Magnetic field correlation contrast in the human brain at 7 Tesla

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Introduction. Magnetic field correlation (MFC) is a recently developed technique [1] to quantify magnetic field inhomogeneities (MFIs) in vivo. This technique is sensitive to the regional distribution of inhomogeneities as generated by, for example, ferritin. It has been suggested to provide a more specific measure of iron concentrations than either T_2 or T_2^* [1,2] and can be of interest for iron quantification in a number of neurodegenerative diseases (e.g. Alzheimer's disease). However the quality of the data is highly dependent on the field strength, both the sensitivity for MFIs and the signal to noise ratio are much higher at 7 T than at 3 T.
Here, we extend the work in [1] by showing the feasibility of human in vivo MFC imaging at 7 T. Data measured at 3 T, at which field strength the weak field approximation is still valid, were used to determine whether this still holds at 7 T. In addition we have measured the MFC for gray matter (GM), white matter (WM) and the globus pallidus (GP) at different echo times (TEs), which yields insight in the scale (macroscopic vs. microscopic inhomogeneities) of the MFIs.

Methods. An asymmetric spin echo (ASE) sequence was implemented on a 3 T and a 7 T MRI scanner (Achieva, Philips Healthcare, Best, The Netherlands) using 8 and 16 channel head coils, respectively. The position of the refocusing pulse was shifted by 0, -.99, -1.98, -3.96, -7.92 ms. These shifts were chosen such that water and fat were in phase at 7 T, since fat suppression performs poorly at this field strength. A fat suppressed, flow compensated three-segment ASE EPI scan was used with the following parameters: TR = 3000 ms, TE = 33, 42 and 50 ms, resolution 1.2x1.4x1.2 mm^3, SENSE factor of 2.3, five averages per shift, scan time of 4 minutes per echo time. Three healthy volunteers (male, mean age 36 years) were scanned at both field strengths and the images were segmented into GM and WM using SPM5; in addition regions of interest were drawn in the GP manually and the mean MFC values were calculated for all regions.

Results. Figure 1 shows a quantitative MFC map for one volunteer at 3 T (top) and 7 T (bottom). The GP is clearly depicted as a hyper intense region on both images. Figure 2 shows a scatter plot of the MFC / B_0^2 of GM and WM at 7 T vs. 3 T together with the line of identity. Figure 3 shows the averaged values for three echo times and for three brain regions.

Discussion. The MFC values are expected to increase quadratically with the field strength, therefore data measured at different field strengths should lay on the line of identity when divided by B_0^2. The results in figure 2 correspond reasonably well with the expected behavior; therefore it is likely that the theory of MFC still holds at 7T. However it is clear that most points are above the line of identity, these deviations could also be caused by superdiamagnetic components. The MFC will decrease with increasing TE due to diffusion of water molecules through inhomogeneities, depicted in figure 3. As expected the sensitivity and the decay rate are much higher at 7 T than at 3 T. Interestingly at 7 T the MFC of the GP decayed much faster than GM and WM. The most likely explanation is the large magnetic field inhomogeneities present in the GP since the diffusion coefficients of these structures are quite similar [3]. As a result the contrast of GP and GM was reversed at TE = 50 ms, this makes the choice for TE very important for this technique.
The MFC includes not only microscopic field inhomogeneities, but also has a macroscopic component, from e.g. veins, or air cavities. By measuring the MFC at different echo times it is possible to distinguish between these. The macroscopic part of the MFC is independent of TE [1] and therefore the strong dependence of echo time on the MFC shown in figure 3, is an indication that the major contribution to the MFC for all the measured regions is from microscopic field inhomogeneities.

Conclusion. We have shown that it is possible to perform MFC imaging at 7 T; the theory is likely to still be valid at this field strength. In addition, measuring MFC at different TEs provided insight into the scale and origin of magnetic field inhomogeneities, the effect and sensitivity of which are improved at high field strength. The contrast of the MFC map is shown to change depending on the TE, and therefore care must be taken when interpreting MFC data measured at a single TE. The technique is capable of differentiating between regions with different scales of MFIs and complements techniques such as susceptibility weighted imaging (SWI).

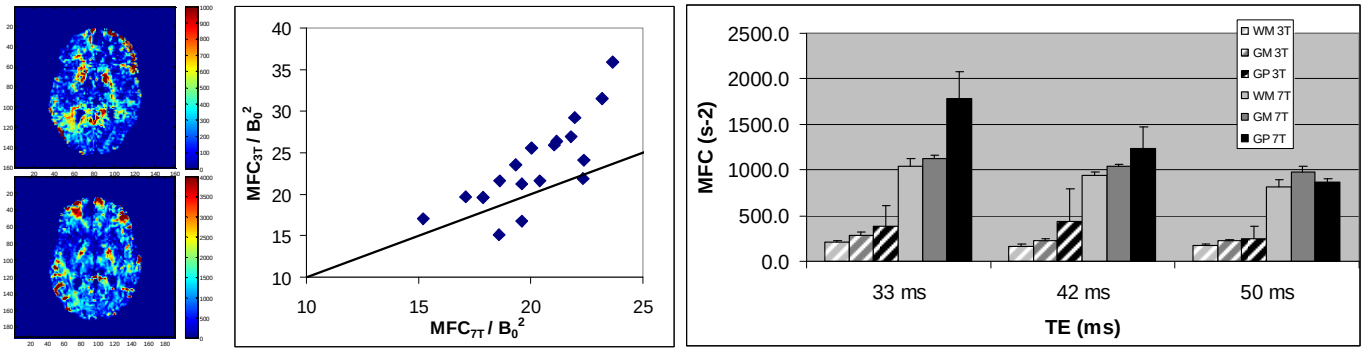

Figure 1: MFC map acquired at 3 T (top, scaled between 0 and 1000 s^{-2}) and 7 T (bottom, scaled between 0 and 4000 s^{-2}), clearly showing the iron rich globus pallidus. **Figure 2:** Relation between MFC values at 3T vs. 7T for gray-, and white matter regions for all volunteers (n=3). **Figure 3:** Averaged MFC values at three echo times, error bars indicate the standard deviation.

References: 1. Jensen, J.H. et al. *Magn Reson Med* **55**: 1350-1361(2006). 2. Ramani, A. et al. Proc Intl Soc Magn Reson Med **14**: 1559 (2006). 3. Ramani, A. et al. Proc Intl Soc Magn Reson Med **13**: 2177 (2005).