Design of a More Stable Phantom for Combined NIR and X-ray Imaging

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Abstract

Optical imaging used for medical applications has been commonplace for decades. With advances in camera technology and increased consumer interest in surgeries where post-operation is more cosmetically appealing and with faster recoveries. These shifts have pushed advancements in clinical procedures that require precision surgical instruments. Phantoms can serve as a calibration tool for surgical equipment as well as training for surgical procedures allowing an accurate representation of human tissue. The drawbacks of the phantoms currently on the market are, limited applications, short "shelf life," and high production costs. We are designing and developing a cost-effective phantom that is both near infrared (NIR) and X-ray penetrable with removable inserts allowing for efficient testing of many different parameters. We will be using various optical techniques to evaluate the properties of current phantoms and design new molds with CAD software such as Meshmixer.

Introduction

An X-ray phantom is a testing object with known features and dimensions designed to be imaged in a medical imaging system for purposes of quality control, equipment calibration, dosimetry, and education [1]. Combined NIR imaging is achieved by combining x-ray images with images achieved using wavelengths that are near infrared on the electromagnetic spectrum. Phantoms designed both to appear realistically in x-ray and NIR imaging must accurately represent human skin and flesh [2] and as a result, often have a short shelf-life due to the materials required to mimic living tissue. The goal of this research is to develop both a more stable phantom that can be used for longer periods of time before degradation than other available phantoms as well as to make the phantom easily producible with highly accurate known locations of features that will appear similar to living bone, tissue, and fluorescent features.

Methods and Materials

The skeletal insert of the mouse phantom, shown in Fig. 1, was created by taking an X-Ray of the Leeds Micro CT Mouse Phantom. This X-Ray file was in a DICOM format. To convert the DICOM file into an STL format (for compatibility purposes), we utilized the software Seg3D which was selected for its ease of use and simple interface. Using Seg3D software, we generated an isosurface that was converted into a mesh within the software and exported as an STL. The STL file was edited in Autodesk Meshmixer, where unwanted artifacts in the mesh were removed, and gaps in the skeletal structure that were not correctly generated from the conversion in Seg3D were filled. Materials used in the phantom were adapted from [2]: a breast phantom with a corn oil and agarose base. Within the breast phantom was another phantom with an ethanol and agarose base to emulate cancer tissue. Copper BBs were placed in an acrylic insert that was cut with a laser cutter, this acrylic insert was then placed inside the phantom to emulate a skeletal structure and the copper BBs would serve as known locations for X-Ray calibration to determine locations of other unknowns. The phantom also has Indocyanine Green (ICG) placed in wells with known locations within the acrylic insert to serve as NIR calibration points.
The mold shown in Fig. 3 was used to cast the phantom was designed in the Autodesk Fusion 360 CAD software and printed in PLA using an Ultimaker S5. The mold serves as a reusable and consistent medium to produce phantoms and is easily and accurately reproducible.

Figures

Figure 1

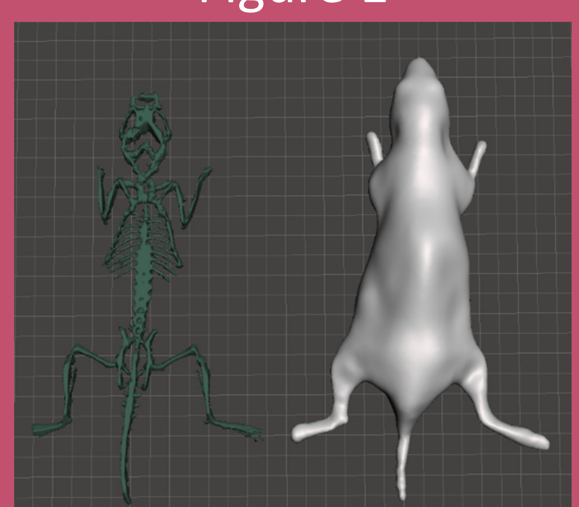


Figure 2

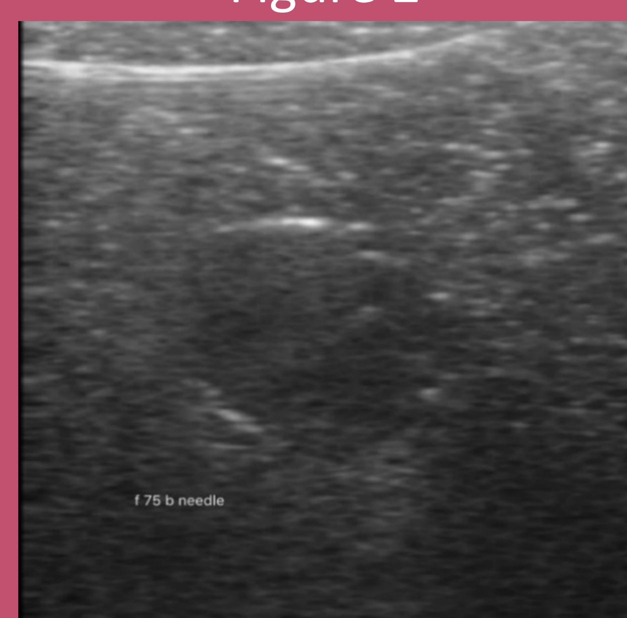


Figure 3

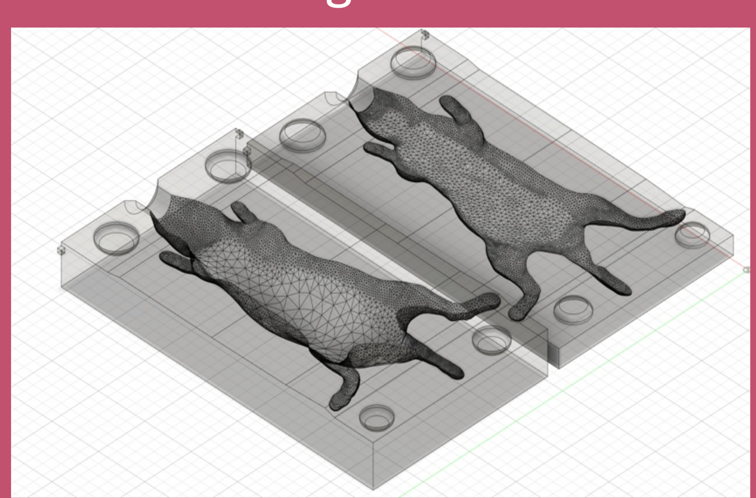


Figure 4

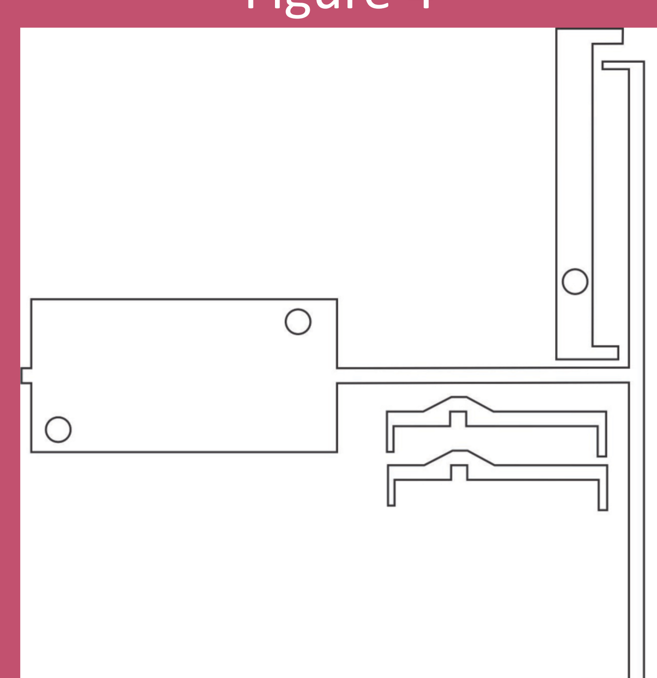
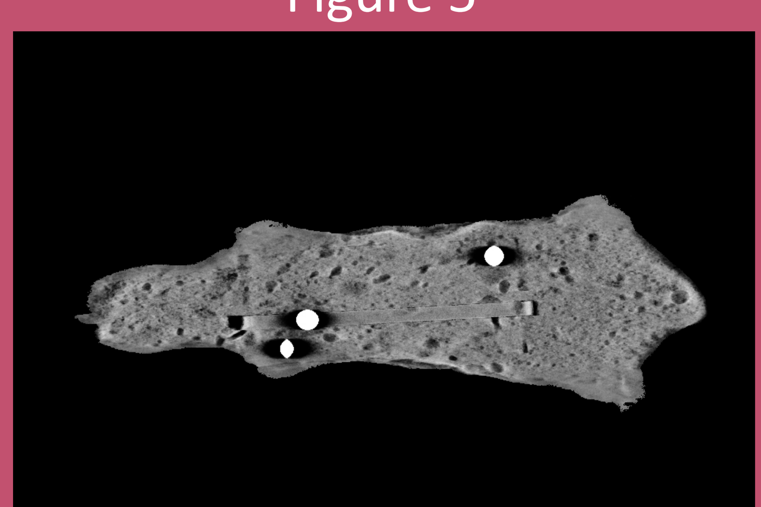


Figure 5



Results

The skeletal insert of the mouse phantom, shown in Fig. 1, was created by taking an X-Ray of the Leeds Micro CT Mouse Phantom. This X-Ray file was in a DICOM format. To convert the DICOM file into an STL format (for compatibility purposes), we utilized the software Seg3D which was selected for its ease of use and simple interface. Using Seg3D software, we generated an isosurface that was converted into a mesh within the software and exported as an STL. The STL file was edited in Autodesk Meshmixer, where unwanted artifacts in the mesh were removed, and gaps in the skeletal structure that were not correctly generated from the conversion in Seg3D were filled. A first design of the skeletal insert was designed in CorelDraw based on the STL skeleton file and was laser cut in acrylic using Epilog's Fusion Pro. An initial functional acrylic-with-copper-BB design, shown in figure 4, was created to achieve the goals of the skeletal insert without immediately facing the issues of structural stability, fit into the mold, or fit of the copper BBs that became apparent in the full skeleton. Although this insert does not visually look like a skeleton, it does achieve the goal in having three known locations to appear in an x-ray, shown in figure 5.

The mouse phantom mold process began with taking a 3D scan of the Leeds Micro CT Mouse Phantom using a Go!Scan 3D scanner and importing the scan file into Autodesk Meshmixer, which was selected for ease of use and free access, to clean up the scan and edit the shape to optimize it for 3D printing. With the resulting OBJ file, the process of designing the mold began using Autodesk TinkerCAD (Autodesk, Inc., San Rafael, CA, USA), which was selected for ease of use, free access, and previous experience. Later, Autodesk Fusion 360 replaced TinkerCAD to make use of more advanced features. 3D printing of prototypes was done with an Ultimaker S5 (Ultimaker B.V., Waltham MA, USA), chosen for availability, reliability, and quality of printing, as well as the Ultimaker Cura software to prepare STL files for printing. An iterative design process was utilized to design, 3D print, and test the molds. Shown in Fig. 1 is the mesh of our initial skeletal insert to the side of our mouse model.

Fabrication protocol for the phantom was adapted from [4]: a breast phantom with a corn oil and agarose base. Within the breast phantom was another phantom with an ethanol and agarose base to emulate cancer tissue. First, the ethanol-based cancer phantom was created, and a spherical Christmas ornament approximately 2.5cm in diameter was used as a mold for the cancer phantom. Then the cancer phantom was made in accordance with [4]. The solution was then poured into a breast mold designed in Autodesk's Tinkercad. The mold was sliced in Cura and printed on an Ultimaker S5. Before the breast phantom had fully hardened, the cancer phantom was immersed into the phantom approximately 10 mm. After allowing to cure for 24 hours, Ultrasound tests were conducted on the phantom to evaluate its ultrasound penetration and clarity. Shown in Fig. 2 is an ultrasound image taken of our phantom at 7.5 MHz in this image, at approximately the center is the ethanol-based cancer phantom. Directly above the cancer phantom is a white streak, which is a metal wire which was inserted into the phantom to provide a visual reference.

Conclusion

This work's objective was to identify potential experimental procedures and material compositions to produce a phantom model capable of dual-modality imaging in the NIR and X-Ray region for clinical and research applications. A 3D printed mold was designed based on a 3D scan of the Leeds Micro CT Mouse Phantom, which was edited in Autodesk Meshmixer. The 3D printed mold was used in the creation of the phantom since 3D printing allows for rapid prototyping of an effective mold that requires minimal post-print processing. Gelatin-based materials were chosen to both properly emulate breast tissue as well as be penetrable by NIR and X-Ray energy. The creation of these phantoms requires a mold. A 3D insert was created that resembles a mouse skeleton. This skeletal insert will be placed into the mouse phantom when the phantom is cast to better emulate in vivo testing of a mouse.

What we hope to accomplish is selecting the materials that will be used in the creation of our phantom. When the development of the phantom has been completed, the goal is to develop a procedure such that the phantom can serve a quantitative purpose. By knowing the coordinate placement of one foreign object within the phantom will allow it to serve as a calibration standard so it can be used to determine the 3D placement of any object within a certain region.

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