World of Phantoms: Reference Standards for Bench to Breast MRI

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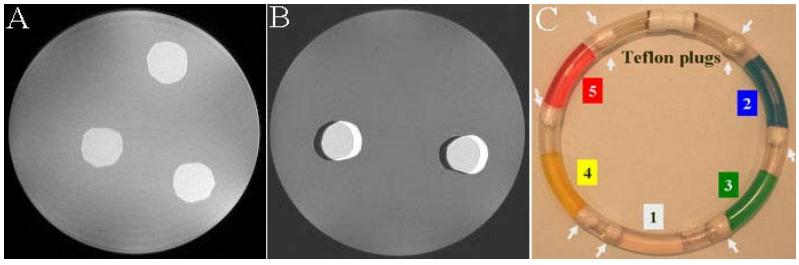
Abstract: We have developed a method for making agar phantoms for MRI that mimic human tissue in terms of their relaxation pathways, including T_1, T_2, and T_2*, and other magnetic interactions. Here, we describe a unique approach to developing air bubble-free phantoms that are sensitive to changes in scanner performance. Phantoms with varying concentrations of agar (0-3%) and Omniscan (0-1 mM) solutions were made, and the T_1 and T_2 values of these phantoms were determined. In addition, fat was suspended in an irregular pattern so that the phantom more accurately mimicked the breast. Here, we describe phantoms designed for two different applications. The first type of phantom can be used for periodic quality assurance to evaluate overall scanner function. The second type is a unique soft phantom, and is designed for attachment to the breast or other areas of the body so that it can be scanned in the course of each clinical protocol.

Introduction: Phantoms are increasingly important for standardizing and optimizing scanner performance, and calibrating data analysis (see, Graves *et al.*, *JMRI*, **28**:278-281, 2008). Agar phantoms have potential advantages because they can be designed to mimic tissue. However, air bubbles in agar present an important challenge to the development of agar-based phantoms. Air bubbles produce large susceptibility gradients; these, in turn, lead to distortions in the images that render the phantoms unusable. Therefore, we have developed a unique approach to developing air bubble-free, ultra-pure agar phantoms. In addition, the phantoms can be very heterogeneous in order to produce a better model for human tissue. In this report, we describe protocols for making phantoms for the periodic quality assessment of the scanner and designs for making reference standards, to be used in the course of each clinical protocol for *in vivo* MR imaging of the breast.

Methods: Ultra-pure agar (0.5-3% w/v) solutions with or without OMNISCAN (0-1 mM) were made in a sealed glass tube at 75 °C. To remove air bubbles, helium gas was flushed through the agar, and vacuum suction was applied. To prevent the agar from solidifying too rapidly, and to remove excess helium gas and remaining air pockets from the viscous agar solution, phantoms were kept under vacuum in the water bath as the bath was allowed to cool slowly to room temperature from ~75 °C. Fat was suspended in the agar so that heterogeneous mixtures were produced. Soft phantoms were designed to be attached to the breast during clinical MRI scans without causing discomfort, to be used as reference standards. High resolution MR images of the phantoms were acquired at 9.4 T using spin echo (SE), gradient echo (GE), saturation recovery (for T_1 measurements), and multi-slice multi-echo (MSME, for T_2 measurements) sequences.

Results: We measured T_1 and T_2 values of phantoms as a function of agar and OMNISCAN concentration (see Table). The uncertainties associated with these measurements were <2%. In panel **A**, an MR image of agar with three different OMNISCAN solutions (0.2-0.5 mM) is shown. Once the agar (2.5%) media solidified, we punched three cylindrical holes and filled these holes with different concentrations of OMNISCAN in 1% agar. For visual inspection, we color coded these solutions. In panel **B**, a similar MR image of agar with 100% fully saturated fat is shown. Relaxation parameters can be measured for multiple media within one phantom without using different glass containers. This provides a good model for human tissue (for example, muscle, fat, bone and tumor). Panel **C** shows a standard agar phantom with different concentrations of OMNISCAN (0-1 mM) as color coded - sections in a larger ring of soft tubing separated by Teflon plugs as shown. These soft phantoms could be easily placed on the breast for scanning in clinical protocols of breast MRI.

Sample	T_1 (ms)	T_2 (ms)
Control – 0.5% Agar	3333.3	170.2
0.2 mM Gd in 0.5% Agar	819.7	142.4
0.5 mM Gd in 0.5% Agar	469.5	117.9
1.0 mM Gd in 0.5% Agar	284.9	93.9
1.0 mM Gd in 1.5% Agar	251.3	51.4
100% Fully saturated fat	609.8	94.3



Discussion: In this study, we developed a series of air bubble-free agar phantoms that mimic human tissue in terms of their relaxation pathways. Heterogeneous phantom mixtures were produced by suspension of other materials in the agar to accurately simulate breast tissue. These phantoms including soft phantoms for breast MRI offer flexibility and a realistic model of human tissue. Various materials can be incorporated into the agar to change relaxation rates and mimic water exchange between compartments. Such phantoms could assist in standardization of scanner performance, and assist in quantitative measurements of contrast media concentration as a function of time after injection.