Application of 3D-Dictionary Learning Compressed Sensing Reconstruction En Route to Isotropic Submillimeter Spatial Resolution Sodium (^{23}Na) In Vivo MRI of the Human Eye at 7.0 Tesla

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Target audience: Imaging scientists, clinical scientists, radiologists and experts interested in ^{23}Na *in vivo* MRI of the human eye at 7.0 T.

Introduction

Sodium ions (Na^+) play a key role in the physiology of living cells. MRI is of proven value for probing Na^+ content in vivo [1,2]. Sodium (^{23}Na) holds the second place in terms of NMR sensitivity among all nuclei present in biological tissues. Its accessible signal-to-noise ratio (SNR) is still around 3000 to 20.000 times lower than SNR of proton MRI. This limitation induces severe spatial resolution constraints and/or long acquisition times. To overcome this challenge, ultrahigh magnetic fields and ultrashort echo time imaging techniques are of substantial benefit. Compressed sensing (CS) based reconstruction methods provide an alternative for enhancing spatial resolution and for shortening scan times [3]. This work examines the applicability 3D dictionary learning compressed sensing reconstruction (3D-DLCS) for isotropic (sub)millimeter spatial resolution ^{23}Na in vivo MRI of the human eye at 7.0 Tesla.

Methods

To acquire high-spatial resolution ^{23}Na images of the human eye, we used a six-channel transceiver array that conforms very well to an average human head. 3D-density-adapted projection reconstruction was used for ^{23}Na MRI data acquisition (TR = 17 ms, TE = 0.55 ms, FA = 41°). Proton MRI was conducted with a birdcage coil (Siemens, Erlangen, Germany) (Figure 1). Human imaging study was performed on a 7.0 Tesla whole-body system (Magnetom, Siemens Healthcare, Erlangen, Germany). ^{23}Na MRI of the human eye was performed in one healthy, adult volunteer (sex: male; age = 26 years; BMI = 19.9 kg/m^2). The data (A) acquired with $N_{projections}$ = 50000, $N_{averages}$ = 1, TA = 14.2 min were reconstructed with conventional gridding and applying Hamming filter (Figure 2). The data (B) with $N_{projections}$ = 10000, $N_{averages}$ = 5, TA = 14.2 min were additionally reconstructed with the 3D-DLCS algorithm (block size B = 6, dictionary size D = 500, weighting parameter for dictionary representation λ = 0.5, sample number N_{samp} = 500000). Furthermore, one reconstruction was performed for a reduced dataset ($N_{averages}$ = 4, TA = 11.3 min).

Results

Both datasets (A) and (B) were reconstructed with a standard reconstruction method and were used as baseline images [4] (Figure 2). Dataset (B) was reconstructed with 3D dictionary learning compressed sensing (3D-DLCS) algorithm using 4 and 5 averages (Figure 2). Using only 4 averages instead of 5 does not lead to any drop in the performance of the 3D-DLCS reconstruction algorithm and the quality of the final image. This gain can be used to reduce total acquisition time for protocol (B) by almost 3 minutes. It is demonstrated that applying 3D ^{23}Na dictionary learning compressed sensing reconstruction for ^{23}Na in vivo MRI of the human eye at 7.0 Tesla preserves all of the details and leads to markedly reduced noise.

Discussion and Conclusion

To summarize, 3D ^{23}Na dictionary learning compressed sensing reconstruction is conceptually appealing for enhancing SNR in ^{23}Na in vivo MRI of the human eye at 7.0 Tesla. This gain can be invested in reduction of total acquisition time or in spatial resolution enhancements. This improvement makes submillimeter ^{23}Na MRI of the human eye at 7.0 Tesla feasible within acceptable scan times. This feasibility of high definition ocular ^{23}Na MRI is of high relevance for precise diagnostics of various diseases of the eye including radiation planning and therapy monitoring of small ocular masses. Eye compartments, which are crucial in the context of sodium physiology, are very subtle (e.g. aqueous humor, lens). Resolving these subtle eye compartments requires high definition sodium MRI of the eye with submillimeter spatial resolution to obtain meaningful results from patient studies including ocular melanoma, glaucoma and cataract.

References

1. Madelin G, Regatte RR, JMRI, 2013; 2. Thulborn KR, Neuroimage, 2016; 3. Behl NGR, et al., MRM, 2015; 4. Wenz D, et al., ISMRM 2017.

Figure 1: Whole setup which was used to obtain high-resolution ^{23}Na images of the human eye at 7.0 Tesla along with proton anatomical reference images: the 6-channel transceiver array (^{23}Na) placed on the volunteer's head inside the volume coil (^{1}H).

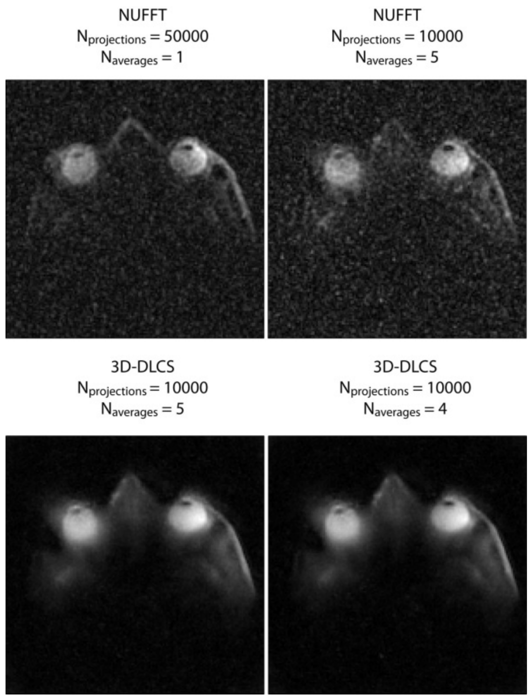

Figure 2: Comparison of images which resulted from using two different protocols: (A) $N_{averages}$ = 1, $N_{projections}$ = 50000 and (B) $N_{averages}$ = 5, $N_{projections}$ = 10000. Images were reconstructed with non-uniform fast Fourier transform (NUFFT) (top row) and with 3D dictionary learning compressed sensing (3D-DLCS) algorithm (bottom row). The image in bottom row (right) was obtained using only 4 averages what can be used in order to decrease scan time by about 3 minutes without losing fine details which are still present in the image.