Phase Contrast in the Human Brain and its Field Dependence

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Introduction The phase information intrinsically contained in MR data is being increasingly used to enhance visualisation of the vasculature in magnitude images (SWI, [1]), to visualise subcortical structures with higher CNR and better spatial definition than in magnitude images [2], or even to distinguish between different types of brain lesions [3] (calcifications are more diamagnetic than normal brain tissue, while microbleedings are more paramagnetic). However, the microscopic origin of the susceptibility contrast between tissue types is not fully understood. Differences between distributions of capillaries, iron content, exchange with, and content of, macromolecules, and myelin content, have been proposed as contributors to the phase contrast between white and grey matter in the brain [2-5]. The quantitative interpretation of phase contrast is further complicated by geometrical effects and the fact that a well localised variation in susceptibility can give rise to much more extended variations in the magnetic field [6]. Most of the discussion regarding phase contrast is focussed on specific ROIs which are well characterised with respect to their iron content, where the latter is expected to play an important role in determining the susceptibility of the tissue. Regions such as the basal ganglia, substantia nigra or the red nuclei have high iron content [7], strong phase contrast but also very specific geometries, which can induce additional local perturbations of the field and influence the phase contrast in their vicinity. In this study, we have investigated the field dependence of the phase contrast of the entire brain, in addition to specific ROIs, at three fields (1.5T, 3T and 4T). We have used field maps and not single-TE phase images which are more difficult to compare between fields.

Methods Measurements were performed using three nearly identical whole-body scanners, operating at field strengths of 1.5T (Siemens Avanto), 3T (Siemens Trio) and 4T (Siemens/Bruker MedSpec). The scanners have identical software platforms except for different SYNGO version numbers and very similar hardware. All three gradient coils had maximum field strengths of 40mT/m on each axis. At 1.5T and 3T, an RF body coil with very homogeneous B_1-field distribution over the head was used for RF transmit and 12-element, phased-array head coils for signal detection. At 4T, a composite transmit/receive head coil was used, consisting of a birdcage coil for transmit and an 8-element phased-array coil for signal detection. Twelve healthy volunteers (8 males, 4 females, average age 34 (SD 9) years, ranging from 23 to 54 years) were scanned at all three fields over a period of one month. The average interval during which the three scans were performed on any given volunteer amounted to 17 (SD 10) days. Field mapping was performed with a multi-slice, multi-echo, gradient echo sequence in a variant named QUTE [8]. Separate k-spaces were acquired for 32 echoes and magnitude as well as phase images corresponding to each echo time were reconstructed. Details regarding the acquisition are provided in [9]. The whole cerebrum and part of the cerebellum were covered with the QUTE sequence (two sets of interleaved 27+28=55 slices). The in-plane resolution was 1mm x 1mm and the slice thickness was set to 2mm. The AutoAlign facility of the SYNGO software was used in order to acquire slices in nearly identical positions at all three fields. The alignment was good between 1.5T and 3T but not better than manual repositioning at 4T, due to differences in the software versions. Volumes were constructed from the acquired slices for each method. The images corresponding to the first echo of the T2* data, acquired at 1.5T and 4T, were aligned to the data acquired at 3T using FSL [www.fmrib.ox.ac.uk/fsl] routines. The phase was unwrapped in the time dimension and the evolution of the phase (in rad) with echo time (in s) was described with a linear fit. The leading order coefficient represents the field map (in Hz). A high-pass filter was applied to the field maps, in order to correct for the global field variations. Regions-of-interest were selected in the globus pallidus (GP), nucleus caudate (NC), putamen (PU), red nuclei (RN), substantia nigra (SN), corpus callosum (CC), as well as in superior WM and GM regions. Histograms of the whole-brain phase distribution were created. The phase shift in selected ROIs, defined with respect to the centroid of the whole-brain histogram, was described as a linear function of the field strength.

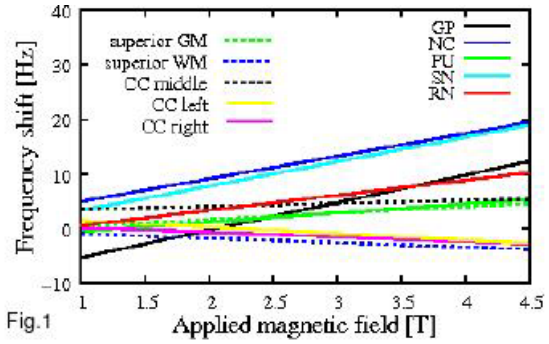

Fig.1

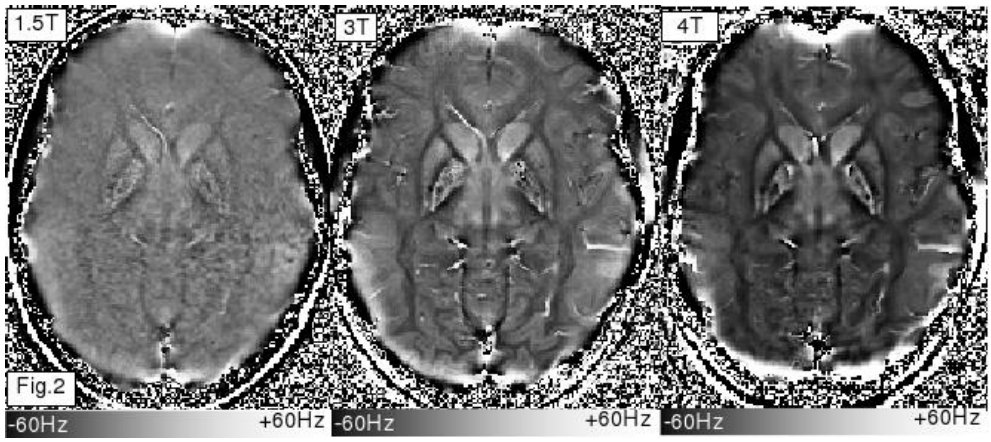

Fig.2

Results and discussion The variation with field of the phase shift of selected regions was found to be well described by a linear fit. The linear dependence is plotted in Fig. 1 for different ROIs. The frequency shift of the deep grey matter regions with respect to the centroid of the whole-brain distribution increases towards more positive values with increasing field. The values are different for different structures and range from ~ 5Hz/T for globus pallidus to ~ 1Hz/T for WM in superior regions of the brain. In contrast, the field shifts of white matter ROIs become more negative with increasing field, at a rate of ~ -1Hz/T. Interestingly, the phase shift in the corpus callosum, and its field variation, is different in different regions (left and right extremities, compared to the central part).

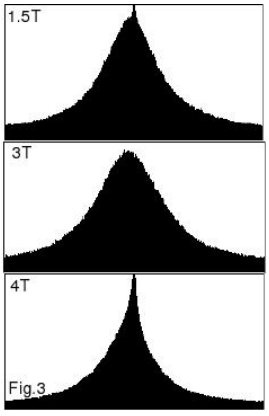

Fig.3

The phase contrast at the three different fields in shown in Fig.2 for a representative volunteer. The effect of the lower SNR at 1.5T is clearly seen, but already at 3T a high level of anatomical detail is reflected in the field maps. Some changes in phase contrast are visible. Even for a linear dependence of the phase shifts on field, the field-normalised phase contrast will change with field, due to the presence of non-negligible intercepts. To enforce this point, Fig. 3 shows the whole-brain histogram for one volunteer at all three field strengths. The change in the shape of the whole-brain phase distribution from the lower fields to 4T is clear, and at variance with the observation of Zhong et al. [10] for a single slice at fields of 1.5T, 3T and 7T. In conclusion, the field dependence of the phase shift of the individual ROIs can be satisfactorily described as linear, suggesting a dominant susceptibility effect in these regions. However, the changes observed in the whole-brain distribution of the phase require further investigation.

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