# Novel Technique for MR Phantom Manufacturing

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**Background**

Use of MR phantoms is considered critical for successful longitudinal monitoring and calibration of scanner performance and for multicenter studies, when scanners at several locations are used in parallel (1). This is even more important with today's improved protocols for detecting pathology from MR images, typically using automated quantitative analysis methods that detect subtle changes in structure and texture. Phantoms have been suggested for sensitive procedures such as breast imaging (2) and gel-filled phantoms for radiotherapy dosimetery (3, 4). Yet current phantom manufacturing technology is limited by the coarse structure achievable with standard machining techniques. This prohibits creating phantoms with micro-features to calibrate for disease detection thresholds and to include realistic anatomy structures.

A promising phantom technology has been developed by Objet Geometries Ltd. (Rehovot, Israel); a 3D prototyping technology based on inkjet-type deposition of photopolymer. Layers of both hard, curable plastic and a gel-like support material can be "printed" at resolutions of 600x300x1600 dpi (42x84x16 microns) for objects as large as 33x34x20 $cm^3$. According to manufacturer specifications, free standing structures as small as 0.6 mm can be created making this an ideal platform to produce anthropometric phantoms for MR calibration and standardization. Interestingly, the support material for internal structures is a tissue-like gel that is typically imbedded with disk-shaped solid support structures, around 0.4 mm in size, used as a thickener to prevent flow during curing. To evaluate the polyjet method, several 4-cm cube-shaped phantoms were created and the hypothesis that the support gel was MR visible was tested. Additionally, the MR properties of the gel and minimum achievable structure size without gel removal were determined.

**Methods**

To investigate the potential utilization of the technology, the first two phantoms were parallel plate phantoms (figure 1a) with varying thicknesses of plates - one with a clear gel with a planned grid like "texture" by imbedding an array of 0.4 mm disk-shaped structures. The third phantom was a mixture of various millimeter scale textures, as seen in figure 1b. The 4-cm cube phantom had plate thicknesses of 350, 300, 250, 200 160, 96, and 48 microns, and the texture phantom structures at 1-mm and 2-mm structural sizes. These phantoms were scanned on a 1.5 Tesla GE Signa scanner with console version LX 9.0. Pulse sequence parameters used for routine human imaging were used: standard T1 weighted spin echo (SE) sequences, were obtained with a GE foot coil with TR 300 msec, TE 14 msec, FOV 5 cm, 512x192, Thk 10 mm, 2 NEX, 1:59 minute scan time. In addition inversion recovery SE and multiple-echo SE images were obtained for T1 and T2 estimation.

**Results**

Image signal to noise ratio was sufficiently high for phantom needs, and the grid-like texture was visible in the gel (figure 1a - insert). It can be seen that all plate thicknesses were visible. The relaxation coefficients for the gel are calculated at approximately T1 110 msec and T2 45 msec. It can be seen from figure 1b and 1c that the desired imbedded texture and structures are fully reproduced in the phantom. This is true for even sub-millimeter structures and textures and all are fully visible using standard MR imaging techniques and equipment.

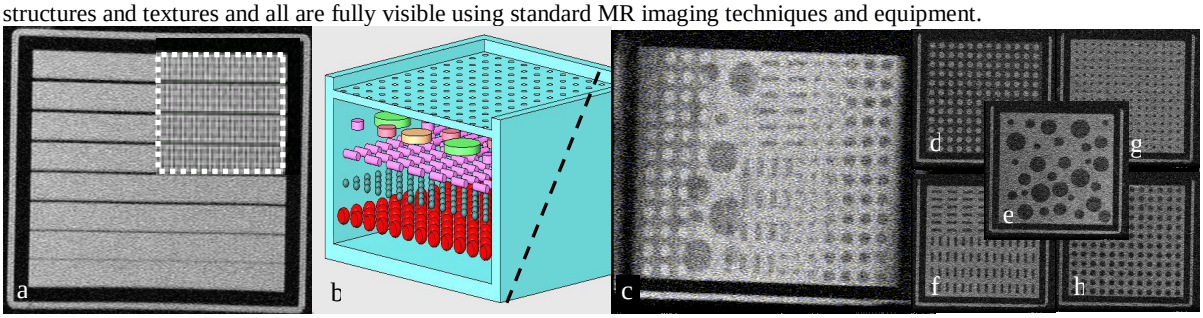


Figure 1: (a) 4-cm cubic parallel-plate phantom model and insert showing gel texture pattern. (b) 4-cm model for texture demonstration showing image plane for image (c) - oblique cross section through model. (d-h) individual layers in model.

**Discussion**

The images of figure 1 indicate the feasibility and potential of this phantom manufacturing technique. The textured gel regions and the thin plate structures are visible using standard equipment and sequences, and detectable texture changes show feasibility for a variety of phantom applications. Such applications can include cross-site and longitudinal calibration, system quality assurance using barely detectable objects, training phantoms for interventional radiology and technician training. These phantoms show promise in being able to model tissue texture, something the gross phantoms in use today cannot do, as well as microstructure such as trabecular bone networks.

Besides serving as a basis for generating intensity textures in the gel, micro-particle arrays can be used to change apparent relaxation and proton density. Susceptibility differences between the solid and gel phases can cause enhanced T2 relaxation and regions of different signal intensity can be generated by including solid micro-particles in the gel by utilizing image partial volume effects. Additionally, the micro-particles can be used as diffusion barriers from research into diffusion tensor imaging. Overall, the phantom tested here demonstrate that the structure size is sufficient for MR phantom use, both in mimicking solid structures and tissue textures as seen in pathology.

One of the limitations of current phantom fabrication is the inability to modify the MR relaxation properties of the gel locally. It would be desirable that the phantom mimic the MR properties (T1, T2, magnetic susceptibility, etc) of the tissue being modeled, and that these be variables that can be changed on a local basis to create multiple tissue type phantoms, such as for imaging the head. MR relaxation parameters can be designed as susceptibility differences between the solid and gel phases and then imbedding solid microstructures of certain shapes within the gel or by mixing contrast agents and paramagnetic materials in the gel. Both of these changes to the chemistry of the photopolymer need further investigation.

**Bibliography: (1)** Tofts PS. Standardisation and optimisation of magnetic resonance techniques for multicentre studies. J Neurol Neurosurg Psychiatry. 1998 May;64 Suppl 1:S37-43. **(2)** Liney GP *et al.* A simple and realistic tissue-equivalent breast phantom for MRI. J Magn Reson Imaging. 1999 Dec;10(6):968-71. **(3)** Low DA, *et al.* Evaluation of polymer gels and MRI as a 3-D dosimeter for intensity-modulated radiation therapy. Med Phys. 1999 Aug;26(8):1542-51. **(4)** Koch N, *et al.* Assessment of geometrical accuracy of magnetic resonance images for radiation therapy of lung cancers. J Appl Clin Med Phys. 2003 Autumn;4(4):352-64.

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