A 3D printed patient-specific dual compartment breast phantom for validating MRI acquisition and analysis techniques

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Abstract: Anthropomorphic phantoms are essential tools that are used to validate MRI acquisition and analysis techniques. 3D printing technologies are rapidly advancing and can be utilized to achieve anatomically realistic geometries that are not attainable using traditional manufacturing methods. Herein, we present the design of a 3D printed anthropomorphic breast phantom that includes the key breast tissue compartments which are filled with desired tissue-mimicking fluids. The breast phantom can be used for validating MR, coil development, safety evaluation and pulse sequence evaluation.

I. Introduction

A common method for validating magnetic resonance imaging (MRI) acquisition and analysis techniques is through the use of objects of known geometries and/or configuration, which are known as physical phantoms. A number of MRI phantoms are commercially available; however, these phantoms tend to be costly and feature simplified geometries [1-3]. Many applications may require customizable and anatomically realistic configurations, which are not typically achievable with traditional manufacturing technologies.

Three-dimensional (3D) printing/additive manufacturing technologies are rapidly advancing and can be utilized to achieve anatomically realistic geometries that are not attainable using traditional manufacturing methods. [4]. In this study, we aimed to assess the feasibility of manufacturing an anatomically accurate, patient-specific 3D printed anthropomorphic breast phantom that includes the two key breast tissue compartments. The breast phantom can be used to validate MRI coil development and pulse sequences as well as to perform safety evaluations.

II. Material and Methods

A clinical MRI of the breast was obtained and fibroglandular tissue (FGT) and fat were segmented from this MRI data (Mimics 21.0, Materialise, Leuven, Belgium). The image segmentation was converted to 3D surface mesh models which were hollowed with a 7mm external wall thickness for the fat and 3mm thickness for the FGT (3-matic 13, Materialise, Leuven, Belgium), (Figure 1).

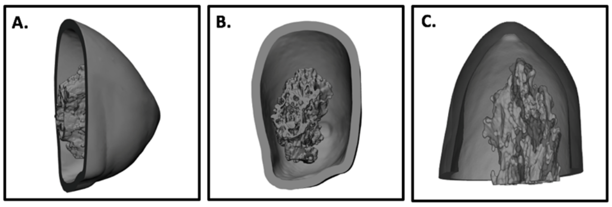

Figure 1: A. Sagittal view, B. Coronal view and C. Axial view of 3D computer model generated from clinical MRI data highlighting the fat (outside) and FGT (inside) compartments.

In the 3-matic software, a 3D base was designed with an engraving to align the FGT with the other printed parts. In addition, individual fill ports were incorporated so that the fat and FGT could be filled with anthropomorphic materials. Each part was separately 3D printed in acrylonitrile butadiene styrene (ABS) with a 0.178 mm layer thickness (Fortus 360mc, Stratasys, Eden Prairie, MN), (Figure 2); and the 3D printed components were assembled.

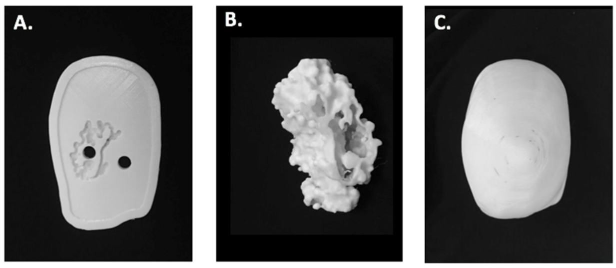

Figure 2: A. 3D printed base with grooves for FGT placement, B. 3D printed FGT, and C. 3D printed breast model.

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In order to mimic the dielectric properties of human breast tissue, the FGT compartment was filled with a polyvinylpyrrolidone-based material (σ =0.3 S/m, ε_r =45) and the fatty compartment was filled with peanut oil (σ =0.1 S/m, ε_r =7.4) [5,6].

To determine the accuracy of the 3D printed breast model MR images of the 3D printed phantom were acquired on a 7T system (Magnetom, Siemens, Erlangen, Germany) using a Siemens 7.0T Tim Head Coil (Invivo Corp., Pewaukee, WI). A 3D volumetric sequence with a spatial resolution of 1.1 mm x 0.7 mm x 0.7 mm was used, with the following imaging parameters: FA =10˚, TR = 7.61 ms, TE = 2.00 ms, Averages =7. The FGT and fatty compartments visualized in the phantom model were segmented as described above and 3D surface meshes were generated. The 3D volumes obtained from the segmented 3D printed model were compared to those obtained from the original MRI data, and the DICE similarity coefficient (DSC) was calculated.

III. Results

The 3D printed phantom was successfully configured and no leaks were observed. Figure 3 shows a representative MR image of the 3D printed breast model, with the black representing the 3D printed material, FGT in light gray, and fat represented in dark gray.

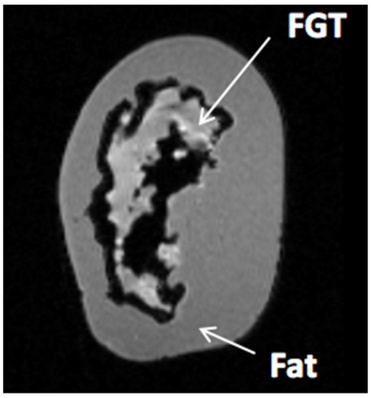

Figure 3: MR image of the 3D printed breast model which was filled with tissue-mimicking materials to represent fat (dark gray) and FGT (light gray). The black internal section represents the internal 3D printed FGT compartment.

Corresponding 3D reconstructions of the 3D printed breast phantom model are shown in **Figure 4.**

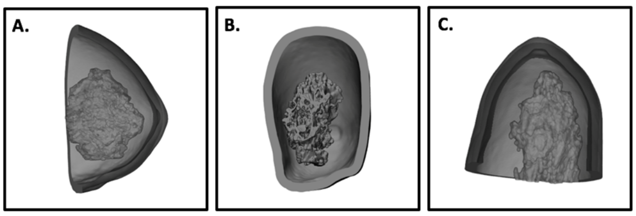

Figure 4: A. Sagittal view, B. Coronal view and C. Axial view of 3D computer model created from the 3D printed breast model highlighting the fat (outside) and FGT (inside) compartments.

The 3D printed breast phantom demonstrated a good visual match to the original 3D model which was created from source MRI data. The volume of the segmented fat was 169,083 mm^3 and 151,195 mm^3 on the original MRI images and 3D printed phantom images respectively (DSC = 0.94) and the FGT volumes were 45,290 mm^3 and 56,514 mm^3 respectively (DSC = 0.89).

IV. Conclusions

3D printing offers novel and flexible opportunities for creating models with realistic distributions of human tissue. We have demonstrated the feasibility of constructing an anatomically accurate 3D printed breast phantom that mimics the complex FGT and fat distribution in an individual human breast. The phantom allows each compartment to be filled with desired tissue-mimicking fluids.

In general, MRI phantoms may be used for routine quality assessment tests that are necessary to allow for quantitative imaging, including diffusion weighted imaging and MR spectroscopy, especially to obtain consistent measurements across different vendor hardware and using varied magnetic field strengths. The anthropomorphic 3D printed breast phantom presented here can be used for validating quantitative MRI techniques, coil development, safety assessment, and pulse sequence evaluation. New 3D printing technologies and materials are rapidly emerging, therefore we expect to be able to create highly accurate 3D printed anthropomorphic phantoms with even more complex geometries in the future. In addition, future studies will evaluate phantom performance at 1.5T and 3T.

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