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Original Contribution

Fat suppression techniques for obtaining high resolution dynamic contrast enhanced bilateral breast MR images at 7 T

Tijl A. van der Velden [a,*], Alexander M.Th. Schmitz [a,b], Kenneth G.A. Gilhuijs [a,b], Wouter B. Veldhuis [a], Peter R. Luijten [a], Vincent O. Boer [c], Dennis W.J. Klomp [a]

[a] University Medical Center Utrecht, Department of Radiology, Heidelberglaan 100, 3584CX, Utrecht, the Netherlands
[b] University Medical Center Utrecht, Image Sciences Institute, Heidelberglaan 100, 3584CX, Utrecht, the Netherlands
[c] Danish Research Centre for Magnetic Resonance, Centre for Functional and Diagnostic Imaging and Research, Copenhagen University Hospital Hvidovre, Kettegaard Allé 30, DK-2650, Hvidovre, Denmark

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ABSTRACT

Objectives: To compare water selective excitation (WSE) and Dixon fat suppression in the context of high-resolution dynamic contrast enhanced MRI of the breast at 7 T.
Methods: Ten healthy volunteers and one patient with a malignant breast lesion were scanned at 7 T. The MRI protocol contained 3D T1-weighted gradient echo images obtained with both WSE fat suppression, multi echo Dixon fat suppression, and without fat suppression. Images were acquired at a $(0.8\ \text{mm})^3$ or $(0.7\ \text{mm})^3$ isotropic resolution with equal field of view and optimized such to obtain a maximal SNR. Image quality was scored qualitatively on overall image quality, sharpness of anatomical details, presence of artifacts, inhomogeneous fat suppression and the presence of water-fat shift. A quantitative scoring was obtained from the signal to noise ratio and contrast to noise ratio.
Results: WSE scored significantly better in terms of overall image quality and the absence of artifacts. No significant difference in contrast to noise ratio was found between the two fat suppression methods.
Conclusion: When maximizing temporal and spatial resolution of high resolution DCE MRI of the breast, water selective excitation provides better image quality than multi echo Dixon at 7 T.

Introduction

Dynamic contrast-enhanced (DCE) magnetic resonance imaging (MRI) is increasingly used for the assessment of breast tumors, which is one of the most common tumors in women worldwide. Although DCE MRI provides a sensitivity of over 90% in the detection of breast tumors, much research is performed to increase the specificity of DCE MRI, which is currently between 70% and 92% [1,2]. High specificity with less variance may be found in observing tumors at high spatial resolutions, which improves the characterization of spiculi and irregularity of tumor borders, characteristics which are related to high grade tumors [3].

Successful bilateral breast MRI at 7 T has recently been demonstrated by several groups [2,4–6]. However, as the chemical shift dispersion as well as the magnetic field distortions and T_1 relaxation parameters are increased at higher fields, the conventional DCE MRI approach must be revisited for high field use.

A technique commonly used in DCE MRI is fat suppression. The T_1 of fat is much shorter than the T_1 of glandular tissue and will therefore appear very bright in the images. This obscures the enhancement in areas where the contrast agent is taken up. Subtraction techniques to remove the bright fat signal in DCE MRI may lead to substantial artifacts in the presence of subtle patient motion, particularly at higher spatial resolutions [7]. Especially at higher field strengths, where differences in T_1 relaxation times of tissues tend to increase, the hyper intense signal of fat can cause much larger variations in the calculation of enhancement curves due to subtle motion than caused by the contrast agent. To reduce these large variations, fat suppression may be essential to obtain high resolution DCE images with good and robust diagnostic value at high field strengths.

On 1.5 T and 3 T MR systems, a wide variety of fat suppression techniques is available. These techniques may be available at 7 T as well, albeit that the performance of fat suppression can be different. Specifically for DCE imaging, care must be taken to deal with inhomogeneous B_1^+ fields, an inhomogeneous B_0 field and an increase in T_1 relaxation times. Combined with a desired temporal resolution of maximal two minutes at high spatial resolution [3], but preferably down to a few seconds [6,8] to enable the possibilities for kinetic

* Corresponding author at: E01.132/Q02.4.309, Heidelberglaan 100, 3584CX, Utrecht, the Netherlands. Tel.: +31 6887550913.
E-mail address: T.A.vanderVelden@umcutrecht.nl (T.A. van der Velden).

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Table 1
Overview of the main scan parameters used in the different acquisitions.

	Main scan parameters		
	No fat suppression	WSE[a]	ME[b] Dixon
Field of view	339×119×147 mm^3	339×119×147 mm^3	339×119×147 mm^3
Resolution	0.8 × 0.8 × 0.8 mm^3	0.8 × 0.8 × 0.8 mm^3	0.8 × 0.8 × 0.8 mm^3
TE/TR	2.9/7 ms	3.2/6.7 ms	2.5–3.9/6.0 ms
Flip angle	8°	8°	8°
Water fat shift	3.4 pixels	3.4 pixels	1.1 pixels
Bandwidth	296 Hz	296 Hz	917 Hz

[a] Water selective excitation.
[b] Multi echo.

modeling [9], two optimal fat suppression techniques are available for DCE MRI of the breast at 7 T. The first is water selective excitation (WSE) (also known as ProSet) [10], which uses a chemical shift selective RF pulse that excites only the water at 4.7 ppm without exciting the main fat spins resonating at 0.9 ppm. The second technique is multi echo (ME) Dixon [11,12], where, based on phase difference between multiple echoes, a water and fat image can be calculated.

Other fat suppression techniques that are often used, e.g. fat selective saturation or (frequency selective) inversion recovery techniques, were discarded due to the requirement of a homogeneous B_1^+ field (e.g. SPIR), the requirement of long inversion times (due to longer T_1 values) (e.g. STIR, SPAIR), SAR limitations (e.g. SPAIR) and/or the incompatibility with the injection of a T_1 shortening contrast agent (e.g. STIR).

A previous study compared the two most efficient fat suppression techniques for the breast at 3 T, where ME Dixon outperformed WSE [13]. However, considering the higher order B_0 shimming available at 7 T, which is particularly beneficial for WSE, the difference in performance between ME Dixon and WSE at 7 T breast MRI is yet unknown.

The aim of this study was to investigate fat suppression techniques within the context of high spatio-temporal resolution DCE bilateral breast imaging at 7 T. WSE, ME Dixon and non-fat suppressed scans were obtained in volunteers and assessed qualitatively and quantitatively. Moreover, additional fat suppression by means of subtraction of images pre and post gadolinium contrast uptake was demonstrated in a patient with a malignant breast lesion.

Materials and methods

Ten healthy female volunteers (mean age 27.1 ± 4.6 years) were scanned on a Philips Achieva 7 T MR system (Cleveland, Ohio, USA) equipped with a bilateral 4-element breast transmit/receive coil (MR Coils B.V., Drunen, The Netherlands). All experiments conducted were in accordance with the guidelines of the local ethical committee and, prior to the exam, written informed consent was obtained from all volunteers. For all subjects, image based 3rd order spherical harmonics B_0 shimming was performed. A 3D B_0 map was acquired with a field of view (FOV) closely fitted around the breasts, as suggested by Hancu et al. [14]. Region of interests (ROIs) were drawn by hand over the breasts and an additional mask based on image intensity was applied. Strengths of the individual B_0 shim terms were calculated by minimizing the least squared error of the residual field inhomogeneities.

Three different T_1 weighted gradient echo sequences were compared: one without fat suppression, one with WSE and an ME Dixon acquisition (i.e. multiple acquisitions within a single repetition). All scans were 3D scans with equal FOVs and resolutions. Slab selection was performed in the feet-head direction. The readout was performed in the right-left direction to minimize scan time. For ME Dixon, two echoes were acquired. The WFS was set such that a maximum SNR was obtained with the minimum in and out of phase echo times possible. A 1-3-3-1 binomial pulse was used as a WSE pulse. To obtain equal T_2^* weighting, the echo time was set to be the average of the ME Dixon echo times. The WFS with the WSE sequence was adjusted such that a maximal SNR was obtained. Details of the different scan parameters are shown in Table 1.

Image quality was qualitatively assessed, as if it was a clinical scan, by a radiologist with 8 years of experience in reading breast MRI, of which 3 years with 7 T breast MRI. First, the overall image quality and visibility of anatomical details were both scored on a 1 to 5 scoring scale: 1: no diagnostic value; 2: difficult for diagnostic use (poor); 3: acceptable; 4: good; 5: excellent. Second, the presence of imaging artifacts, the homogeneity of fat suppression, and the presence of a water-fat shift was scored on a 1 to 3 scoring scale: 1: present and of influence on image assessment; 2: present but not of influence on image assessment; 3: not present.

Quantitative image assessment was performed on a slice in the image including the mammilla. In the ME Dixon scan, this was performed on the calculated water image. For the other two acquisitions, it was performed directly on the reconstructed magnitude image. In both breasts, the mean signal of fat and parenchyma was measured on the lateral and medial using an ROI of 5×5×1 voxels containing fat or parenchyma only. In addition the mean signal intensity of both pectoral muscles was measured using an ROI of 5×5×1 voxels.

The standard deviation of the noise (σ_{noise}) was measured in a region in air. For this purpose, the signals of the two coils were combined (μ_{signal}) with fixed amplitude and phase settings resulting in uniform noise levels over the images albeit at suboptimal SNR. No corrections were performed for optimizing the receive inhomogeneity of the coil. Using the same uniform noise reconstruction, the SNR ($SNR_A = \frac{\mu_{signal}}{\sigma_{noise}}$) and contrast to noise ratio (CNR) ($CNR_{A,B} = SNR_A - SNR_B$) between parenchyma (A) and fat (B) were calculated.

Statistical analysis was performed on both the qualitative as well as the quantitative results. A pairwise Kruskal–Wallis 1-way ANOVA analysis was performed using SPSS 20 (IBM SPSS Statistics). Results were considered significantly different between scan protocols when the p-value was smaller than 0.05.

While subtraction would reduce SNR by $\sqrt{2}$, i.e. noise power is accumulated by subtracting two scans [15], and makes images more prone to motion artifact, we also investigated the potential of using the high SNR of 7 T to further improve fat suppression. We have calculated the subtracted images (i.e. pre contrast scan subtracted from dynamic scans post contrast) of an ultra-high resolution $(0.7\ mm)^3$ DCE scan (FOV: 160×160×348 mm; flip angle of 15°; TR/TE: 5.8/2.5 ms; 8-fold SENSE acceleration; temporal resolution: 91 s) of a women with breast cancer.

Results

Examples from the same slice of the two fat suppression techniques of different volunteers are displayed in Fig. 1. The non-fat