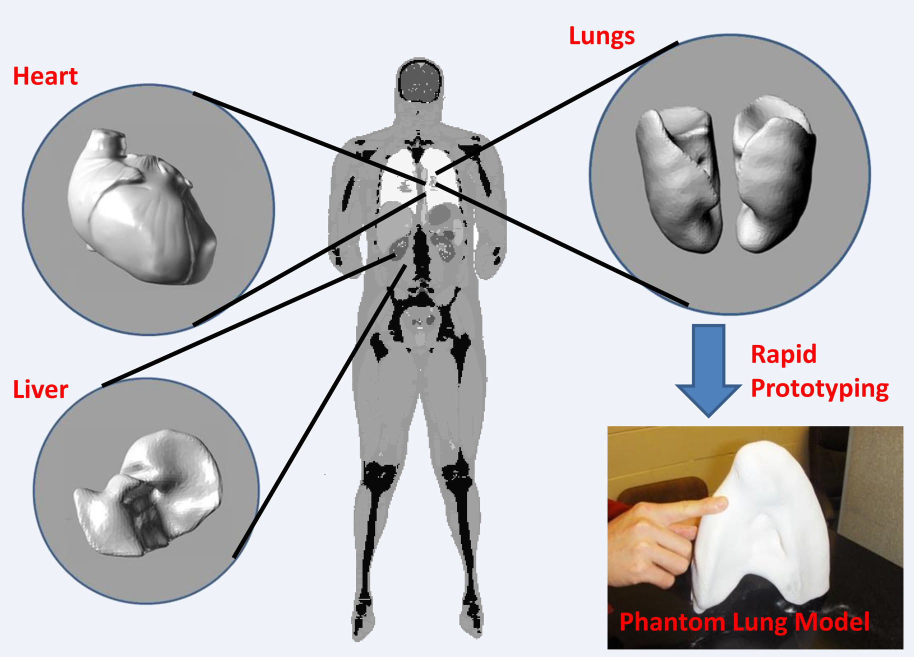

Fig. 2. Schematic of the phantom fabrication method. Organ mesh files are generated for the VIP Man voxel data and used to create physical models via rapid prototyping.

Fig. 3. The Z-Corp Z402 3D Printer

Fig. 4. The plaster prototyped lung

The Z-Corp 3D Printer (Fig. 3) in Rensselaer's Advanced Manufacturing Laboratory (AML) was used to create a plaster prototype. The Z-Corp Z402 3D uses a powder-binder printing process to create parts. Each printed layer is 0.004 inches thick. After one layer has been completed, the build platform lowers and the next layer is printed. The total printing time for the lung was roughly 3 hours (Fig. 4).

The plaster material from which the prototype is made is not suitable to be used directly as a lung phantom. Instead, the plaster model must be used as a basis for the creation of a mold from which tissue equivalent lungs copies can be cast. The mold was created using an RTV Silcone rubber (Fig. 5).

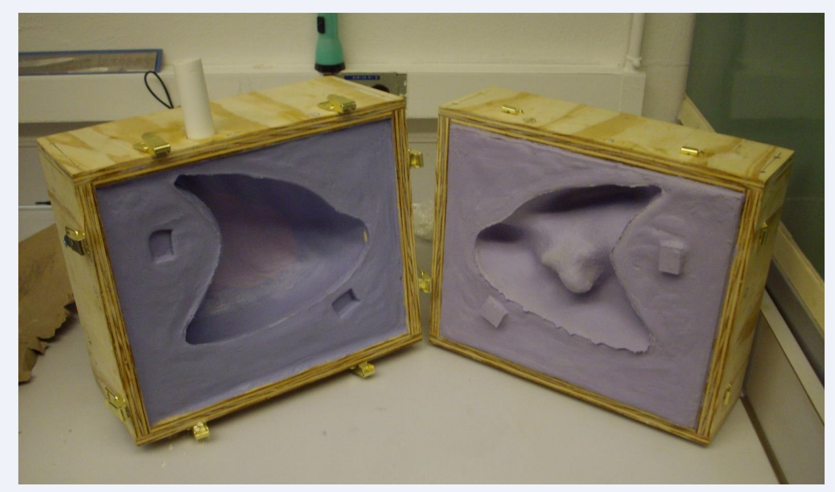

Fig. 5. Silicone rubber mold of the lung model is used to cast tissue equivalent parts.

$$Z_{eff} = \left(\sum_n f_n Z_n^{\xi}\right)^{1/\xi}$$

$$\xi \sim 2.94$$

$$f_n = fraction\ of\ electrons\ belonging\ to\ n^{th}\ element$$

The lung tissue substitute used in this work was described by Traub et. al. 2006. The base material for the tissue substitute is a commercially available two-part expanding polyurethane foam mixed with a compound of high-Z materials to increase the electron density. In this case, we add 5.25% $CaCO_3$ by weight.

The expanding polyurethane foam exerts great force on the mold. On recommendation from Dr. Traub of PNNL (Traub et al. 2006), aluminum plates connected by threaded metal rod were used to secure the two halves of the mold and to prevent excessive amounts of mold flashing (Fig. 6).

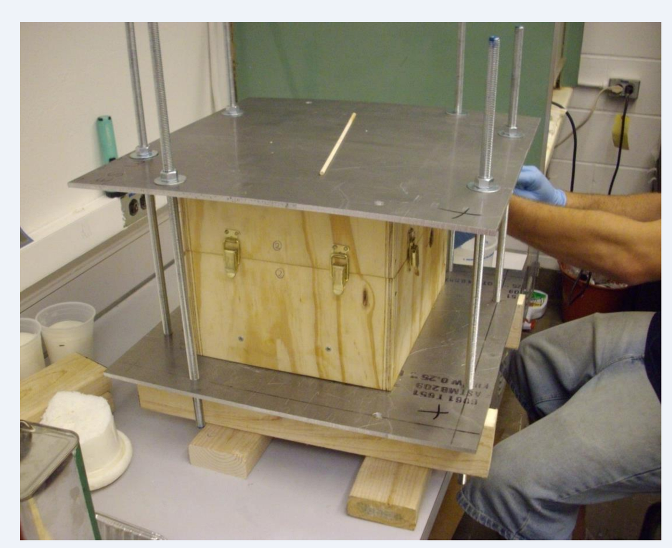

Fig. 6. Aluminum plates secure the mold during casting

Results And Conclusions

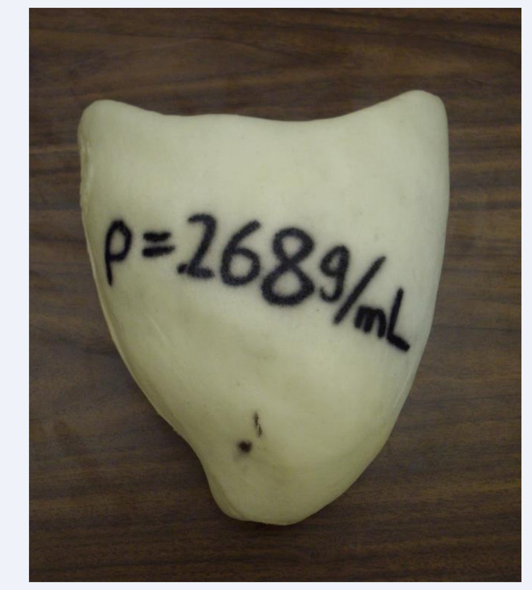

Fig. 7. The physical phantom lung

The final lung has a volume and shape similar to that of the VIP-Man computational model and a density and effective atomic number similar to real human lung (ICRP 89). The density of the lung was calculated weighing the phantom lung and was determined to be 0.268 g/cm^3. The radioactivity can be added to the lung materials to create a phantom useful for in-vivo radiobioassay calibrations. Color pigments will also be added to the polyurethane for the purpose of qualitatively gauging uniformity of the radioactivity. In the future, the elemental composition of the lung phantom will be verified by elemental analysis methods.

The value of the described method lies in the fact that it is completely generalizable to one's specific needs and to many different applications. Ultimately, it will be possible to use medical images to create person-specific physical phantoms (an assembly of many different organs) for radiobioassay applications.

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