Ramp sampling strageties for high resolution single-pass Dixon imaging at 3T

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Introduction: Single-pass Dixon sequences acquire all echoes necessary for fat-water separation within a single TR, and can dramatically decrease imaging time compared to multi-pass Dixon sequences. However, errors may occur in the separation algorithm when these echoes are not acquired at the echo times assumed by the separation algorithm. This is particularly a challenge at higher field strengths, where shorter echo spacings are required due to the increased frequency shift between lipid and water signals. Increasing resolution exacerbates the problem further, since a greater span of k-space must be covered during each readout. While sampling is typically performed only during the flat-top portion of the readout gradients, minimum echo times as well as echo spacing may be reduced by sampling during the attack and decay ramps as well. This study examines the effect of echo spacing on a 2-point Dixon algorithm [1] and demonstrates the benefits of ramp sampling in a single-pass, dual-echo gradient echo sequence for sub-millimeter fat/water imaging at 3T.

Methods: A dual-echo 3D gradient echo sequence was modified to allow ramp sampling. When this option was enabled, the sampling window was increased to fill approximately 75% of the ramp time while the flat-top duration of the pulse was shortened to maintain the same k-space coverage during the extended sampling window. The area of the readout dephasing pulse was also reduced to bring echo formation back to the center of the readout pulse. Spacing between all shortened gradient pulses in the readout direction was then eliminated, reducing echo times as well as the spacing between echo times. An asymmetric option was also enabled that combined the first half of a flat-top readout with the second half of a ramp sampled readout. Data was resampled to the prescribed matrix size before Fourier transform reconstruction. All images were acquired on a 3T Signa Excite HDx whole body imager (General Electric Healthcare, Waukesha, WI). To observe the effect of sampling method on echo times, sequences were constructed with slice thickness = 1 mm, number of slices = 64. For each sampling method, the echo times and number of sample points were recorded for (FOV, matrix size, bandwidth) = (300 mm, 320, ±166.67 kHz) and (400, 288, ±142.86 kHz). Axial volumes were also acquired of patients referred for breast cancer screening, approximately 7 to10 minutes after contrast administration, using both flat-top and symmetric sampling techniques. Acquisition was performed using an 8-channel coil (HD Breast Array, General Electric Coils, Aurora, OH) with FOV = 28-30 cm, readout matrix size = 288-320, phase encodes = 352, slice thickness = 1.8 mm, and number of slices = 120-126. Outer k-space regions were accelerated by a factor of 3 in the phase encode direction (left/right) using self-calibrated ARC [2]. A Dixon algorithm [1] was then applied to the resulting complex images to produce separate water and lipid images. Water images were compared for image quality and suppression of lipid signal.

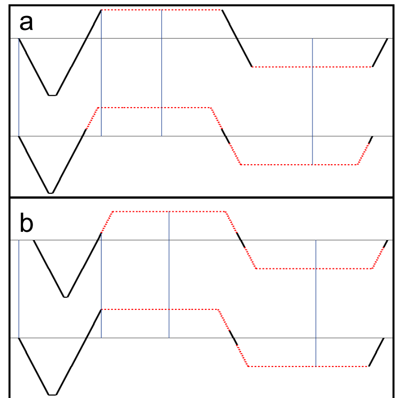

Figure 1: (a) Conventional flat-top (top) versus ramp sampled (bottom) dual-echo readouts when start of sampling is not constrained. (b) Symmetric (top) versus asymmetric (bottom) ramp sampling when start of sampling is constrained. Dotted lines indicate times of active sampling.

Table 1: Echo times and sample points for slice thickness = 1 mm

FOV (mm)	Readout Matrix Size	Bandwidth (kHz)	Sampling Type	First TE (msec)	Second TE (msec)	Sample Points
300	320	± 166.67 (1042 Hz/pixel)	Flat-top only	1.364	2.676	320
			Symmetric ramp	1.276	2.416	362
			Asymmetric ramp	1.364	2.508	338
400	288	± 142.86 (992 Hz/pixel)	Flat-top only	1.260	2.605	288
			Symmetric ramp	1.276	2.508	312
			Asymmetric ramp	1.260	2.496	300

Results: Echo times for the sequences are shown in table 1. Symmetric ramp sampling reduced both echo times at sub-millimeter resolution. Asymmetric ramp sampling decreased echo times relative to symmetric ramp sampling at resolutions near or above 1.35 mm. In patient images (figure 2), excellent fat suppression was observed on all water images. Images acquired without ramp sampling exhibited some edge ringing artifacts and loss of fine structures.

Discussion: Since the background field is assumed to vary slowly in space, large deviations from theoretically assumed echo times may cause suboptimal separation at sharp fat-water boundaries, resulting in edge artifacts or even complete loss of thin features, as shown in fibroglandular tissue of the breast images. Thus with correct echo times, smaller lesions can be identified. Since minimum echo times are usually limited by the readout gradient axis, symmetric ramp sampling would benefit most protocols for this sequence. Ramp sampling is demonstrated to be effective for achieving the correct echo times for Dixon fat-water separation in a single pass dual-echo acquisition, even with clinical protocols that require sub-millimeter resolution at 3T.

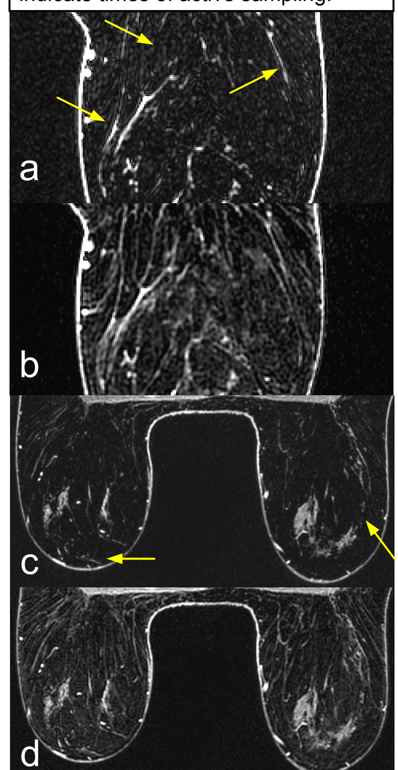

Figure 2: Breast images processed from data acquired using the dual-echo sequence without ramp sampling (a,c) and with ramp sampling (b,d). Arrows indicate areas with edge artifacts and fine structure loss attributed to the deviation between actual and theoretically assumed echo times when ramp sampling is not applied.

References: 1. Ma J, MRM 2004, 52:415-419. 2. Brau AC et al, Proc. ISMRM 2006, p 2462.