Parallel Imaging of Knee Cartilage at 3 Tesla

J. Zuo[1], X. Li[1], S. Banerjee[1], E. Han[2], and S. Majumdar[1]

[1]Radiology, University of California, San Francisco, San Francisco, CA, United States, [2]Applied Science Lab West, GE Healthcare, Menlo Park, CA, United States

Introduction With recent developments, magnetic resonance imaging (MRI) is capable of evaluating cartilage degeneration not only qualitatively, but also quantitatively. Relaxation times such as T1rho, T2 and morphological parameters have become very important tools for early detection of osteoarthritis (OA) and monitoring disease progression. However, high resolution anatomical images for cartilage volume and thickness measurements as well as multiple T1rho/T2-weighted images for T1rho/T2 fitting all require long image acquisition time. This introduces motion artifacts, high radio frequency (RF) power deposition, increased patient discomfort and high scan cost. Consequently, not all quantitative measurements can be done during a limited scan time. The introduction of parallel imaging provides a remedy to this problem. With parallel imaging techniques, the spatial information related to the phased array coils are utilized for reducing conventional Fourier encoding to shorten acquisition time. While only the T1rho parallel imaging method was studied previously [1], in this study, we demonstrate the feasibility of applying sensitivity encoding (SENSE) [2] to a complete quantitative cartilage imaging protocol to reduce scan time and evaluate the reproducibility of the technique. Furthermore, the impact of the acceleration factor (AF) on the quantification precision of the measures of morphology, T1rho and T2 was determined.

Method An 8 channel phase array knee coil (General Electric Medical Systems, WI) was used for both regular and SENSE parallel imaging on a 3T GE Signa scanner. The left knees of 6 healthy volunteers (ages 27-30) were scanned with both regular and parallel imaging (AF = 2) methods at sagittal plane. Five volunteers were repositioned between repeated parallel scans with AF = 2 while the sixth was scanned with AF =3. The imaging protocol consisted of a T2 weighted fast spin echo (FSE) sequence (matrix 288×224, 40 slices, slice thickness/Gap = 2/0.5mm, number of excitation = 2, total imaging time 6min 40s, 3min 42s for AF= 2, 2min 43s for AF = 3), a 3D spoiled gradient echo (SPGR) sequence for knee morphological parameter measurements (matrix 512×512, locations per slab (LPS) = 100, slice thickness = 1mm, flip angle = 18°, total imaging time 14min 28s, 7min 14s for AF =2, 4min 49s for AF =3), a previously developed 3D T1rho mapping using segmented elliptic-centric SPGR sequence that acquires data during transient signal evolution (tsT1rho)(matrix 256 ×128, LPS = 36, slice thickness = 3mm, time of spin lock (TSL) = 0/10/40/80 ms, spin lock frequency = 500 Hz, views per segment = 48, flip angle =12°, total imaging time 12min 34s, 6min 19s for AF =2, 4min 22s for AF =3) [3] and a 3D T2 mapping by adding a nonselective T2 prep imaging sequence to the same SPGR sequence (tsT2) (matrix 256×128, LPS = 36, slice thickness = 3mm, 4 different images were acquired with TE = 4.1/14.5/25/45.9 ms, total imaging time 9min 44s, 4min 54s for AF =2, 3min 24s for AF =3) [4]. Field of view was 14-16cm for all sequences. Cartilage measurements were evaluated in 5 segmented knee compartments: Medial/Lateral Femur Chondyle (MFC/LFC), Medial/Lateral Tibia (MT/LT) and Patella (Pat). The 3D high resolution SPGR images were segmented to calculate cartilage volume and mean cartilage thickness. For T1rho and T2 maps, the regions of interest (ROI) were defined on the images with shortest TSL and shortest time of echo (TE), respectively. Different from steady-state 3D T1rho SPGR sequence (ssT1rho) which requires T1 information for T1rho fitting and is specific absorption rate (SAR) sensitive [1], the tsT1rho imaging sequence employed here does not require the knowledge of T1 for cartilage and yields much less SAR and shorter scan time, making tsT1rho more appropriate for clinical study compared to ssT1rho. All post-processing was performed on a Sun workstation (Sun Microsystems, Palo Alto, CA).

Results Computed femoral cartilages with regular imaging method and with the AF =2 parallel imaging method are shown in Fig.1a and 1b with colorbars indicating the cartilage thickness in mm. The T1rho map from the AF =2 parallel imaging method (Fig.1d) shows comparable results (in ms) as the one from the regular imaging method (Fig.1c). Similar results were observed in T2 maps. Bland-Altman analysis of mean cartilage thickness, T1rho and T2 (Fig. 2) reveals precise agreement of measurements by regular and parallel imaging (AF = 2) methods. The intra-class correlation coefficient (ICC) of the two methods is 0.998 for cartilage volume, 0.979 for mean cartilage thickness, 0.949 for T1rho and 0.967 for T2. Excellent reproducibility was demonstrated in all ROIs as: <5% for cartilage volume and < 3.5% for cartilage thickness, similar to the values found in the literature [5]; <6% for both T1rho and T2 studies versus <8% for regular T1rho mapping and <6% for regular T2 mapping studied earlier by our group. The average ratio of the signal to noise ratio (SNR) between regular imaging and parallel imaging AF= 2 calculated in all ROIs is 1.38, in accordance with the fact that the SNR is inversely proportional to the square root of AF, which is 1.41. With higher acceleration factor (AF =3), the image became much more noisy and the aliasing artifacts became apparent. Figure 3 shows the T2 measured in different ROI with different imaging schemes (regular imaging, parallel imaging AF =2 and 3). Though mean T2 values are close to each other, much higher standard deviation was founded with AF =3 method.

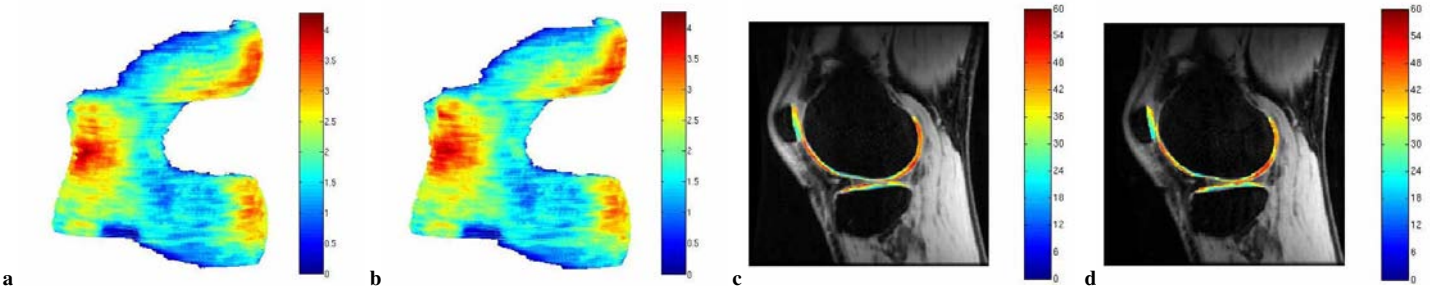

Fig.1. **a**: Cartilage thickness map from regular method; **b**: Cartilage thickness map from AF =2; **c**: T1rho map from regular method; **d**: T1rho map from AF =2.

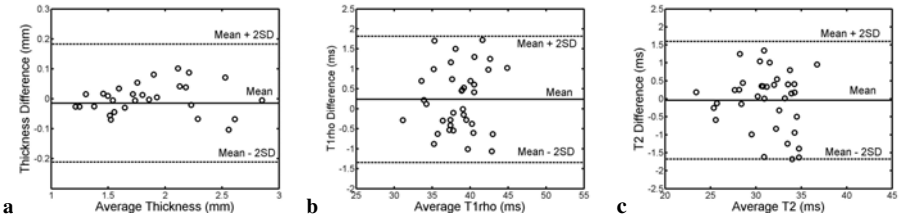

Fig.2. Bland-Altman plots of **a**: mean cartilage thickness; **b**: T1rho; **c**: T2 from regular method and AF =2.

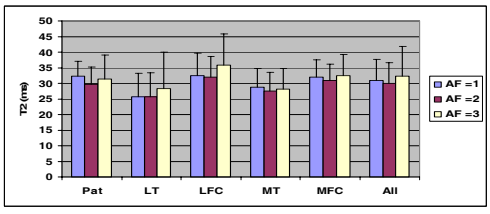

Fig. 3. Comparison of T2 measured from different schemes.

Discussion The study demonstrated that SENSE can be applied to current knee cartilage quantification at AF=2 without degrading measurement precision while efficiently reducing scan time. The measured results from parallel imaging (AF =2) showed good reproducibility. Even shorter imaging time could be achieved at the cost of lower SNR, which might ultimately introduce larger measurement error. It is expected that this technique will be applied to OA patients for further research and clinical applications.

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References [1] Pakin, et al. Magn Reson Med 2006; 56:563-571. [2] Pruessmann, et al. Magn Reson Med 1999; 42:952-962. [3] Han, et al. ISMRM 2005. [4] Oh, et al. Magn Reson Imaging 2006; 24:33-43. [5] Marshall, et al. J Orthop Res 1995; 13: 814-823.