Impact of Compressed Sensing on Volumetric Knee MRI

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INTRODUCTION: Volumetric (3D) fast spin echo (FSE) with flip angle modulation (e.g., CUBE, SPACE, VISTA) may enable faster overall exam times in MRI of joints [1], which is of particular value in pediatrics. Wider adoption is hampered by long scan time and the limited quality of reformatted images. Parallel imaging is used to reduce scan time, but acceleration is limited by coil geometry. Thus we investigated whether a compressed sensing (CS) strategy to obtain thinner slices with higher acceleration improves volumetric pediatric knee MRI exams.

MATERIALS AND METHODS: A 3D fast spin echo sequence with flip angle modulation (CUBE) was modified to collect k-space data using a Poisson disc sampling pattern [2] that could produce anisotropic and fractional reduction factors in the ky×kz directions (Fig. 1). With IRB approval and informed consent/assent, 24 consecutive pediatric patients referred for routine clinical knee MRI exams on a 3T scanner (MR750, GE Healthcare, Milwaukee, WI, USA) with an eight channel knee coil additionally underwent volumetric imaging with primary "slices" in the sagittal plane. For the first 12 patients, 2x2 (total of 4) acceleration was used to obtain 1 mm slice thickness, whereas 2.2 x 2.2 (total of 4.84) acceleration for 0.8 mm slices was used for the last 12 patients. Data was then reconstructed with parallel imaging (ARC) and a CS algorithm (L1-SPIRiT) [3,4]. Remaining scan parameters were unchanged at 16 cm FOV, 320x288 matrix, z-interpolation factor of 2, TR 1600 ms, TE 27ms, with number of slices adjusted to the size of the knee.

Volumetric images along with routine two-dimensional FSE images were transferred to a workstation with multiplanar reformation capability for review (Osirix). For each subject, 12 anatomic structures (Fig. 3) were evaluated on both volumetric ARC and CS images by two radiologists on a 5 point scale (1 nondiagnostic, 2 limited, 3 diagnostic, 4 good, 5 outstanding). Further, quality of delineation of those anatomic structures was compared between volumetric CS and 2D FSE images on a seven point scale (-3 less delineation, -2 not preferred, -1 minimally inferior, 0 same, 1 minimally superior, 2 preferred, 3 more delineation). To test the null hypothesis that ARC and CS images are equivalent, a Wilcoxon rank sum test was performed. To test the null hypothesis that the relative quality of delineation of structures on volumetric images is unchanged with higher acceleration, a Kruskal Wallis test was performed.

RESULTS: Figs. 1 and 2 show representative images. Mean age for low and high acceleration groups were 14 and 15 years, respectively, with mean scan times of 4.6 and 5.1 minutes. CS images were superior to ARC images for all structures except for the lateral collateral ligament and the medial retinaculum (both for one reader), with p value under 0.05 for all other cases (Wilcoxon rank sum test). The relative performance of volumetric imaging to 2D imaging was unchanged at higher acceleration for most structures. However, thinner slices enabled by higher acceleration better delineated the medial and lateral collateral ligaments for both readers (p values of .002 - .01 for MCL and .003-.005 for LCL, Kruskal Wallis test) and the medial retinaculum for one reader (p-value .04), though still not as well as conventional 2D FSE.

CONCLUSION: Thinner slices afforded by compressed sensing improves volumetric knee MRI, particularly for delineation of structures primarily evaluated on reformatted images (MCL, LCL, medial retinaculum). Further improvement may be required for delineation of structures on reformats equivalent to that of conventional 2D FSE.

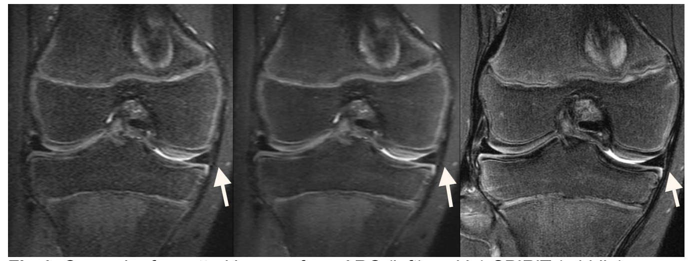

Fig 1: Coronal reformatted images from ARC (left) and L1-SPIRiT (middle) reconstructions with 2 x 2 acceleration. Note delineation of MCL arrow), which is sharper on conventional 2D FSE imaging (right).

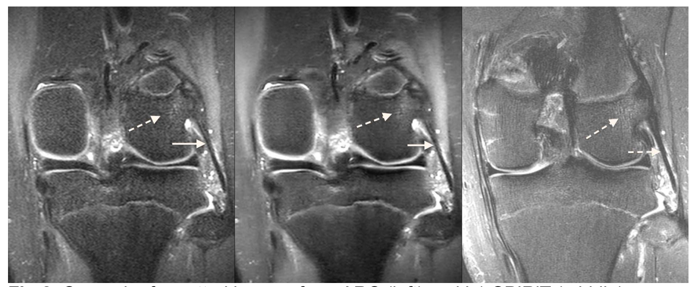

Fig 2. Coronal reformatted images from ARC (left) and L1-SPIRiT (middle) reconstructions with 2.2 x 2.2 acceleration (i.e. higher than supported by the coil array with parallel imaging alone). Note improved sharpness and good delineation of LCL (arrow), though still inferior to 2D FSE imaging (right). L1-SPIRIT improves conspicuity relative to ARC of subtle lateral condylar edema (dashed arrow).

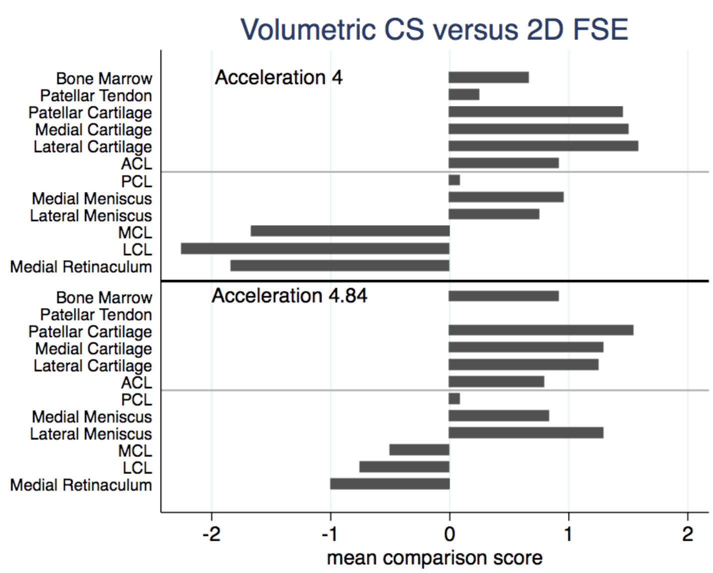

Fig 3. Mean score of delineation of anatomic structures on volumetric CS images at lower acceleration (top) and high acceleration (bottom) versus conventional 2D FSE. With higher acceleration and thinner slices, MCL, LCL, and retinaculum are still inferior on volumetric images, but to a significantly less degree. ACL = anterior cruciate ligament, PCL = posterior cruciate ligament, MCL = medial collateral ligament, LCL = lateral collateral ligament.

REFERENCES: **[1]**: Kijowski et al., Radiology 252:2(486-495), 2009. **[2]** H. Tulleken et al., Poisson Disk Sampling Tutorial, Dev. Mag. Magazine 2008; **21**:21-25 (devmag.org.za). **[3]** M. Lustig et al., ISMRM, 2009; Honolulu, p. 379. **[4]:** S. Vasanawala et al., Radiology. 2010; **256**:607-616. Research funded in part by NIH RR09794-15, NIH R01 EB009690, Tashia & John Morgridge Foundation, and GE Healthcare.