Significant reduction in scan time for ultra short TE imaging of the knee

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Target Audience: Researchers and clinicians interested in ultrashort echo time imaging and fast imaging.

Purpose: Ultrashort echo time (UTE) imaging is attracting increasing research and clinical attention for its ability to detect tissues with very short T2 relaxation time [1], such as cortical bone, cartilage and meniscus. UTE can be used for investigating diseases like chronic fibrosis, hemorrhage, multiple sclerosis and calcification [2]. In applications such as T1/T2* measurement [3] or field map estimation needed for susceptibility mapping [4], scan times are long due to the fact that multiple echoes are required. Compressed sensing has been applied to 2D UTE [5]. In this work, we apply compressed sensing to 3D UTE human knee data to achieve a 5-fold reduction in scan time towards making UTE clinically possible in applications like quantitative susceptibility mapping (QSM).

Methods: The reconstruction problem is:

$$x_r = \text{argmin}_x\{\|Gx\|_1 + \lambda\|SFx - y\|_2^2\} \quad (1)$$

which applies a total variation norm as regularization, aiming to preserve sparsity in the gradient image [5]. Here, x stands for the reconstructed complex image, G the gradient operator, S the data sampling operator, F the Fourier transform operator and y the measured k-space data. A fixed point method [4] was applied to find x_r with properly chosen regularization weight λ. A 3D UTE sequence was implemented at 3T (GE Healthcare, Waukesha, WI). This sequence employed nonselective hard pulse which excited the entire volume, followed by 3D radial ramp sampling. A healthy volunteer's knee was scanned using following parameter: FA=10, FOV=22 cm, $0.8 \times 0.8 \times 0.8$ mm^3, TR=10.5 ms, 50,000 radial projections (which number is typically used for fully 3D radial sampling [1]) and TE = 0.05, 0.1, 1 and 3 ms. Then the data were under-sampled by a factor of 5, resulting in 10,000 projections. Each coil and each echo were reconstructed independently. Both fully-sampled and down-sampled data were also reconstructed using gridding for comparison.

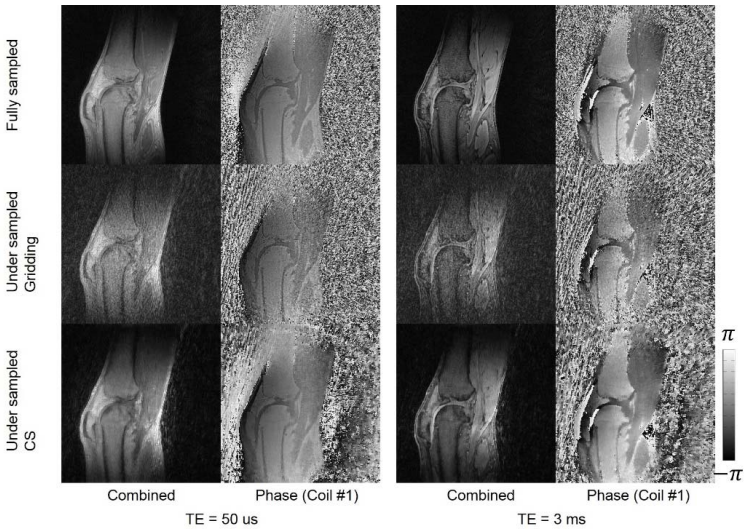

Figure 1. Sum of square combined coil image and phase image for one coil at TE=50us (Left) and TE=3ms (Right). The CS reconstructed results suppress noise and streaking artifact, and preserve most structural detail in both phase and combined coil image.

Results: In proposed reconstruction λ=100 was used. As shown in Fig. 1, with under-sampled data, the magnitude image with gridding displays a high level of noise and streaking artifact, while using CS regularization effectively suppresses both artefacts, while preserving most structural features when compared to fully sampled result. The phase image (from 1 coil) of the CS reconstruction similarly shows superior image quality with lower overall noise.

Discussion: The under-sampled data at a factor of 5 was able to maintain most structural details while suppressing noise and streaking artifact, compared to the result obtained with gridding. However, the choice for regularization parameter λ is essential in determining the reconstruction quality, and was set manually throughout the work. Future work involves incorporating heuristic methods for selecting the optimal regularization. SENSE imaging using a separately estimated coil sensitivity map is expected to further improve reconstruction performance. Furthermore, the under-sampling factor may be optimized in terms of phase quality in phase sensitive application such as quantitative susceptibility mapping.

Conclusion: Our preliminary results show 3D UTE data with compressed sensing reconstruction can preserve structural and phase information, with significant reduction in scan time. This may make 3D UTE imaging plausible *in vivo* for application such as QSM.

References: [1]. Du, J., et al. MRI. 2011. 29(4): 470-482. [2]. Gatehouse, P., et al. Clinical Radiology. 2003. 58(1): 1-19. [3]. Juras V., et al. MRM. 2014. 71(3): 1015-1023. [4] Liu, T., et al. MRM. 2013. 69(2): 467-476. [5] Fabich H.T., et al. JMR. 2014. 245: 116.