

Abstract

A 3D printed anthropomorphic MRI phantom using contrast matched silicone–silicone oil–gelatin inks

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Radiation therapy is one of the major modalities for cancer treatment. Image-guided radiation therapy, particularly the magnetic-resonance-guided linear accelerator (MR-Linac), offers the potential to precisely track and destroy moving tumors by dynamically adjusting the therapeutic X-ray beam in real time [1]. This emerging treatment approach requires MRI phantoms that can simulate tissue responses to both imaging and radiation therapy for development and validation. An MRI phantom is a replicate tissue imaging characteristics such as contrast and signal intensity. They provide standardized images (ground truth) for scanner calibration, personnel training, and the development of new imaging methods.

Conventional MRI phantoms use simple moulds (e.g. cylinders or spheres) filled with aqueous fluids such as Gd^{3+} , Cu^{2+} , Mn^{2+} salts, or gels such as agarose, gelatin, carrageenan to enable specified MR T_1 and T_2 relaxation times, mimicking tissue contrast [2–3]. However, water-based phantoms can produce neither anthropomorphic phantoms, nor simulate the regional heterogeneity, nor the anisotropy of human tissue physiology.

Here we reported a silicone–silicone oil–gelatin (SSOG) system for anthropomorphic phantoms using 3D printing to directly manufacture phantoms for use in a 7T field strength, preclinical MRI scanner. This allows a variation in T_1 ranging from 1245 ms to 2242 ms, and T_2 ranging from 14.4 ms to 389 ms. The T_1 and T_2 values of the SSOG materials both increased as the weight fraction of gelatin gel increased. By varying the composition of the gel formulations, it is possible to mimic the T_1 and T_2 values of a range of human tissues and with and without disease pathology. Rheological tests were carried out to evaluate 3D printability of SSOG formulations, which confirmed appropriate shear thinning behavior, beneficial for direct ink printing. From the amplitude sweep results, the loss modulus gradually decreased as the weight fraction of gelatin gel increased from 0 wt% to 40 wt% which shows that the addition of gelatin gel leads to a reduction in the structural elasticity of the materials. Finally, we fabricated human brain MRI phantoms using extrusion-based 3D printing, these successfully demonstrate MRI visibility and tissue matched contrast.

AUTHOR'S STATEMENT

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