Methods

In this study, 7 patients with 8 biopsy-proven lesions (7 malignant, 1 benign) underwent gadolinium enhanced dynamic and high resolution MR imaging. All images were acquired using a 1.5T Signa (Milwaukee, WI) scanner with a dedicated breast coil. After injection of a 0.1 mmol/kg Gd-DTPA bolus (Magnevist), dynamic images were acquired at 32 slice locations for 213 seconds using a water-selective 3D spiral imaging technique [1] (TR/TE/FA = 38/12.3/40\(^\circ\), Matrix = 188x188, 20 mmol/kg Gd-DTPA bolus (Magnevist), dynamic images were acquired) in a temporal resolution of 10.64 seconds. High resolution imaging was then performed using a three dimensional water selective spectral spatial spoiled gradient echo acquisition magnetization transfer (3DSSMT) pulse sequence (TR/TE/FA = 33/9/30\(^\circ\), Matrix = 512x192, 1.3-2mm thickness, 20cm FOV) with centric k-space encoding to yield 60 slices through the breast over the following 420 seconds. Dynamic spiral imaging was then resumed for another 277 seconds.

In order to create a parametric map from the dynamic spiral image series, we used a vascular permeability parameter, \(k_2\), which was based on a two-compartment pharmacokinetic model where the blood plasma comprised one compartment and the extracellular space comprised the other. The rate of exchange of Gd-DTPA contrast material between these compartments was determined by \(k_1\) [2].

The \(k_2\) values were calculated by curve-fitting the intensity values from the dynamic spiral data using a gradient-expansion algorithm on a pixel-by-pixel basis to create a parametric map corresponding to each 3DSSMT slice. The \(k_1\) parameter information was then incorporated into the 3DSSMT images by modulating the hue of each pixel as a function of the corresponding \(k_1\) value while keeping the overall intensity values proportional to the original 3DSSMT image. The curve-fitting program and parametric display interface were written in IDL (Interactive Data Language, Research Systems, Inc., Boulder, CO).

Results

Our method of parametric map presentation, intensity-modulated parametric display, was evaluated independently by five radiologists (RLB, BLD, SH, DMI, RJH) and compared to traditional overlaid parametric display methods (as used in functional MRI) in which pixels in the anatomic image that correspond to parameter values above a certain threshold are entirely replaced by colored pixels representing only parametric information. The readers were asked to numerically rate the two methods according to a number of different criteria. The ratings showed the greatest preference for the intensity-modulated parametric display method over the overlaid parametric display method, as measured by the magnitude of the difference in ratings, for the following criteria: ability to display morphological details including shape, margins, internal features, and intensity of enhancement; ability to correlate parametric values with lesion morphology; ability to characterize features associated with malignancy such as breast architectural distortion and skin or chest wall invasion; ability to depict normal breast features such as blood vessels and enhancing abnormalities distinct from the lesion; and finally, ability to suppress noise and spurious parametric data. The ratings showed a less significant preference of the intensity-modulated parametric display method for the following criteria: ability to identify lesion location within the breast, and ability to display heterogeneity and distribution of parametric values within the lesion.

Discussion

As shown in the images above and in the results of the radiologists' assessment, intensity-modulated parametric display provides an efficient and intuitive synthesis of spatial and dynamic MRI information for the purposes of breast cancer diagnosis and assessment of the extent of breast lesions.

The ability of this method to suppress noisy parametric values arises from the fact that the intensity values are modulated as a function of the 3DSSMT image at every pixel, and consequently, the 3DSSMT image acts as a filter which significantly de-emphasizes parametric values that do not correspond to an area of high signal intensity. Implicit in this method is the assumption that the areas of interest correlate to areas of moderate to high signal intensity on the 3DSSMT images.

The greatest difficulties encountered in this study involved patient motion between the two sets of dynamic data acquisitions, and noise in the dynamic data sets. In two cases, the latter half of the spiral data set had to be ignored due to patient motion, but the parametric calculations were still possible with the first half of the data points. Furthermore, the noise in the dynamic data made curve-fitting the time-dependent signal difficult at various pixels, but these points were infrequent allowing a consistent reliability in the calculation of parametric maps. Many of these points also corresponded to areas of low 3DSSMT signal intensity and were made inconspicuous by the intensity-modulated display.

Finally, our method of calculating pharmacokinetic parameters on a pixel-by-pixel basis rather than for an entire ROI offers many advantages. It allows one to assess the distribution of the parametric values throughout the lesion, to observe the heterogeneity of parameters within the ROI, and to correlate parametric information to specific regions within the lesion. This extra information, in turn, may allow for new criteria to be considered in the evaluation of breast lesions which may ultimately improve the diagnostic abilities of MR mammography.

References


Acknowledgments

This research was supported by NIH grant ROI CA65785.