SILICONE-BASED GEL PHANTOMS FOR MULTIMODAL IMAGING

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We present a new class of materials designed for performance assessment of optical, acoustic and photoacoustic technologies, which hold the potential for extension to even more medical imaging modalities, such as MRI and CT.
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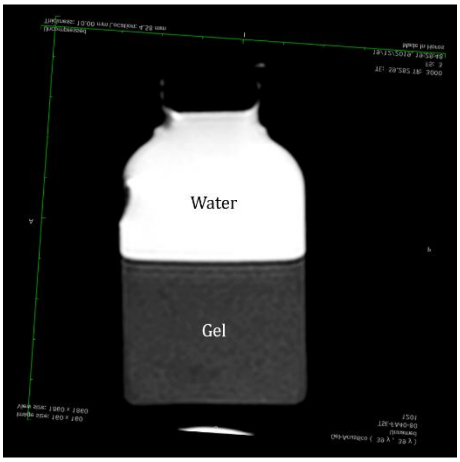
1. Abstract

Recent advances in the field of medical technologies are arousing a demand for new kinds of anatomical phantoms that may encode the biophysical features and enable an impartial validation of the technical specs of interest. In particular, this issue becomes more urgent and complex as the technological platforms are more multimodal or hybrid or involve multiple scales, anatomical sites or medical problems, as in the case of photoacoustic imaging (PAI) or bimodal PAI / ultrasound imaging, where the mechanism of contrast is optical or both optical and acoustic, and the detection is acoustic. In this context, several materials are under consideration [1], but a unitary standard for cross-platform implementation is still lacking.
Here, we propose a hybrid material made of a water-in-oil emulsion of glycerol and polydimethylsiloxane (PDMS) as a versatile platform for phantoms for PAI. This material displays intrinsic optical scattering, which varies with the ratio of glycerol to PDMS within the entire range of biological tissue, thus making it suitable for optical imaging [2]. On the other hand, PDMS is already in use in dynamic phantoms for ultrasound imaging, thanks to its acoustic versatility, in terms of attenuation and speed of sound, and its integrability with microfluidic circuitry.
We have shown that hybrid organosilicon / polyol phantoms retain the acoustic features of PDMS, i.e. speed of sound around 1150 ± 30 m/s and attenuation around 3.5 ± 0.4 dB/(MHz·cm), which resembles the value of tendon and may be steered to approach other cases of bio tissue [1]. Moreover, glycerol enables the incorporation of hydrophilic dyes as well as biological pigments of interest in PAI. In particular, we tested the use of hydrophilic or amphiphilic dyes, such as indocyanine green, PEGylated gold nanorods and whole red blood cells [1], or hydrophobic dyes as graphene. We have verified the use of this material under a commercial B-mode scanner and a homemade A-mode stage for photoacoustic analysis to recapitulate the ground-truth encoded in a multilayer architecture. We have also addressed its shelf life, and found that its acoustic and optical parameters remain consistent over at least three months of preparation.
Finally, we discuss the possibility to replace the polyol component with other viscous solutions, such as an aqueous paste of 9% polyvinyl alcohol, which may convey more fidelity in terms of thermodynamic coefficients, including in particular the Grüneisen parameter responsible for the efficiency of photoacoustic conversion. Moreover, having an aqueous paste confined within micro-droplets in a silicone continuum may evoke more analogies, such as the extent of macromolecular crowding of the cytosol and the cellularity of tissue. We have verified the use of this material as a phantom for Magnetic Resonance Imaging (see Figure 1). Images of the apparent diffusion coefficient of water display an average value around 700 mm^2/s, which is about 1/3 of that of pure water, and falls in the range of relevant cases of human tissue, such as brain.



T2-weighted morphological MRI image of a bottle containing a PDMS / aqeuous PVA mixture acquired with a Philips Ingenia 3T clinical MRI scanner

Overall, we believe that a water-in-oil emulsion featuring a silicone backbone may represent a versatile and biomimetic strategy for the fabrication of phantoms for hybrid PAI / ultrasound imaging, which may enable an immediate integration of microfluidic tools to simulate such structures as arterial and venous vessels. The replacement of the polyol component with other viscous and complex solutions may allow recapitulating even more thermodynamic, biochemical and biophysical parameters of interest for other technological platforms, such as MRI and computed tomography.
In conclusion, our approach may pave the way for a new generation of anatomical phantoms capable to encode a broad variety of relevant features for performance assessment of complementary and multimodal kinds of medical technologies.
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