Multiple-Contrast and Parametric Imaging with RAD-GRASE

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Synopsis
In RAD-GRASE different radial lines of k-space data are collected with signal magnitude and phase variations that arise due to T2 decay, T2* decay, field inhomogeneity, and chemical shift. Such variations can lead to artifacts in images reconstructed from complete data sets. However, because of the oversampling of k-space near the origin, partial data can be used to reduce data inconsistency as well as select image contrast. Furthermore, multiple images reconstructed using different partial data sets can be combined to estimate parameter maps such as T2, T2*, and fat and water content images – all from a single RAD-GRASE data set. Examples of this capability are shown.

Introduction
Gradient and Spin Echo (GRASE) imaging uses a combination of gradient and RF refocusing to produce a train of echoes. Signal magnitude and phase evolve during the echo train leading to data inconsistencies and concomitant image artifacts. In standard 2D Fourier GRASE, contrast is selected and artifacts minimized by careful view ordering. Radial acquisition of data (RAD-) GRASE is an alternative to the 2D Fourier method. In RAD all lines of data pass through the origin in k-space and contribute more-or-less equally to the image contrast. It has been shown that T2 contrast can be varied in RAD-FSE using a subset of the data near the origin in k-space [1], and with RAD-GRASE, that both T2 and T2*- weighted contrast can be obtained from a single data set [2]. With RAD-FSE parametric maps of T2 can be produced [3]. With RAD-GRASE one can expand on this concept to produce parametric maps of equilibrium magnetization, T2, T2*, and fat and water content all from one data set.

Methods
Imaging was done on a 1.5 T GE Sigma LX MR1 instrument. A RAD-GRASE sequence was written using refocusing gradients to collect multiple radial lines within each spin-echo (SE) period. A series of SE periods are created by a train of 180° RF refocusing pulses. The number of echoes (radial lines) per SE period (GE/SE) times the number of SE periods equals the echo train length (ETL) of the sequence. Two timing parameters, TEs and Δn, characterize the timing (and contrast dependence) for each radial line. When GE/SE is odd, the middle echo in each SE period occurs centered on the SE point (Δn=0). Outer echoes are temporally shifted (Δn≠0) and incur additional signal decay and phase shifts due to field inhomogeneity and chemical shift. Specific image contrast can be selected using partial Fourier data in the center of k-space. High spatial resolution is maintained by using more (or all) data as one moves towards the periphery of k-space. Depending on the number of radial lines (views) collected with a particular timing characteristic (e.g. TEs or Δn), there exists a “Nyquist radius” for which partial data with that specified contrast satisfy the sampling condition. A full radial data set can be regenerated by interpolation of the partial data sets followed by filtered backprojection reconstruction. Alternatively, regridding can be used for reconstruction. The former approach was used for the results presented here.

Parametric images are generated by first creating images with contrast corresponding to different TEs or Δn. T2 and T2* maps are obtained from the set of images with varying TE by fitting to the appropriate exponential decay curve on a pixel-by-pixel basis. The signal model includes the equilibrium magnetization, the T2 decay factor = exp(-TE/T2), and the additional decay due to field inhomogeneity = exp(-Δn/T2*). Fat, water, and field inhomogeneity images are generated from a set of images reconstructed with varying Δn, using a variant of the Dixon technique [4].

A phantom was used for the imaging experiments. The phantom consists of a 5.5 cm dia. cylindrical container with four vials. Two of the vials are filled with baby oil. The other two vials are filled with water doped with Gd-DTPA – one at 300:1 concentration and the other with a more dilute concentration of 1000:1. Water in the cylinder is doped with 1000:1 Gd-DTPA. A RAD-GRASE sequence was employed with parameters GE/SE=3, ETL=12, BW=±62.5kHz, TR=2000ms, FOV=16cm, slice=4mm, 256 points per radial line, and 384 view angles (total imaging time = 64s). At this BW, the separation between the SE point and nearby echoes is Δn=2.7ms, which is close to the out-of-phase condition for fat and water at 1.5 T.

Results and Discussion
Fig. 1 shows images generated from a single RAD-GRASE data set. Fig. 1a shows the image from all the data. Figs. 1b, 1c, and 1d were obtained by reconstructing separate images for each TE (12 images in this case) and then fitting the data to the signal decay model. Fig. 1b is the equilibrium magnetization, which is approximately equal to the proton density because TR is relatively long and there is little T1 effect. Fig. 1c is the T2 map, and Fig. 1d is the field inhomogeneity plotted as (1-exp(-Δn/T2*)) so that dark corresponds to uniform field (long T2*) and bright corresponds to decreased T2*. The last two images are water and fat. These were obtained by reconstructing one image with the partial data from the SE points (in-phase image) and two images from the shifted (out-of-phase) echoes. These were then combined via a Dixon method to generate separate water (Fig. 1e) and fat (Fig. 1f) images.

Fig. 1. RAD-GRASE images generated from a single data set.
Qualitatively, these images show the expected behavior. The water and fat appear in the correct regions. The proton density is fairly uniform, the T2 of baby oil (vials in upper right and lower left) is low, the T2 of the more heavily doped water (upper left vial) is lower than the other water vial, and T2* is increased in oil regions surrounded by water. There are clearly some artifacts in these images. The T2 map shows some bright signal at the edges of the baby oil vials and some variations in the T2 of the surrounding water. The fat image shows some ringing in the signal intensity. These artifacts arise due to the k-space data inconsistencies in partial data sets. Ongoing work is aimed at quantitative assessment of the parametric accuracy, characterization of the artifacts, and optimization of the data acquisition and processing techniques to improve the performance.

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References