3D Gradient Echo MRE of the Liver with CLEAR Parallel Image Reconstruction

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Introduction: Clinical MRE is acquired and processed as 2D data sets. A true 3D wave field sample with 3D processing would provide a more accurate estimate of the tissue stiffness. 2D multi-slice spin echo EPI is a common approach used to acquire the needed wave field of the entire liver in a few breath-holds. EPI provides fast acquisitions and ample coverage; however, it does present some image artifacts that need to be addressed. This paper presents a 3D GRE sequence capable of acquiring fewer slices with fewer artifacts than can be obtained with EPI.

Methods: Volunteer scans were performed under an IRB-approved protocol on a GE 1.5 HDx scanner. The 2D multi-slice EPI scan was acquired with a prescribed resolution of x/y/z=96/96/32, TE=45.2ms, TR=1333ms, FOV=44.8cm, slice thickness=3.5mm, ASSET R factor=2, S/I Sat. The EPI scan was acquired in three 21s breath-holds. The 3D 3-axis GRE scan was acquired with a 3x randomly under-sampled pattern in ky-kz according to a variable-density Poisson disk distribution seen in Figure 1. Each motion encoding direction and phase offset used a different random sampling. The data was acquired with a prescribed resolution of x/y/z=90/90/12, TE=13.4ms, TR=16.7ms, FOV=36cm, slice thickness=4mm, flip=15°. S/I Sat was not used to save time. Each of four single side phase samples was acquired in an 18s breath-hold scan that obtained 1080 samples. Image reconstruction from the under-sampled GRE k-space data was performed using a generalization of CLEAR [1] that was adapted to promote local low-rankedness (LLR) jointly across the coil, motion encoding direction, and phase offset dimensions. The LLR penalty was defined over a set of disjoint 3D spatial blocks (block size=6x6x6) which was randomly shifted at each of 50 iterations of the algorithm with a manually selected regularization parameter. The algorithm was implemented offline in a MATLAB script.

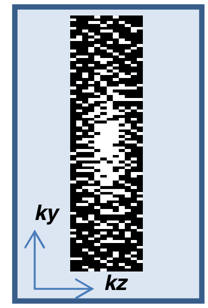

Figure 1: 3D GRE ***k***-space sampling pattern

Results: Both scans provided depictions of the 3D wave field as seen in Figure 2. Due to imperfect slice profiles, cross talk between slices produces a striping artifact in the reformatted sagittal slices seen in Figure 3. If not removed, these stripes would bias the stiffness estimates. The stripes appear as high frequency components in frequency space and are commonly removed with a low pass filter.

Conclusions: Single slice 2D GRE MRE acquisitions can be performed in a single breath-hold. The proposed 3D GRE sequence can provide similar slice throughput with four to six 3D processed images obtained in four breath-holds. Due to the nature of the acquisition, no phase striping artifacts are generated obviating the need for additional filtering. The CLEAR reconstruction algorithm provided superior ghost reduction compared to ASSET while providing additional acceleration.

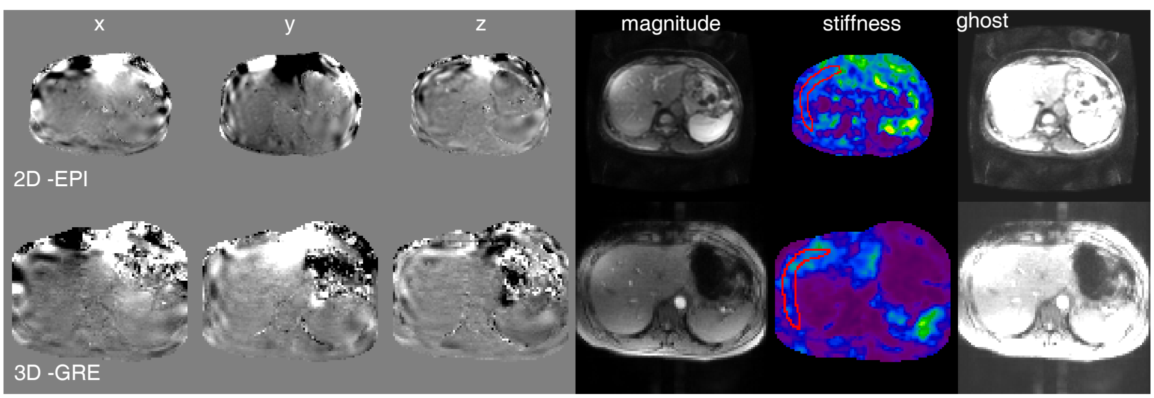

Figure 2: The unwrapped phase data for the 2D multi-slice EPI and 3D GRE scan show typical wave patterns for a healthy volunteer with short wave lengths and high attenuation. Stiffness estimates from a 3D LFE were obtained showing 2.29kPa and 2.44kPa for the GRE and EPI scans respectively. Residual ghosting is more prominent in the EPI scans. The lack of S/I sat bands is seen in the GRE scans.

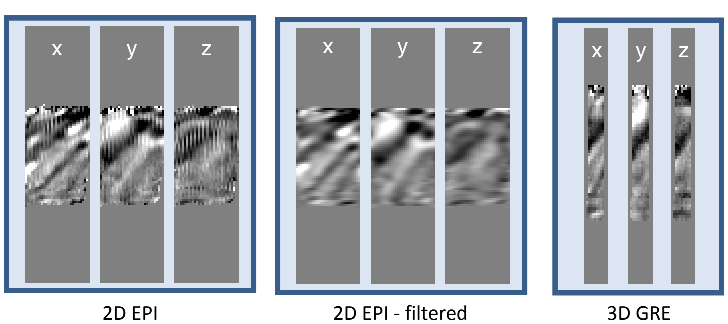

Figure 3: Sagittal reformats of the wave field images. The sampled 2D EPI show the slice-to-slice cross talk phase striping. These striping artifacts can be removed with a Butterworth low pass filter. There are no striping artifacts seen in the GRE wave images.

References: [1] JD Trzasko and A Manduca, "CLEAR: Calibration-Free Parallel Imaging Using Locally Low-Rank Encouraging Reconstruction", Proc. ISMRM 2012, p.517.