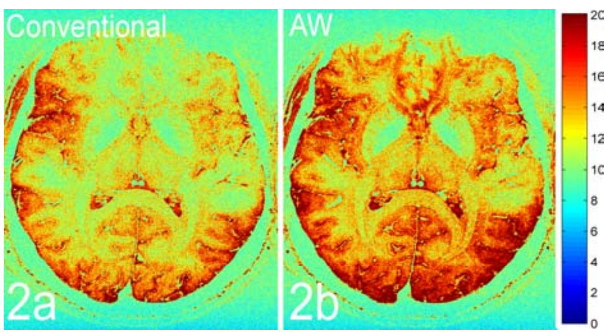
Ultra-High-Resolution Imaging of the Human Brain at 9.4 T Using k-Space Weighted Acquisition

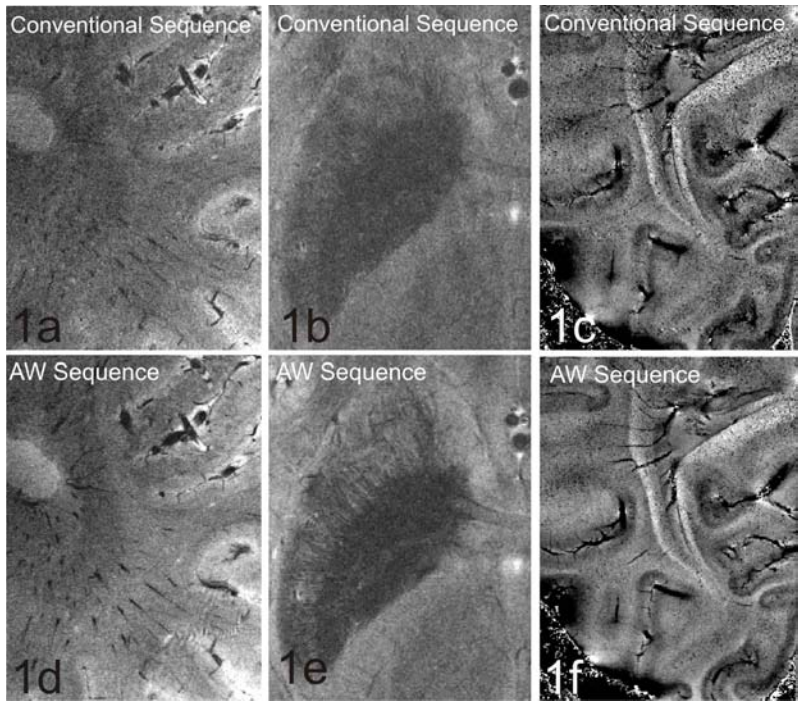
Juliane Budde[1], G. Shajan[1], Klaus Scheffler[1,2], and Rolf Pohmann[1]

[1]*Max Planck Institute for Biological Cybernetics, Tuebingen, Germany,* [2]*Department for Biomedical Magnetic Resonance, University of Tübingen, Tuebingen, Germany*

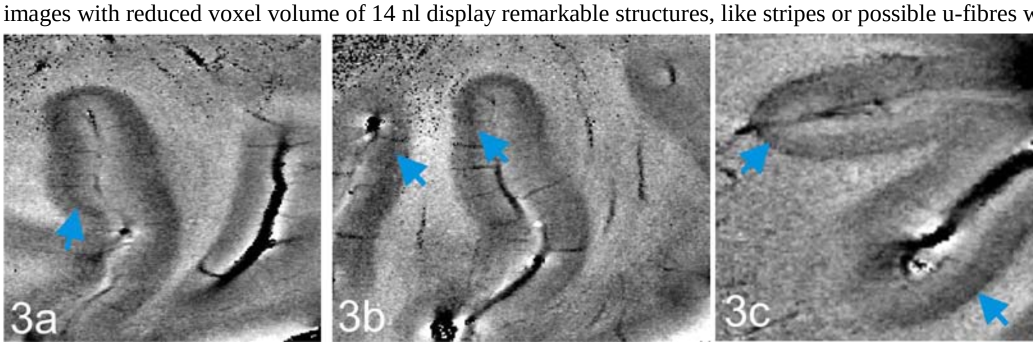
Introduction: Acquisition-weighted (AW) imaging by acquiring a varying number of averages depending on the position in k-space is widely used in CSI for suppression of contamination by the sidebands of the spatial response function (SRF). In addition, it has been shown that the apparent SNR can be increased due to the reduction of negative signal contributions from adjacent voxels [1]. In cases where averaging is required anyway for SNR reasons, AW can be realized without sacrificing spatial resolution or scan time. So far, these advantages have only rarely been used in imaging [2]. For ultra-high resolution imaging, SNR and Gibbs-ringing are crucial, and averaging is often used to obtain sufficient SNR. Here, this technique is used at a field strength of 9.4 T with a highly sensitive receive array to obtain images from the human brain with a voxel size down to 14 nl.

Methods: Data was acquired at a 9.4 T scanner on human subjects, using a 16 channel transmit/31 channel receive coil combination [3]. 3D GRE images were acquired with a conventional sequence with 3 averages and an AW technique with the same scan time, with weighting in both PE-directions based on a Hanning function, but modified for the relatively low number of scans [4]. The resolution was kept equal by covering a larger region of k-space in the weighted image, which was verified by an analysis of the width of the SRF. First images with a resolution of 0.2×0.2×0.5 mm^3 were acquired within 13:20 min with both techniques (TE 18.4 ms, TR 26 ms, 16 slices, BW 120 Hz/px, FA 10°). Ultra high resolution phase images (0.13×0.13×0.8 mm^3) were processed from an AW data set (TE 17.3 ms, TR 27 ms, 22:09 min).





Results: The first set of images has a voxel volume of 20 nl. The reconstructed phase and magnitude images display fine brain structure. In the AW case, details, such as slightly angled veins in magnitude images (Fig. 1a,d) are less obscured by noise. This can also be seen in phase images (mIP projection of 3 slices, Fig. 1c,f). Due to the reduced contamination from adjacent voxels, finer structures are discernable within the putamen (average of 3 slices, Fig. 1b,e). An SNR comparison of 3 subjects yielded an increase of 19 % - 25 % with the pseudo-multiple replica (PMR) method and 16 % - 28 % by an analysis of 20 brain and 4 noise ROIs for the AW technique. An SNR comparison with PMR is shown in Fig. 2. In Fig. 3, phase images with reduced voxel volume of 14 nl display remarkable structures, like stripes or possible u-fibres within the cortex, marked by arrows.



Discussion/Conclusion: Here, the increase in apparent SNR due to AW is used to obtain ultra-high resolution images from human volunteers. The resolution is not compromised, as demonstrated by the small structures visible in the putamen. The gain in SNR is used for higher resolution, but could also be invested into shorter scan duration or more flexible averaging. With the high resolution and the long scan times, the images are liable to motion degradation. Some motion correction should be implemented to further improve image quality. In practice, AW is easily incorporated into sequences with Cartesian sampling. Imaging protocols which require averaging could profit from the demonstrated gain in SNR in AW, yielding higher resolution, more flexible averaging, or shorter scan times.

[1] Pohmann, MRM 45:817, 2001 [2] Geier, MAGMA 20:19 , 2007 [3] Shajan, ESMRMB 351, 2012 [4] Pohmann, ISMRM, 2007 [5] Li, NeuroImage 32:1032, 2006