Computer-Generated Abdominal Phantom for Evaluation of MR Estimation Techniques

C. Graff[1], E. Clarkson[2], E. K. Outwater[2], and M. I. Altbach[2]

[1]Program in Applied Mathematics, University of Arizona, Tucson, AZ, United States, [2]Department of Radiology, University of Arizona, Tucson, AZ, United States

Introduction: Computer-generated phantoms provide a convenient way to generate large numbers of sample data sets, and have been used in a variety of contexts in MR imaging [1,2]. However, care must be taken in interpreting the results of computer-phantom studies since a computer simulation is always a simplification of the real imaging process. For example, compressed-sensing reconstruction techniques have recently become popular in MR [3]. These techniques have been shown to be extremely accurate for objects of low total-variation, like the Shepp-Logan phantom and most types of physical phantoms used in MR. In contrast, the human body contains much more variability, and thus results from phantom studies may not accurately predict performance with in vivo data.

Quantitative evaluation in MR imaging typically involves measuring a signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), or using a group of radiologists to rank images. With the increasing interest in non-Cartesian imaging and parameter map estimation, the linearity assumptions that justify the use of SNR and CNR as a measure of image quality are no longer always valid. Using radiologists to rank images can be costly and time consuming, and may not be a relevant measure of reconstruction quality if the images or parameter maps are to be used for computerized diagnosis. Evaluating methods for reconstructing parameter maps can be problematic in vivo because of the lack of a gold-standard measurement and the difficultly in obtaining sufficient numbers of patients.

To overcome these problems, we have developed a computer-generated phantom for the evaluation of MR-parameter estimation techniques in the abdomen. In our phantom, a variety of practical effects, such as tissue texture and variability, along with coil sensitivities and fat suppression have been modeled to produce data sets which are as close as possible to in vivo data.

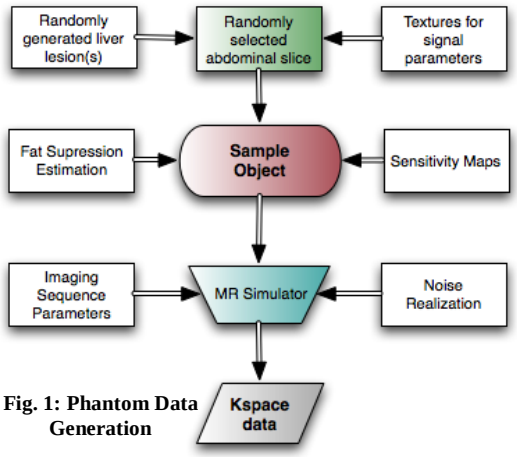

Fig. 1: Phantom Data Generation

Methods: The procedure used to randomly generate a k-space data set is shown in Fig 1. The model for the abdomen's anatomical structure is derived from high-resolution photographic images obtained from the Visible Human Project [4]. These images are segmented into 15 different tissue types as shown in Fig. 2. Within each tissue type, the distribution of possible T1, T2 and proton density values are obtained from literature. We are mainly interested in evaluating T2 estimation techniques for small lesions in the liver, so special care was taken to achieve the proper variability of parameter values within the liver. High resolution, high SNR, spin-echo scans of ex vivo cow liver were taken on a Bruker 4.7T scanner. From these images, measures of spatial variability and the range of possible parameter values were calculated.

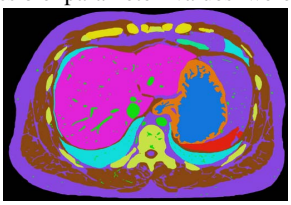

Fig 2: Segmented Image

To estimate coil sensitivity functions, experiments with a body coil and an 8-channel phased array coil were performed on a GE NV-CV/I Signa scanner at 1.5T. By taking the ratio of the phased array coil data and the uniform sensitivity body coil, realistic coil sensitivity functions were estimated. These estimates were fitted to 2D polynomials to obtain coil sensitivity functions which are scalable to the resolution of our phantom and cover the entire field of view (Fig. 3). Many clinical sequences incorporate fat suppression. This technique was modeled by performing analogous water suppression experiments at 1.5T. Once the phantom is completely specified, k-space data can be generated from a 2D Fourier transform, a Radon transform, or more sophisticated MR simulators like OD1N [5] or SIMRI [6].

Even though our phantom is defined discretely, it has approximately 10 times the resolution of typical clinical scans, so it approximates well the continuous nature of the human body. In-plane partial volume effects are created by this difference in resolution. Through-slice partial volume is modeled for the tumors by considering the slice to be of finite thickness and placing the 3-D tumor randomly along the slice direction.

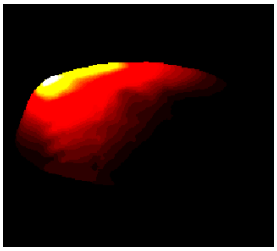

Fig 3: Sensitivity Map

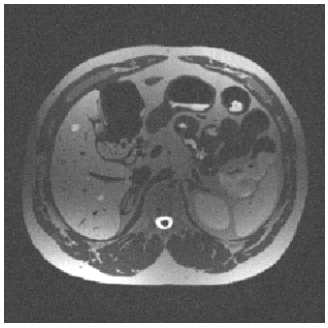

Fig 4: Sample image

Results: An example of a reconstruction obtained for T2-weighted radial data generated from our phantom is shown in Fig. 4. The phantom data produces reconstructed images which closely match those obtained in vivo.

Conclusions: The phantom has been developed to evaluate T2 estimation techniques for small lesions in the liver, but the same procedure can be used to evaluate accuracy on any similar type of estimation task. The ability to generate realistic simulated data, where the true underlying tissue parameters are known, is a valuable tool which will become increasingly important as more sophisticated imaging techniques are developed.

Acknowledgement: This work is supported by NIH grants CA099074 and HL085385.

References: [1] Collins IEEE TMI 17 (1998) 463-468. [2] Morgan MRM 46 (2001) 510-514. [3] Lustig Proc. ISMRM 07 [4] Ackerman Proc. IEEE 86 (1998) 504-511. [5] Jochimsen JMR 170 (2004) 67-78. [6] Benoit-Cattin JMR 173 (2005) 97-115.