Digital Breast Phantom for Evaluating Dynamic Accelerated Imaging Methods

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INTRODUCTION: Currently, there is widespread debate on the value of temporal resolution in Dynamic Contrast Enhanced Breast MRI. There is speculation that increased temporal resolution, along with high spatial resolution, could improve differential diagnosis through better depiction of the initial contrast uptake curves in the tissue and differential enhancement patterns in heterogeneous lesions. Recent work on accelerated MRI has produced a variety of methods that could be applied to this situation. Many of these methods are nonlinear and include tradeoffs in terms of spatial and temporal accuracy, which makes it hard to predict and validate how they will perform in a complex imaging environment like the breast. Clinical validation presents an added problem as inter-patient variability makes it difficult to compare performance of different methods and prove additional temporal information has been captured.

To address this problem, we have created a digital breast phantom comprised of enhancing lesions surrounded by normal background breast tissue. This phantom will allow for detailed study of the performance of various acceleration methods through comparison with the 'true' reconstruction. The digital phantom will also allow the performance of individual methods to be compared to one another since all will be operating on the same digital truth.

THEORY AND METHODS: The phantom was developed to provide a simulated but realistic breast DCE MRI data set. The phantom incorporates realistic differentially enhancing fat and fibroglandular tissue, lesions following both benign and malignant enhancement patterns, a variety of lesion morphologies, multi-coil data, a noise free 'gold standard' reconstruction, variable SNR levels for simulated data and the ability to support Cartesian and non Cartesian reconstructions.

Realistic background tissue for the phantom were created from an IDEAL[1] scan of a healthy volunteer using a GE 1.5 T Signa HDx Scanner and an 8-Channel HD VIBRANT Breast array with parameters chosen to achieve similar contrast to those seen in clinical exams. The fat and water images produced by IDEAL allow for the simulation of varying levels of fat suppression and differential enhancement patterns in the fat and water tissues. Images were processed to remove noise using an adaptive template filter as described in [2]. Simulated lesions can be added at user-specified shapes, sizes and locations. Example enhancement curves are shown in Fig. 1 c. Spatially, lesions can enhance heterogeneously or homogeneously, though currently this variation is limited to circularly symmetric functions. Complex images are created by multiplying all phantom images by actual or simulated sensitivity maps. Final k-space data is obtained by performing a Fourier transform, selecting the desired k-space lines for a Cartesian scan, or performing an inverse gridding operation to get the desired k-space points for non Cartesian scans, and then adding Gaussian noise to achieve the desired SNR in the simulated source data.

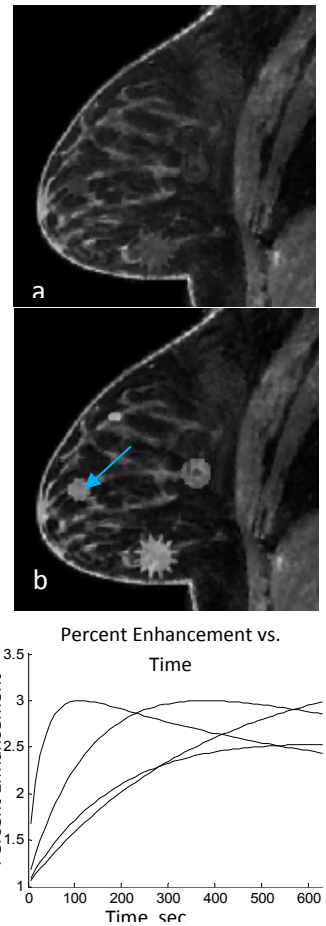

Figure 1. (a) Digital simulation of breast enhancement after contrast injection, with 4 lesions present, 10 min after contrast injection.(b) Image obtained by subtracting non-enhanced image initial image from the final image at 10 min improves visualization of simulated lesions. Arrow indicates lesion for which subsequent error calculation has been performed (see below) (c) signal intensity vs. time (SIT) curve curves associated with lesions shown in (a) and (b).

RESULTS AND DISCUSSION: A sample slice from the digital phantom is shown in Fig. 1. In order to demonstrate how the phantom can be used to test deterministic performance, k-space data was generated for a radial acquisition and I-HYPR[3] reconstruction. I-HYPR is an iterative reconstruction based on the HYPR projection reconstruction method and ordered subset expectation maximization (OSEM). Knowledge of the 'truth' as provided by the phantom allows for analysis of reconstruction errors as shown in Fig. 2. From this data, it can be seen that for these settings and 5 iterations of the I-HYPR algorithm, I-HYPR accurately preserves temporal information with only moderate loss of edge definition. Typical maximum spatial error around the circular lesion in the posterior breast that can be seen in Fig. 2 is 10%. In this example, the acquisition of the input projection and I-HYPR reconstruction was performed using Matlab. Performing filtered back projection in Matlab is known to introduce errors and lower the resolution of the resulting reconstruction. The results of the digital phantom indicates this fact and suggests that a more accurate back projection operation will result in a more accurate reconstruction.

Currently, the phantom data is limited to providing data for 2D slice acquisition simulations. Future work will include providing the capability for 3D acquisitions. Lesions will also be updated to include more realistic shapes and heterogeneous enhancement patterns that can vary radially and azimuthally.

CONCLUSIONS: The digital breast phantom provides a platform that allows for the study of the performance of accelerated imaging methods in DCE Breast MRI. The phantom has realistic enhancing background tissue, which creates realistic image sparsity, and the phantom provides a means to measure the likely performance of a given method under study and indicates direction where further effort would improve the method. Though this phantom is designed specifically to study breast exams, the concept is applicable to any imaging situation.

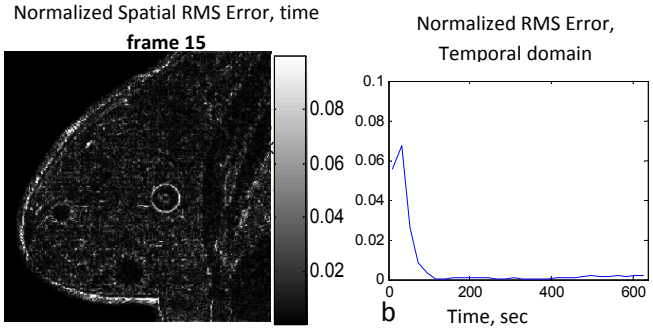

Figure 2. (a) Data from digitally simulated enhancing breast was input into I-HYPER algorithm and normalized RMS error image generated (at 158 sec after contrast injection). (b) Normalized RMS error as a function of time.

Acknowledgements: Research supported by NIH 5 T32 GM08349 and NCI R01 CA116380-03. We also gratefully acknowledge assistance of Chihwa Song and the support of GE Healthcare.

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