Personalized three-dimensional printed breast model for quantitative assessment of breast density using magnetic resonance imaging

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Editorial

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ABSTRACT

Three-dimensional (3D) printing has become an increasingly developed technique in the medical field and has been used in many clinical applications. Research has consistently shown that 3D-printed models derived from patient’s imaging data can serve as valuable tools for examining different breast-MRI protocols, testing radiofrequency coils, and evaluating system performance. This editorial highlights the utility of personalized 3D-printed breast model for the quantitative breast density assessment using MRI. A personalized 3D-printed breast model was developed and fabricated using silicone and peanut oils to mimic the MR-associated properties of fibroglandular and adipose breast tissues. The silicone and peanut oils’ T1 relaxation times were correspondingly determined on a 3T MRI system and linked to the tissue reference values.

Key Words
Magnetic resonance imaging (MRI), breast density, fibroglandular-tissue, three-dimensional printing, model, silicone oil, peanut oil, quantitative, assessment

Implications for Practice:

1. What is known about this subject?
Magnetic resonance imaging (MRI) is widely used as an adjuvant modality for the screening of women at high-risk of developing breast cancer, such as those with high breast density.[1,2] Although some research has been conducted on the use of 3D printing techniques to develop breast phantoms for MRI, there are currently no phantoms available for quantitative breast density assessment based on a realistic morphology of breast structures derived from MR images of human tissues.[3-10]

2. What new information is offered in this editorial?
Personalized 3D-printed breast model using silicone and peanut oils simulates the MR-related characteristics and appearance of fibroglandular and adipose breast tissues, respectively. This editorial summarises our research experience of using 3D printing techniques and tissue mimicking materials (TMMs) to resemble the T1 relaxation times of the corresponding breast tissues.

3. What are the implications for research, policy, or practice?
A personalized 3D-printed breast model can be used to identify the optimal breast MRI protocol and measurement method for the quantitative assessment of breast density, thus estimating the risk of developing of breast cancer.

Introduction

Breast density-an autonomous risk element of breast cancer-is defined as a measure of dense fibroglandular tissue relative to non-dense fatty tissue.[11-13] In line with this risk association, women with dense breasts have shown a greater probability of inducing breast cancer relative to those with fatty breasts.[14,15]
Although some research has been carried out on the development of anthropomorphic breast models for X-ray

imaging, there is still inadequate data available for MR imaging.[3-10] Also, much uncertainty still exists as to whether the most relevant TMMs are able to sufficiently replicate the MR-related characteristics and resemblance of breast structures, especially fibroglandular tissue.[16-19] This has been corroborated by our latest experiment using 3D-printing methods and tissue-equivalent materials to mimic the breast tissue relaxation times for MR imaging.[20] Notwithstanding considerable information about the role of MRI's in quantitative breast density analysis, the optimal imaging protocol and measurement method have not generally been agreed in this repect.[21,22] This editorial summarises some of the experiment's main findings and demonstrates the utility of a personalized 3D-printed breast model for quantitative breast density assessment using MRI.

Personalized 3D-printed breast model using silicone and peanut oils for quantitative breast density assessment

3D-printed models based on patients' imaging data have allowed to learn procedures, educate students, and enhance the individual's perception of complex anatomical structures and pathologies by using such realistic reproductions. In this study, a 3D-printed breast model was developed, with the intention of providing a more precise assessment of breast density based on a realistic morphological breast structures that obtained from MR images of human-tissue. The breast examination was performed on a 1.5T MRI system (MAGNETOM Aera, Siemens, Germany) with a dedicated breast coil. Based on the recommendations from our recent systematic review and meta-analysis, the protocol for breast imaging has been selected as high-resolution, non-contrast-enhanced T1-weighted images, which assist in the distinction between non-glandular fatty tissue and glandular tissue.[21]

Overview and design

The personalized 3D-pinted breast model comprises two main parts: an outer shell, which simulates the texture and form of the skin, and an inner structure, including fibroglandular and fatty tissues, which imitates the breast compositions. Firstly, the 3D skin shell and the cover have been made from polylactic acid (PLA) with the fused deposition modelling (FDM) technology. [20] The outer shell was printed in 0.15 mm layer height, took an average of 40 hours printing time, and had a 3.0 mm average thickness and 12.5 µm resolution (Table 1). Figure 1 shows the personalized 3D-printed breast model of the outer skin layer and sections to be filled with fibroglandular- and adipose-equivalent tissues. Then, the 3D fibroglandular models were constructed as hollow structures and have been made from photopolymer resin with the digital light processing (DLP) technology. [20] They were printed with 10 seconds of curing time per layer, 0.05 mm in layer thickness, took an average of 17 hours printing time for both left- and right-models, and had a 2.0 mm average thickness and 47 µm resolution (Table 1). Figure 2 shows the fabrication of the hollow 3D-printed for both left- and right-fibroglandular models. Finally, the fibroglandular models were submerged in a fat-equivalent medium to replicate the adipose tissue's MR-related properties and T1 relaxation time. The hollow skin and fibroglandular 3D-printed models were scanned on a 3T MRI system (MAGNETOM Prisma, Siemens, Germany) to ensure neither the PLA nor the photopolymer resin produce MR signal.

Results and discussion

The T1 relaxation times of the five designated substances (agarose gel, silicone rubber with/without fish oil, silicone oil, and peanut oil) were determined on the same 3T MRI system, with the objective of simulating the MR-associated properties of the fibroglandular and adipose breast tissues. As shown in Table 2, results indicated that the silicone and peanut oils were found to be closely analogous to the T1 relaxation times and MR-associated properties of the respective tissues, which are 1515.8 ± 105.5 and 405.4 ± 15.1 ms, respectively. Consequently, those substances were selected to fill the hollow 3D-printed models. Figure 3 demonstrates a summary of the fabrication procedure of the personalized 3D-printed breast model. In a brief summary, the hollow 3D-printed fibroglandular models were filled with a silicone oil and then closed using UV-curable resin. Subsequently, the fibroglandular models were fastened inside the skin model using an acrylic-based adhesive. Next, the space between the skin shell and the fibroglandular models was filled with a peanut oil. Thereafter, the breast model was bounded with a self-constructed silicone gasket and cover. Finally, the cover was sealed using polycarbonate bolts and nuts. On completion of the construction process, the personalized 3D-printed breast model was examined on the same 3T MRI system in a prone position using a dedicated 18-channel breast coil. Interestingly, T1- and T2-weighted MR images of the personalized 3D-printed breast model using silicone and peanut oils showed that such model can be utilized as substitutes for the fibroglandular and adipose tissues, respectively. As shown in Figure 4, these selected oils in both T1- and T2-weighted images, yielded a tolerable degree of contrast and MR-associated features. Overall, the T1 relaxation times of the silicone and peanut oils used to imitate the fibroglandular and adipose breast tissues are comparable to their corresponding reference values stated in the literature.

Summary and conclusion

Personalized 3D-printed breast model based on TMMs can be used to determine the optimum MR breast-imaging protocols and measurement methods for the purpose of providing more precise assessments of breast density, thus estimating the risk of breast cancer. The developed model represents a novel approach of utilizing 3D-printing technique by further expanding its applications in the medical domain.

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PEER REVIEW

Peer reviewed.

CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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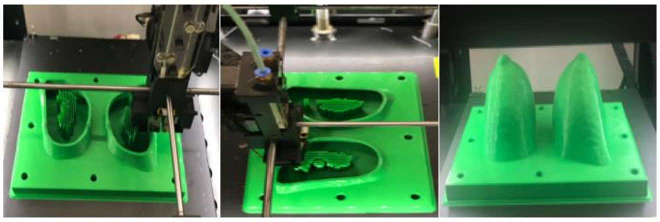
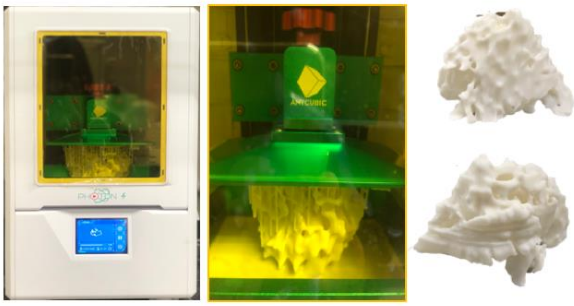
Figure 1: 3D-printed breast model of the outer skin layer and compartments to be filled with fibroglandular- and adipose-equivalent tissues. Reprinted with permission under the open access from Sindi et al.[20]



The 3D-printed skin shell and the cover have been made from polylactic acid (PLA) on a Raise3D N2 Plus 3D printer with the FDM technology. The outer shell was printed in 0.15mm layer height, took an average of 40 hours printing time, and had a 3.0mm average thickness and 12.5µm resolution.

Figure 2: 3D-printed models of the internal structures, which are the fibroglandular hollow structures. Reprinted with permission under the open access from Sindi et al.[20]



The 3D-printed fibroglandular models were constructed as hollow structures and have been made from photopolymer resin on an Anycubic Photon S 3D DLP UV resin printer with the digital light processing (DLP) technology. They were printed with 10 seconds of curing time per layer, 0.05mm in layer thickness, took an average of 17 hours printing time for both left- and right-models, and had a 2.0mm average thickness and 47µm resolution

Figure 3: Flow chart demonstrates the construction process of the personalized 3D-printed breast model for MRI. Reprinted with permission under the open access from Sindi et al.[20]

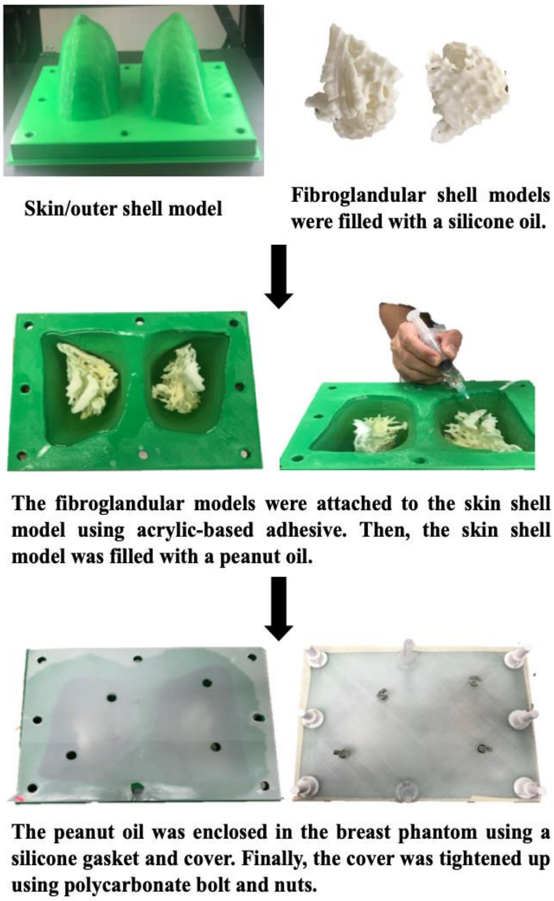
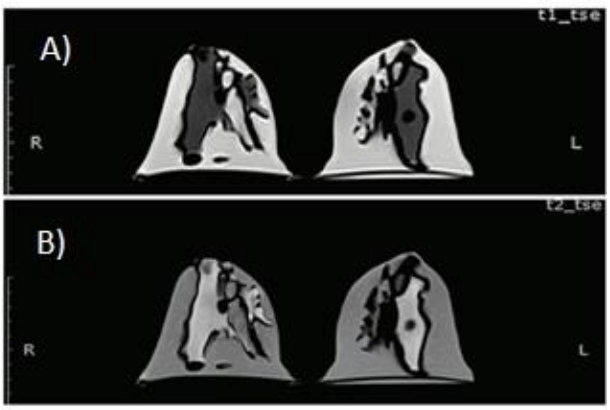


Figure 4: MR images of the personalized 3D-printed breast model. (A): T1-weighted image. (B): T2-weighted image using turbo spin echo (TSE) pulse sequence. Reprinted with permission under the open access from Sindi et al.[20]



The T1- and T2-weighted MR images of the personalized 3D-printed breast model using silicone and peanut oils as TMMs of the fibroglandular and adipose breast tissues, respectively.

Table 1: 3D-Printing parameters used for the development of the personalized 3D-printed breast model

3D printing parameters	Skin model	Fibroglandular model
Thickness (mm)	3.0	2.0
Layer height (mm)	0.15	0.05
Resolution (µm)	12.5	47
Curing time (sec)	-	10
Printing time (h)	40	17*

(*): For both left and right fibroglandular models.

Table 2: T1 Relaxation times of different materials for tissue surrogates used in the experiment. Reprinted with permission under the open access from Sindi et al.[20]

Phantom	T1 (average±SD, ms), 3T Siemens MR Scanner
Tissue Mimicking Material	
Fibroglandular shell	No signal
Skin/outer shell	No signal
Silicone rubber	577.2±107.8
Silicone rubber with fish oil	902.1±120.5
Fresh Silicone rubber	638.3±108.5
Silicone oil 50mm^2/s*	1515.8±105.5
Peanut oil (Basso)	405.4±15.1
Peanut Oil (Pressed Purity)	404.1±10.5
Agarose gel 0.5wt%	4015.5±100.2
Agarose gel 1.0wt%	3877.8±130.5
Agarose gel 1.5wt%	3404.8±255.9
Agarose gel 2.0wt%	3572.6±100.4
Agarose gel 2.5wt%	3617.2±101.5

(*): Viscosity unit.