Improved single-pass dual echo Dixon imaging with ramp sampling and flexible echo times

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Introduction

Single-pass two-point Dixon sequences acquire both echoes necessary for fat-water separation within a single TR, and can dramatically decrease imaging time compared to multi-pass Dixon sequences. However, high resolution imaging at high field strengths can be challenging with readout gradients of alternating polarity because it entails a large echo spacing that leads to increased chemical shift induced spatial misregistration between fat and water signals. To alleviate this challenge, we investigated combining ramp sampling [1] to improve sampling efficiency and a flexible TE fat/water separation algorithm [2] to enable longer echo times or more flexible echo spacing. The feasibility and potential improvement of the proposed method is demonstrated with phantom and in vivo abdominal images at 3T.

Methods

A dual-echo 3D gradient echo Dixon sequence was modified to enable ramp sampling and allow acquisition without echo timing constraints. With ramp sampling, the readout window was increased by about 10% while the flat-top duration of the pulse was shortened for the same k-space coverage. The area of the dephasing gradient was also reduced, thus allowing a shorter echo time compared to when no ramp sampling was used. With no constraints on echo timing, the dead spacing between all gradient pulses in the readout direction could be eliminated to achieve the minimum TE for both echoes.

All images were acquired on a 3.0 T whole body imager (MR750, General Electric Healthcare, Waukesha, WI). The sequence was applied with and without ramp sampling to an oil and water phantom in a 32-channel head coil (General Electric Coils, Aurora, OH), with thickness = 1.6mm and total number of slices = 32. Abdominal axial volumes were also acquired of volunteers scanned under an IRB protocol, using an 8-channel cardiac array coil (General Electric Coils, Aurora, OH), with thickness = 4mm and total number of slices = 52. The acquisition was accelerated by a factor of 2 using parallel imaging (ASSET). Each line of ramp sampled data was interpolated to the originally prescribed number of readout points before volume reconstruction. Fat/water decomposition was performed offline with MATLAB (Mathworks, Natick, MA). With a self-calibrated signal model for fat, a flexible TE Dixon algorithm similar to that proposed in Ref. [2] was applied to the raw complex images to produce separate water and fat images. Water images were compared for image quality and suppression of fat signal.

Table 1. Scan Parameters

Subject	Sampling	Points	FOV	Matrix	BW	TE1	TE2	ESP	TR	Time
Phantom	Flat	256	24.0	256x256	142.86	1.53	2.93	1.40	5.11	20.6
	Ramp	300				1.37	2.48	1.11	4.49	18.4
Abdomen	Flat	320	32.0	320x224	166.67	1.38	2.70	1.32	4.45	14.6
	Ramp	360				1.30	2.43	1.23	4.18	13.7
Abdomen	Flat	448	32.0	448x224	166.67	1.70	3.43	1.73	5.51	18.0
	Ramp	492				1.68	3.21	1.53	5.33	17.4

Results

Fat signal was evenly suppressed in all water images. TE's, TR, and acquisition times were shorter with ramp sampling enabled due to the shorter gradient pulses. No fat/water swaps were observed despite the long echo times of the flexible TE acquisition, even at the highest readout resolution of 0.72 mm and longest echo spacing of 1.73 msec. No loss of resolution or image quality was observed with ramp sampling.

Discussion

Ramp sampling and flexible TE fat/water separation are demonstrated to achieve sub-millimeter resolution at 3T with a single-pass dual-echo sequence. With previous two-point Dixon algorithms, large deviations from theoretically assumed in-phase and out-of-phase echo times may cause inaccurate separation of water and fat, as well as sharp edge artifacts or even loss of thin features. By shortening TR, ramp sampling also shortens overall acquisition time, allowing for shorter breathholds and improving temporal resolution for dynamic studies. Flexible TE acquisitions with ramp sampling achieves the maximum data acquisition efficiency for a given protocol and at the same time minimizes potential chemical shift induced misregistration artifacts.

References: [1] Hwang KP, ISMRM 2010, 5049 [2] Ma J, ISMRM 2012, 4045.

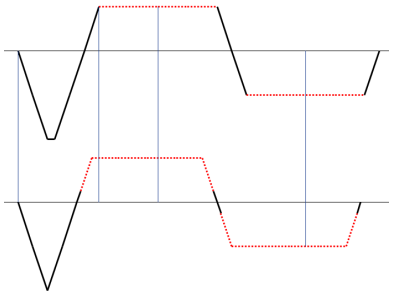

Figure 1. Sampling (indicated in red) during conventional flat-top (top) versus ramp sampled (bottom) readouts.

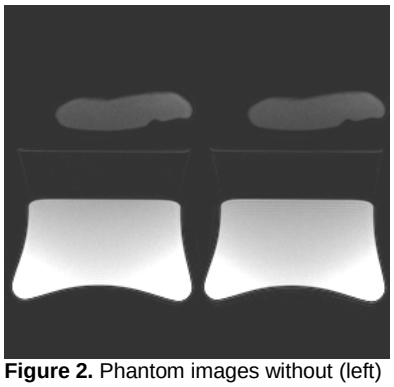

Figure 2. Phantom images without (left) and with (right) ramp sampling, windowed to highlight lipid suppression.

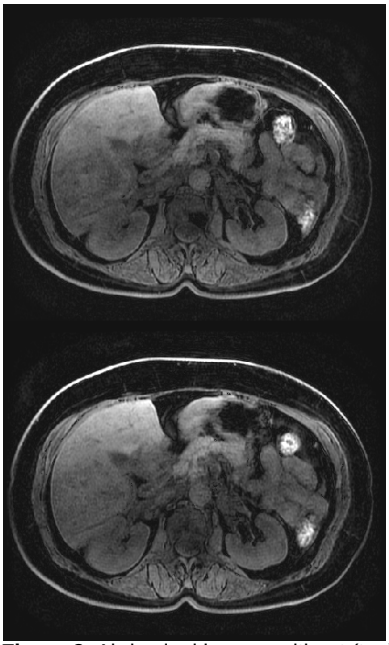

Figure 3. Abdominal images without (top) and with (bottom) ramp sampling, acquired with 1 mm resolution in the readout direction.