In-vivo High Resolution Imaging of Fine-Scale Anatomical Structures at 3T with Simultaneous Bias/Variance Reduction

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PURPOSE: In neuroscience and medicine, the need for high resolution imaging to visualize the cytoarchitecture and myeloarchitecture of the brain is well supported by a large body of evidence which shows that the functional specialization of the cortex is associated with its structural differentiation into cortical layers[1]. Recent studies demonstrate an ability to detect the Stria of Gennari (SoG) and white matter lesions in MS with 7T magnets[2] but a key limitation of this work is that 7T scanners are not widely used in clinical practice. Here we propose a novel, unified reconstruction strategy that overcomes prior art limitations and show that the strategy can be applied to imaging the SoG *in vivo* in a reasonable amount of time on a conventional 3T magnet, where individual high resolution images are guaranteed to be very noisy compared to those that can be obtained with higher field magnets.

METHODS: Conventional MRI acquisition combines the data from multiple receiver coils into a high SNR magnitude image. This technique is suitable in high SNR settings only, and introduces a signal bias related to noise magnitude, and fails to compensate for variation in signal phase across the data measurement. It is critical to address these reconstruction problems to enable the formation of high SNR images with minimal bias. Unfortunately, simultaneous reduction of bias and variance can only be achieved by averaging[5], which would require prohibitively long scan times. To overcome these limitations we apply two major improvements:

Coil Sensitivity Estimation. The image with maximized SNR is obtained by combining the coil images with a spatial matched filter[3] (SMF), which involves coil sensitivities. Even if the coil signal magnitude is adequate to generate good coil sensitivity estimates in high SNR settings, it is however highly biased by the large noise amplitude of high resolution images. To circumvent this issue, we compute coil sensitivity estimates from low resolution surface and body coil images as follows: we smooth the surface coil complex signals by Gaussian filtering, normalize them by their root-sum-of-squares, subtract the body coil signal phase to the resulting signals and finally upsample the result to the targeted high resolution. This approach benefits from the high SNR of a low resolution acquisition and gets rid of most phase artifacts by body coil normalization.

Multi-Session Complex Averaging. The magnitude image formed using the previously estimated SMF still has a bias proportional to the amount of noise in the complex coil images. Thus, while reducing the amount of noise, an imaging strategy that repeatedly collects high resolution magnitude images from the scanner and average them out will fail to reduce the bias. The correct approach pertains to repeatedly collect coil complex images and averages them out prior to image reconstruction. However, proper complex averaging requires compensating for phase variations arising in the coil images over time due to phase drifts and gradient heating. In details, for each repeated measure, we estimate the phase at the k-space center as the mean phase of the SMF-reconstructed complex image we subtract it from the coil complex images.

MRI Experiments: We imaged a 21 year-old male healthy volunteer on a 3T Siemens Skyra MRI. We acquired axial T2 turbo-spin echo (AXT2-TSE) images at 0.38x0.38x0.8 mm^3 resolution (TA 3min45s) repeatedly over two scan sessions (S1, 12 repeats, 45min; S2, 9 repeats, 34min) and targeted imaging of the SoG. We additionally acquired one AXT2-TSE at lower 1.12x1.12x1.1mm^3 resolution (current clinical resolution for structural MRI) and a set of low resolution (2mm^3 isotropic) surface and body coil images. We used a single-repeat magnitude image (M0) as benchmark and we applied 5 different imaging reconstruction strategies: low-resolution scanner-reconstructed image (M1), M1 + upsampling to high resolution (M2), single-session averaging of scanner-reconstructed magnitude images (M3), single-session proposed imaging reconstruction (M4) and M4 + multi-session (M5).

RESULTS: We evaluated the reconstruction performances based on the proportion of voxels with intensity corrupted by artifacts (QI1: over background voxels; QI2: overall)[4], SNR in the SoG and CNR between SoG and adjacent gray matter (Table 1). Structures were identified from the peaks in cross-sectional intensity profiles of the calcarine fissure (Fig. 1). We also provide pictures of the imaged SoGs (Fig. 2) for qualitative assessment.

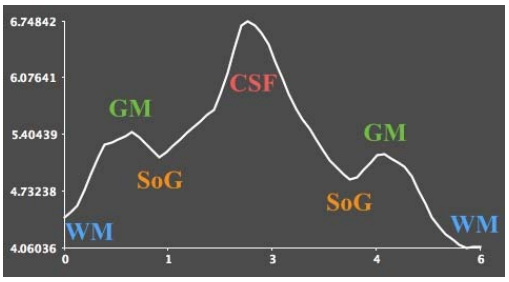

Figure 1- Cross-sectional intensity profile in the calcarine cortex obtained by our method.

CONCLUSION Our proposed technology enables image reconstruction from inter-session and intra-session k-space data that corrects for intra-session and inter-session phase variation to enable arbitrarily high SNR imaging. Intra-session repeated imaging allows for short scan times with breaks in between, so this is valuable for enabling high SNR imaging while allowing rest and motion in between. In particular, the imaging experiment shows that our imaging reconstruction strategy (M5) generates fewer corrupted voxels than prior art methods and achieves the best SNR in the SoG. The multi-session technology further provides a boost in SNR in the SoG at the cost of a slight decrease in CNR that may be attributed to between-session registration errors.

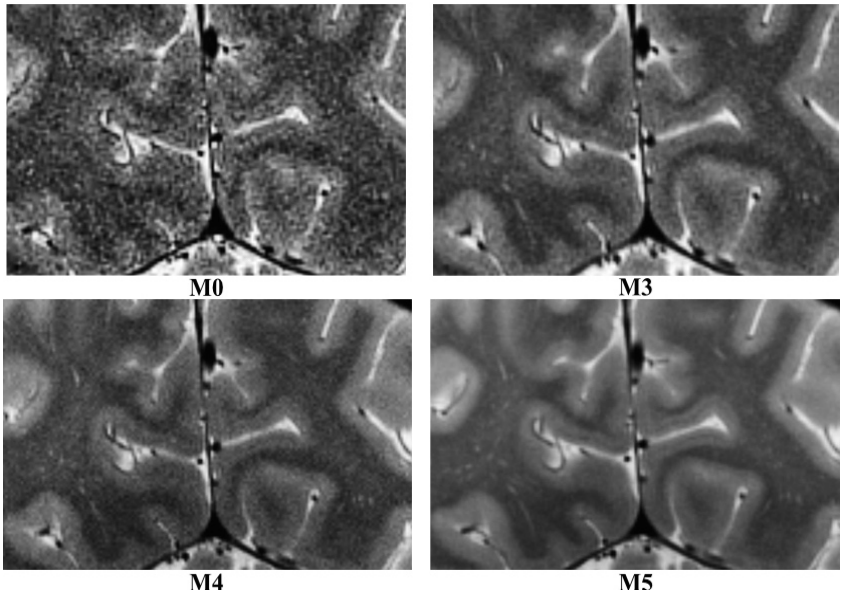

Figure 2- Stria of Gennari obtained by different reconstruction strategies.

	QI1	QI2	CNR	SNR
M0	51.1	23.4	1.10	5.30
M1	17.5	13.3	-	-
M2	30.8	23.0	-	13.5
M3	77.6	30.4	1.33	11.97
M4	49.4	30.0	2.35	23.91
M5	39.4	19.4	2.01	49.00

Table 1- Quality metrics reported for each reconstruction

REFERENCES

1. Van Essen et.al, Neuroimage 2014;. **2**. Trampel et. al. CerebralCortex 2011. **3.** Roemer et. al MRM 1990. **4.** Mortamet et. al MRM 2009