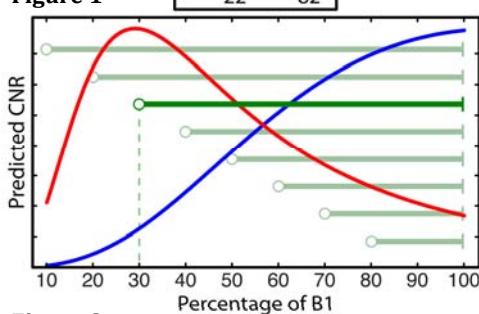


# Correcting for B1 inhomogeneities in post-mortem DWSSFP human brain data at 7T using multiple flip angles

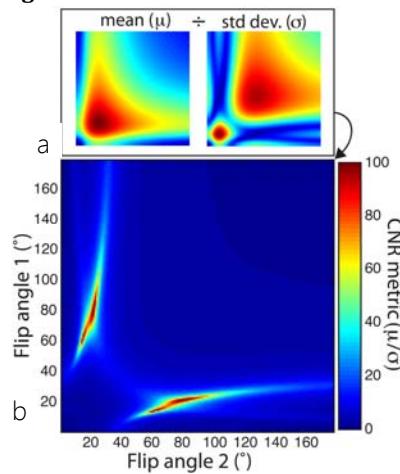
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**INTRODUCTION:** Diffusion imaging of post-mortem (PM) brain has important applications for both validating diffusion contrast mechanisms through comparison with microscopy and achieving very high-resolution data with long scan times. However, PM diffusion imaging is challenging due to changes to tissue properties (including unfavourable reductions in both  $T_2$  and diffusion coefficient). Previous work has demonstrated improved PM data at 3T using diffusion-weighted steady state free precession (DW-SSFP) imaging compared with DW-SE data due to robust signal in short- $T_2$  species<sup>1</sup>. SNR gains achieved at high field make extending this work to high field PM imaging attractive. However, straightforward translation of 3T protocols to 7T is compromised by B1 inhomogeneities due to the short wavelength of the RF, which is often comparable to the sample itself (~13cm). A characteristic "bright spot" is seen in human brain imaged at 7T due to a combination of effects from the high dielectric constant of human tissue and wave propagation<sup>2,3</sup>. While high dielectric constant shim pads and active B1 shimming can mitigate these effects, these techniques are technically demanding to implement and have only moderate reproducibility. In this work we investigate a simple approach of adapting previous optimizations to explicitly account for B1 inhomogeneity, acquiring a pair of CNR-optimized flip angles with DW-SSFP at 7T.

**Figure 1**



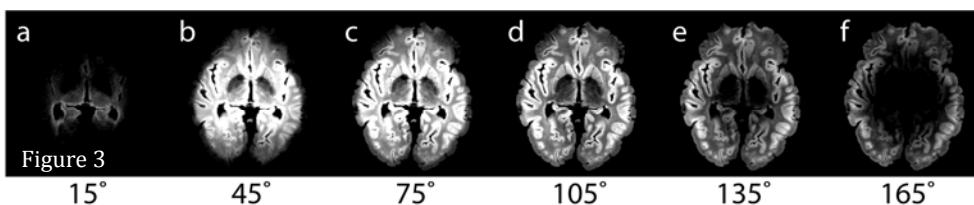
**Figure 2**



**METHODS:** The DW-SSFP signal model<sup>5</sup> was used to calculate the flip angle-dependent diffusion CNR, given by the difference between non-DW and DW signals (assuming values for white matter at 7T:  $T_1=400\text{ms}$ ,  $T_2=30\text{ms}$ , and  $\text{ADC}=3.8\text{e}^{-4}\text{s/mm}^2$ ). Where previous work optimized flip angle with the implicit assumption of homogeneous excitation<sup>1</sup>, at 7T this nominal flip angle ( $\alpha$ ) is only achieved in regions with peak B1. Our new optimization aims to identify two nominal flip angles that maximize CNR over a range of fractional B1 (Fig 1) in order to achieve homogeneous CNR across brain regions experiencing variable flip angles. For every pair of flip angles, we sum the CNR curves (red and blue lines in Fig 1), and then calculate the mean ( $\mu$ ) and standard deviation ( $\sigma$ ) over the fractional range of B1 being considered. One consideration is the range of fractional B1 to include in the optimization (horizontal lines in Fig 1). We considered a range of 30-100% of B1 (dark horizontal line in Fig 1) since this accounted for 90% of the brain and was found to incur negligible CNR loss for regions with high B1 (compared to the optimal performance for peak B1). Our final metric is then the variance-normalized mean ( $\mu/\sigma$ ), which optimizes for a balance of high CNR and homogeneity across a range of B1. Fig 2 shows these quantities for all flip angle pairs. The optimum around  $\sim(20^\circ, 80^\circ)$  reflects the intuitive use of CNR peaks at low and high B1 in Fig 1.

We scanned a whole, fixed PM brain (11 months post-fixation) submerged in Fomblin for susceptibility matching. DW-SSFP data at  $1\text{x}1\text{x}1\text{mm}^3$  were acquired on a human 7T Siemens whole body scanner using a 32-channel head coil. To study flip angle dependence, we acquired non-DW and DW ( $b_{\text{eff}}=7500\text{s/mm}^2$  along the z direction) images for flip angles  $5^\circ$ – $180^\circ$  ( $5^\circ$  increment). Contrast maps were produced at each flip angle. Additionally, two sets of DTI data were acquired with 30 diffusion directions ( $b_{\text{eff}}=7500\text{s/mm}^2$ ). One dataset was acquired with flip angle optimized for peak B1 ( $30^\circ$ , 2 repeats) and the second using our dual-flip scheme optimized for B1 insensitivity ( $22^\circ$  and  $82^\circ$ , 1 repeat per flip angle). B1,  $T_1$ , and  $T_2$  maps were also acquired. Data were processed using MATLAB and FSL. All 3D datasets were registered to correct for  $B_0$  drift and eddy-currents distortions prior to processing. All diffusion data were processed using a modified version of BEDPOST to model the DW-SSFP signal, which incorporates  $T_1$ ,  $T_2$  and B1 maps.

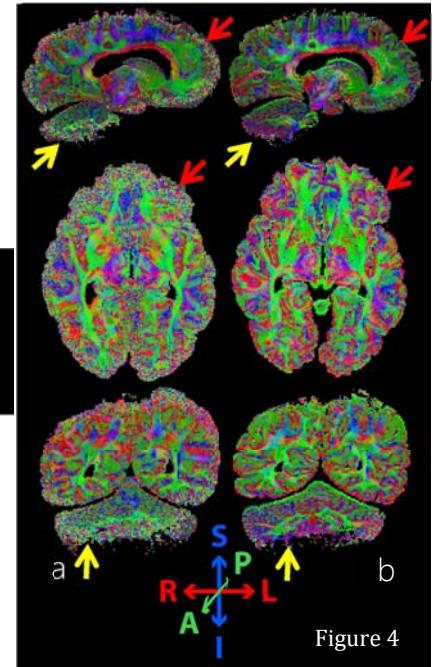
**RESULTS:** Figure 3 demonstrates the effects of B1 inhomogeneity on non-DW data over a range of flip angles, exhibiting very low signal in gray matter at the low flip angles that are optimal for white matter. It is clear that a combination of data acquired at multiple flip angles could improve signal homogeneity across the brain. Principle diffusion direction (PDD) color maps produced from the two DTI datasets are shown in figure 4 [(a)  $30^\circ$ , (b)  $22+82^\circ$ ]. Red and yellow arrows indicate regions in gray matter and cerebellum, respectively, where the multiple flip angle data provide greatly improved estimates of the PDD.



**Figure 3**

**DISCUSSION:** We have demonstrated improvement in DW-SSFP data at 7T through the use of multiple flip angles to counter B1 inhomogeneity. While we expect that this would be useful for any 7T PM study, it would be particularly important for studies that aim to investigate grey matter or to track white matter pathways into their cortical targets. Moreover, any sequence with an accurately described signal model could benefit from this approach.

**REFERENCES:** [1] Miller, NeuroImage, 2012, [2] Yang, MRM, 2002, [3] Collins, JMRI, 2005, [4] Yang, MRM, 2006, [5] Buxton, MRM 1993



**Figure 4**