Original Investigation

Ultrafast Bilateral DCE-MRI of the Breast with Conventional Fourier Sampling: Preliminary Evaluation of Semi-quantitative Analysis

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Rationale and Objectives: The study aimed to evaluate the feasibility and advantages of a combined high temporal and high spatial resolution protocol for dynamic contrast-enhanced magnetic resonance imaging of the breast.

Materials and Methods: Twenty-three patients with enhancing lesions were imaged at 3T. The acquisition protocol consisted of a series of bilateral, fat-suppressed "ultrafast" acquisitions, with 6.9- to 9.9-second temporal resolution for the first minute following contrast injection, followed by four high spatial resolution acquisitions with 60- to 79.5-second temporal resolution. All images were acquired with standard uniform Fourier sampling. A filtering method was developed to reduce noise and detect significant enhancement in the high temporal resolution images. Time of arrival (TOA) was defined as the time at which each voxel first satisfied all the filter conditions, relative to the time of initial arterial enhancement.

Results: Ultrafast images improved visualization of the vasculature feeding and draining lesions. A small percentage of the entire field of view (<6%) enhanced significantly in the 30 seconds following contrast injection. Lesion conspicuity was highest in early ultrafast images, especially in cases with marked parenchymal enhancement. Although the sample size was relatively small, the average TOA for malignant lesions was significantly shorter than the TOA for benign lesions. Significant differences were also measured in other parameters descriptive of early contrast media uptake kinetics ($P < 0.05$).

Conclusions: Ultrafast imaging in the first minute of dynamic contrast-enhanced magnetic resonance imaging of the breast has the potential to add valuable information on early contrast dynamics. Ultrafast imaging could allow radiologists to confidently identify lesions in the presence of marked background parenchymal enhancement.

Key Words: DCE-MRI; breast imaging; lesion kinetics; high temporal resolution.

INTRODUCTION

Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) of the breast is a valuable tool for the detection and diagnosis of breast cancer (1). The kinetics of contrast media uptake and washout yield important markers for malignancy (2,3). Typically, malignant tumors exhibit fast uptake of contrast media followed by washout in the delayed phase (2). Standard clinical contrast-enhanced scans are generally performed with high spatial resolution to enable morphologic evaluation of lesions and detect small cancers (4). The high spatial resolution required, combined with the large fields of view necessary to acquire bilateral images, leads to low temporal resolution, typically in the range of 60–75 seconds. As a result, important kinetic information is obscured.

Acquiring DCE-MRI with high temporal resolution is important, as it allows accurate classification of contrast media dynamics in suspicious lesions, and thus has the potential to aid discrimination between malignant and benign lesions. In addition, high temporal resolution allows accurate measurement of the arterial input function for each patient, a critical step in quantitative pharmacokinetic analysis (5–7). However, the early events in contrast media uptake in normal breast and breast lesions have not been well characterized; thus, it is difficult to know what temporal resolution is optimal for breast MRI.

Jansen et al., Pinker et al., and Planey et al. used conventional Fourier sampling methods to image contrast media uptake in the breast at high temporal resolution (8–10). Improvements in temporal resolution in these studies came at the expense of either greatly reduced coverage or lower spatial resolution than standard clinical scans (eg, Pinker et al. reduced

Acad Radiol 2016; ■:■■–■■

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http://dx.doi.org/10.1016/j.acra.2016.04.008

spatial resolution from 1 mm to 1.7 mm isotropic voxels [10]). Nevertheless, these studies showed advantages in the conspicuity of preinvasive lesions, and estimation of pharmacokinetic parameters compared to standard, low temporal resolution, clinical scans.

The goal of this study was to characterize the kinetics of early enhancement in arteries, veins, malignant lesions, benign lesions, and normal-appearing parenchyma, and to evaluate the performance of parameters descriptive of early kinetics in differentiating malignant versus benign lesions. Potential advantages in lesion detectability were also investigated in this study. The protocol used conventional Fourier sampling to allow robust quantitative analysis, and a novel filtering and analysis method to identify rapidly enhancing lesions. The acquisition protocol used here can be easily implemented in a clinical setting, regardless of vendor or scanner type.

Images were acquired at lower spatial resolution, and relatively high SENSE acceleration factors during the first minute post contrast injection, to produce full bilateral, fat-suppressed breast images with temporal resolution ranging between 6.2 seconds and 9.9 seconds. Following an initial 60 seconds of fast imaging, subsequent images were acquired using a standard clinical protocol with high spatial resolution, intermediate SENSE factors, and low temporal resolution. The ultrafast images during the first minute after contrast media injection provide detailed information on the early kinetics in the breast, whereas later high spatial resolution acquisitions allow assessment of the morphology of small lesions. The results provide new information on contrast media uptake during the first minute after injection and demonstrate the potential diagnostic utility of high temporal resolution imaging. In addition, these results are useful for evaluating acceleration methods, and suggest new approaches to fast data acquisition and quantitative analysis.

MATERIALS AND METHODS

Patient Recruitment

Twenty-three patients, with biopsy-proven lesions or lesions detected on prior imaging studies, were recruited under an institutional review board-approved and Health Insurance Portability and Accountability Act-compliant prospective study after obtaining informed consent. Inclusion criteria were the identification of enhancing lesions in the DCE-MRI series, available pathology results, or identification of stable benign enhancement compared to prior imaging studies. Images from three patients were excluded from the study, one because of failure to identify any residual enhancement postbiopsy, another because no pathology results were available, and one because of technical issues with fat suppression. In total, 18 distinct malignant masses or areas of enhancement were imaged (primary and satellite lesions), as well as 15 benign findings. Malignant lesions imaged included eight primary invasive ductal carcinomas (IDC), four satellite IDCs, four ductal carcinomas in situ, one metaplastic carcinoma, and Paget's disease. The median patient age was 43 years, with a range of 23–73 years. Benign lesions imaged were three fibroadenomas, a complex sclerosing lesion, focal adenosis, papilloma, benign enhancing focus, enhancing skin lesion, usual ductal hyperplasia, ruptured duct, atypical ductal hyperplasia, lobular carcinoma in situ, fibrotic stroma, and focal scar.

MRI Acquisitions

DCE-MRI studies were performed on a Philips Achieva 3T TX scanner (Philips Healthcare, Best, The Netherlands) using a 16-channel bilateral breast coil (MammoTrak, Philips Healthcare). The acquisition parameters for the "ultrafast" and standard clinical acquisition are summarized in Table 1. All images were acquired in the axial plane. Temporal resolution for fast scans ranged from 7 to 10 seconds, depending on the size of the field of view and the number of slices acquired. The DCE series consisted of one standard clinical acquisition and five ultrafast acquisitions preinjection, followed by eight fast acquisitions (starting immediately after injection and ending 55–80 seconds after injection), followed by four standard clinical acquisitions after the injection of contrast media at a dose of 0.1 mM/kg gadobenate dimeglumine (MultiHance, Bracco, NJ) at 2 mL/s, followed by a saline flush of 20 mL at 2 mL/s. The five ultrafast precontrast sequences were acquired to

TABLE 1. Acquisition Parameters for Ultrafast and High Spatial Resolution Sequences

Parameters	Ultrafast	High Spatial Resolution
TR/TE (ms)	3.2/1.6	4.8/2.4
Acquisition voxel size (mm^3)	$1.5 \times 1.5 \times 3.0$	$0.8 \times 0.8 \times 1.6$
SENSE acceleration factor (RL)	4	2.5
SENSE acceleration factor (FH)	2	2
Half scan (partial Fourier) factor	0.75 (ky); 0.85 (kz)	0.85 (ky); 1 (kz)
Temporal resolution range (s)	6.9–9.9	60–79.5
Number of slices	100–120	187–225
Flip angle	10°	
Field of view (mm)	300–370	
Fat suppression method	SPAIR (TR: 155 ms; inversion delay: 80 ms)	

TR, repetition time; TE, echo time; SENSE, sensitivity encoding; RL, right-left; FH, foot-head; SPAIR, spectral attenuated inversion recovery.