Rapid Isotropic Shoulder MRI using 3D SPACE with Incoherent Undersampling and Iterative Reconstruction

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Purpose

3D MRI of the shoulder with isotropic data acquisition is desirable, because it can eliminate partial volume effects and enable multi-planar and curved reconstructions, as well as interactive 3D interpretation. 3D shoulder MRI, however, is particularly challenging because it requires oversampling steps in phase and slice encoding directions to mitigate aliasing artifacts, which can result in long acquisition times of 10-15 min. We therefore prospectively tested the hypothesis that the implementation of pseudo-random k-space undersampling and subsequent iterative reconstruction into a 3D SPACE sequence prototype [1,2] facilitates a rapid, comprehensive, clinical shoulder MRI protocol with image quality similar to a standard 2D TSE protocol.

Methods

10 volunteers underwent 3T MRI (MAGNETOM Skyra, Siemens Healthcare) using a 16-channel receive coil, including standard axial, coronal and sagittal, non-isotropic intermediate-weighted 2D TSE (TR, 4600 ms; TE, 33 ms; pixel size, 0.5 x 0.5 mm²; SL, 3 mm; total acquisition time, 10 min) and axial, coronal and sagittal, non-isotropic T2-weighted fat-saturated 2D TSE (TR, 4000 ms; TE, 61 ms; pixel size, 0.6 x 0.6 mm²; SL, 3 mm; total acquisition time, 11 min) as well as isotropic axial intermediate-weighted accelerated SPACE (TR, 900ms; TE, 29; voxel size, 0.5x0.5x0.5 mm³; MPR SL, 0.5 mm; TA, 5:12 min) and isotropic axial T2-weighted fat-saturated accelerated SPACE (TR, 900ms; TE, 86ms; voxel size, 0.6x0.6x0.6 mm³; MPR SL, 0.6 mm; TA, 5:45 min) sequences. Accelerated SPACE was equipped with the option to use a variable-density Poisson-disc pattern as an undersampling mask [2]. An undersampling factor of 0.18 was chosen. An iterative, SENSE-type reconstruction with L1-Norm-based regularization term was used [3]. Three fellowship-trained, full time musculoskeletal radiologists graded the overall diagnostic quality, artifacts, blurring, fat saturation, fluid intensity, and visibility of cartilage, ligaments and tendons using standardized 5-point Likert scales. Qualitative and quantitative measurements were statistically analyzed using non-parametric tests. P values of less than 0.05 were considered significant.

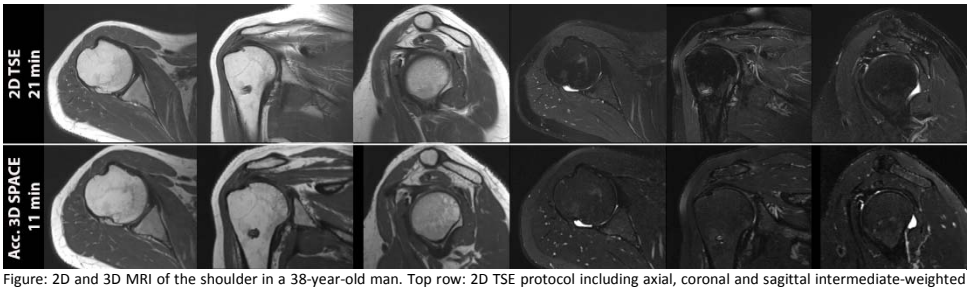

Figure: 2D and 3D MRI of the shoulder in a 38-year-old man. Top row: 2D TSE protocol including axial, coronal and sagittal intermediate-weighted and fat-saturated T2-weighted images. Bottom row: Corresponding axial, coronal, and sagittal reconstructions of one intermediate-weighted and one fat-saturated T2-weighted accelerated 3D SPACE pulse sequence. The total acquisition time of the 2D and 3D protocol is given.

Results

The overall diagnostic quality, fat suppression, fluid intensity, and visibility of cartilage, ligaments and tendons for accelerated 3D SPACE was good to excellent with no statically significant differences when compared to 2D TSE images (p=0.218-0.977). 2D TSE images had mild vascular flow artifacts, whereas there were no flow artifacts on the accelerated 3D SPACE images. Blurring was absent on 2D TSE images and mildly present on accelerated 3D SPACE images ($p < 0.05$).

Discussion

We demonstrate that pseudo-random k-space undersampling and iterative reconstruction allows for substantial acceleration of acquisition times of a clinical 3D MRI protocol of the shoulder. Although SPACE data are not inherently sparse, images without aliasing artifacts due to the high undersampling can be obtained using L1-Norm-based regularization in the wavelet domain [1]. The inline reconstruction time was below 6 minutes for each dataset on the standard hardware of the scanner. Our initial results indicate that this acceleration technique can realize a fast clinical, isotropic, high-spatial resolution 3D MRI protocol of the shoulder with the possibility to achieve diagnostic image quality similar to a more time-consuming standard 2D TSE MRI protocol.

Conclusion

K-space undersampling and iterative reconstruction facilitates substantial acceleration of isotropic SPACE data acquisition allowing for an 11 min, high spatial resolution, comprehensive clinical MRI protocol with the potential to achieve image qualities that are similar to a 21 min standard 2D TSE MRI protocol.

References

[1] Liu et al., Proc Intl Soc Mag Reson Med, #2237, (2012) ; [2] Li et al., Proc Intl Soc Mag Reson Med, #3711, 2012.