Feasibility of accelerating 3 T hip imaging using compressed sensing

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Introduction

Magnetic resonance imaging (MRI) of the hip joint requires high-spatial resolution and signal-to-noise ratio (SNR) to evaluate small structures like the articular cartilage and the acetabular labrum. This results in long scan times that lengthen the duration of the MRI exam, which normally includes multi-slice two-dimensional (2D) acquisitions along different imaging planes. Compressed sensing (CS) techniques [1] exploit sparsity and incoherence in the data to reconstruct MR images from undersampled datasets. The combination of CS with parallel imaging has enabled to reduce scan time by several folds [2]. These techniques have been successfully applied in cardiac imaging and other MR studies that benefit from very high temporal resolution. In this work, we explored the feasibility of using CS to achieve moderate acceleration factors in routine hip imaging, while maintaining diagnostic quality.

Materials and Methods:

We scanned the right hip of a healthy female volunteer on a 3T MR system (Skyra, Siemens Medical Solutions, Erlangen, Germany) using the system bodycoil for transmission and 20 receive coils, selected from the combination of a spine coil with a flexible torso array wrapped around the right side of the pelvis. Coronal, Sagittal and Axial 2D multi-slice image acquisitions were performed with a Turbo Spin-Echo (TSE) sequence, using the same parameters of the routine hip protocol at our institution: 24 slices, FOV = 160 x 160 mm, matrix size = 320 x 256, slice thickness = 3 mm, TE/TR = 32/3000 ms, Turbo Factor = 8, Flip Angle = 140, Bandwidth = 252 Hz/pixel. A 2D sagittal multi-slice multi-echo spin-echo (MSE) acquisition was also performed using: 24 slices, FOV = 160 x 160 mm, matrix size = 256 x 256, slice thickness = 3 mm, TR = 3500 ms, nine echoes with TE = 11–99 ms, Bandwidth = 227 Hz/pixel. All acquisitions were performed using fat saturation and phase oversampling to avoid wrapping artifacts. K-space data were saved and fully sampled reference images were reconstructed using Fourier transform. One representative hip section was chosen from each series and retrospective 4- and 6-fold undersampling were performed on the corresponding fully sampled k-space data. For the TSE images, the random undersampling pattern was defined using an 8th order variable-density polynomial distribution function, which provides high degree of incoherence required by compressed sensing [1]. For the MSE time-series, a different variable-density sampling pattern was used for each time point in order to exploit additional temporal incoherence [2]. Images were reconstructed from the undersampled datasets using a joint compressed sensing and parallel imaging approach that enforces joint multicoil sparsity [2]. For the TSE images, we used a 2D curvelet as the sparsifying transform and an iterative soft thresholding algorithm with decreasing sparsity weighting [2]. For the MSE time-series, a temporal principal component analysis (PCA) was used as the sparsifying transform [3]. T_2 maps for various acceleration factors were calculated on a pixel-by-pixel basis using a nonlinear least-square fitting algorithm. For comparison, the three TSE images were reconstructed also with GRAPPA [4], using 32 central ky reference lines and undersampling the outer ky lines by a factor of 5, for approximately 4-fold effective acceleration.

Results

Scan time was 3 mins and 16 mins for each of the three TSE series and the MSE series, respectively. Fig. 1 shows that it could be possible to accelerate the 2D TSE acquisitions by a factor of 4 using CS, whereas using GRAPPA image quality would be non-diagnostic. Figs. 2 and 3 show that 6-fold acceleration is also feasible for the MSE time-series used to generate T_2 maps.

Discussion and Conclusions

This study suggests that CS reconstruction approaches that are currently used in research to achieve very large accelerations for advanced MR studies, could be applied to achieve moderate accelerations for routine musculoskeletal imaging, which accounts for a large number of clinical MR exams. Furthermore, T_2 maps could be obtained in a clinically acceptable scan time, to allow evaluation of the articular cartilage at a biochemical level, which is critical for early detection of chondral damage. For this preliminary study, we chose to scan the hip, as it represents the most challenging joint. Future work includes implementing the undersampled acquisition at the scanner for truly accelerated imaging, improving CS reconstruction by grouping data from all slices to exploit additional incoherence, and scanning other joints, for which we expect better results.

References

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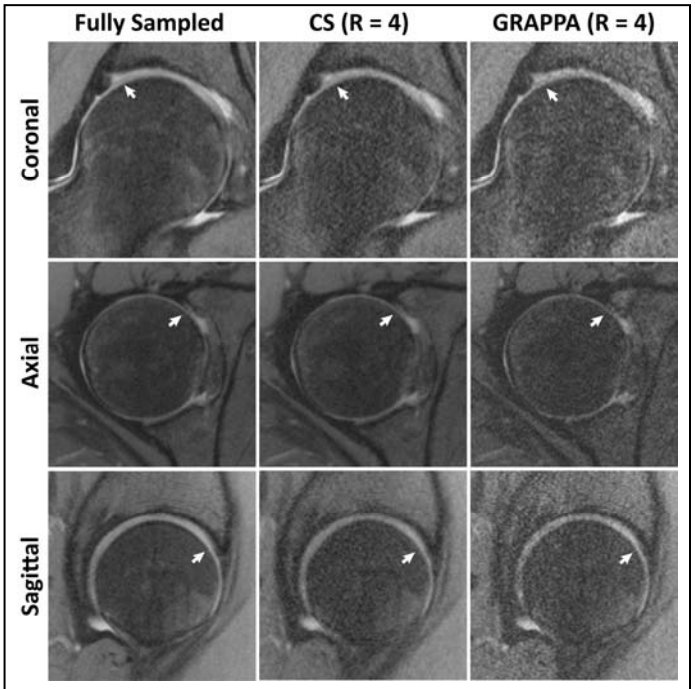

Fig. 1. CS vs. GRAPPA for the case of 4-fold accelerated 2D hip images. Accelerated images of the hip were reconstructed after undersampling fully sampled acquisitions along three orthogonal planes. Both CS (center column) and GRAPPA (right column) images are noisier than the unaccelerated case (left column), but the signal intensity distribution in the articular cartilage and the delineation of the cartilage borders near the chondrolabral junction (white arrows) are only maintained in the CS images.

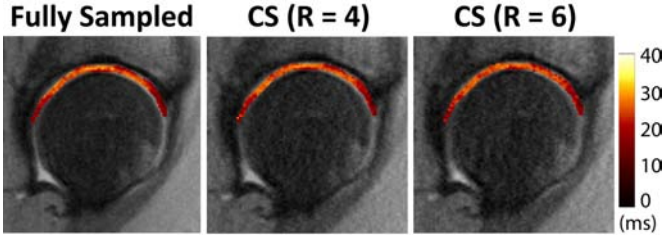

Fig. 2. T_2 maps of the hip articular cartilage superimposed to spin-echo images for different accelerations. T_2 maps were calculated pixel-by-pixel using nonlinear least square fitting with nine spin-echo images. Accelerated T_2 maps were calculated after undersampling the full k-space datasets and reconstructing the same nine images using compressed sensing. The spatial distribution of T_2 for the 4-fold (center) and 6-fold (right) accelerated cases is qualitatively very similar to the fully sampled case.

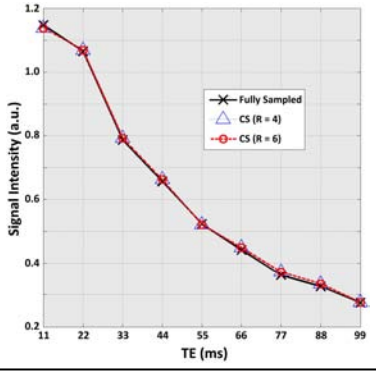

Fig. 3. Average normalized signal intensity in the articular cartilage as a function of echo time. The exponential T_2 decay is almost identical after reconstructing the 9 spin-echo images using CS from data undersampled by a factor of 4 and 6. Small deviations are observed at large echo times due to low signal-to-noise ratio.