Impact of sampling pattern on combined parallel imaging compressed sensing volumetric knee MRI

Umar Tariq[1], Peng Lai[2], Michael Lustig[3], Marc Alley[4], Mian Zhang[5], Garry Gold[4], and Shreyas S Vasanawala[6]

[1]*Department of Radiology, Stanford University, Stanford, CA, United States,* [2]*GE Healthcare, Menlo Park, CA, United States,* [3]*University of Calfornia Berkeley, Berkeley, CA, United States,* [4]*Radiology, Stanford University, Stanford, CA, United States,* [5]*Statistics, Stanford University, Stanford, CA, United States,* [6]*Radiology, Stanford University, Stanford University, CA, United States*

Title: Impact of sampling pattern on combined parallel imaging compressed sensing volumetric knee MRI

Purpose: Knee MR exams consist of two-dimensional (2D) sequences in multiple pre-defined imaging planes (1), which is lengthy and suffers from relatively thick slices and gaps between slices. Volumetric knee imaging (e.g. CUBE, SPACE, VISTA) may address these but so far has not seen wide clinical use due to suboptimal quality of reformatted images. This suboptimal quality comes in part from a prohibitively long scan time to achieve true isotropic submillimeter resolution and blurring from long echo train acquisitions. A potential way to address these problems is combining parallel imaging (2) and compressed sensing (CS) (3) to keep both scan time and echo train length short. CS exploits image sparsity in some transform domain that makes under-sampling possible. Though variable density sampling generally improves image quality, as fine spatial information is contained in the outer portions of k-space, a variable density sampling pattern may be detrimental. Here we compare uniform density (UD) and variable density (VD) sampling strategies to obtain thinner slices with higher acceleration, assessing image quality relative to gold-standard 2D images in the delineation of the anterior cruciate ligament (ACL), medial meniscus, medial collateral ligament (MCL), medial retinaculum and patellar cartilage.

Methods: With IRB approval and informed consent/assent, 23 consecutive pediatric patients (age 14 +/- 8 years, range 5-20 years) referred for 3 Tesla knee MRI exams in November and December 2011, were recruited in the study. One patient was excluded from the study because he could not straighten his leg for image acquisition. Routine 2D images in axial, sagittal, and coronal planes was followed by 3D imaging in the sagittal primary plane with both UD and VD sampling pattern (MR750, GE Healthcare, Milwaukee, WI, USA) with an eight channel knee coil. For both UD and VD, a net acceleration of 2.4x2.4 (total 5.76) was used to obtain 0.6 mm slice thickness. Images were then reconstructed with parallel imaging compressed sensing algorithm (L1-SPIRiT) (4, 5). Other parameters are 16 cm FOV, 320x320 matrix, TR 1400 ms, TE 20.8 ms, echo train length of 37, with number of slices adjusted to the size of the knee.

2D, UD and VD images were transferred to a workstation with real-time multiplanar reformation capability for review (Osirix). For each subject, five anatomic structures (Fig. 3) were evaluated on UD, VD and 2D images by two radiologists independently on a 5 point scale (1 non-diagnostic (cannot see structure), 2 limited (can see structure but not evaluate integrity), 3 diagnostic (can evaluate structure with some confidence), 4 good (can evaluate structure with high confidence), 5 outstanding (entire structure delineated sharply). UD and VD images were presented in randomized blinded fashion; however the radiologists could not be blinded to 2D images. Statistical analyses were performed in the R programming environment. To test the null hypothesis that 2D, UD and VD images are equivalent, a Friedman test was performed on the scores for each structure. To test the null hypothesis that 2D, UD and VD images are equivalent when compared in pairs with each other, a Wilcoxon signed rank test was performed on the scores for each structure. A type I error rate of 0.05 was used for all statistical tests.

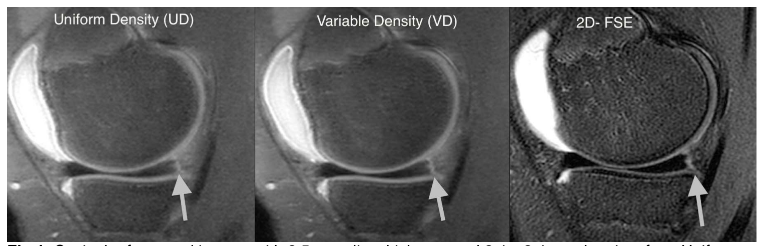

Fig 1: Sagittal reformatted images with 2.5 mm slice thickness and 2.4 x 2.4 acceleration, from Uniform Density (UD) (left) and Variable Density (VD) (middle) reconstructions. Note sharpness and good delineation of torn medial meniscus (arrow) as compared to 2D fast spin echo (FSE) imaging (right).

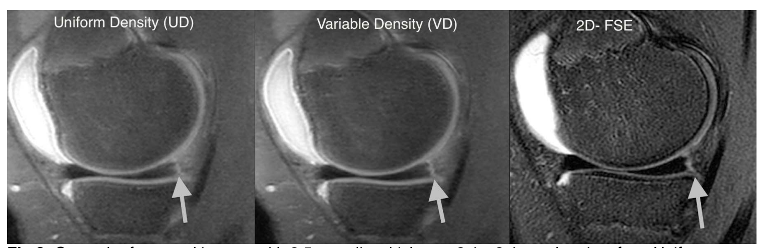

Fig 2: Coronal reformatted images with 2.5 mm slice thickness 2.4 x 2.4 acceleration, from Uniform Density (UD) (left) and Variable Density (VD) (middle) reconstructions. Note delineation of medial collateral ligament (arrow) as compared to 2D- FSE imaging (right). Also, note the bony infarcts.

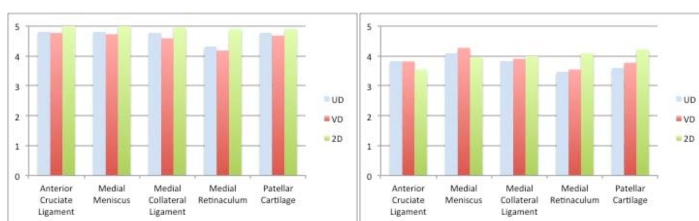

Fig 3. Mean score of delineation of anatomic structures for 2D, UD and VD imaging by reader 1 (left) and reader 2 (right). All three had comparable scores for anterior cruciate ligament and medial meniscus. 2D images had better scores for medial retinaculum from both readers, for medial collateral ligament from the reader one and for patellar cartilage from the reader two.

Results: Figure 1 and 2 show representative images. Figure 3 shows the mean score of delineation of anatomic structures for 2D, UD and VD images. All three had comparable scores for anterior cruciate ligament and medial meniscus ($p>0.05$, Friedman test). 2D images had better scores for medial retinaculum from both readers, for medial collateral ligament from the reader one and for patellar cartilage from the reader two, with p value under 0.05 in all these cases (Wilcoxon signed rank test). However, VD and UD images received equivalent scores ($p>0.05$, Wilcoxon signed rank test) for all five structures, from both readers.

Conclusion: Despite relative undersampling of outer k-space with VD sampling relative to UD sampling, similar image quality was achieved, suggesting robustness to sampling pattern. The quality of delineation of the anterior cruciate ligament and medial meniscus with 3D imaging is similar to that of conventional 2D imaging. Despite thin slices and short echo train length, delineation of fine structures primarily evaluated in reformatted planes, such as the medial retinaculum requires further image quality improvements for 3D imaging to replace widely 2D imaging.

References: [1] Kijowski R et al. JMRI 2011:33:758-771 [2] Griswold M et al. Magn Reson Med 2002; 47:1202-1210. [3] Lustig M et al. Magn Reson Med 2007; 58:1182-1195. [4] Lustig M et al. Magn Reson Med. 2010;64(2):457-71. [5] Vasanawala SS et al. Radiology. 2010;256(2):607-16. Research funded in part by John & Tashia Morgridge Faculty Scholar's Fund, NIH 5R01 EB009690, and GE Healthcare.