High-resolution phase imaging reveals intra-cortical structure of the human cingulate cortex at 7T

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Introduction: The cingulate gyrus is a long medial structure within each cerebral hemisphere, extending in humans about half the total length of the brain in the anterior-posterior (AP) direction. Not surprisingly, its cortex is micro-structurally and functionally heterogeneous [1-3]. This cortex is classified as mesocortex, transitional between allocortex ("old" cortex with 3-5 distinct cytoarchitectonic layers) and isocortex (neocortex with 6 distinct layers), making its characterisation somewhat challenging. Structural features of human brain isocortex, e.g. the Stria of Gennari in layer 4 of the primary visual cortex, can be visualised using high-resolution MRI even at 3T [4,5]. With the higher signal to noise ratio (SNR) of 7 Tesla MRI the voxel size can be further decreased revealing fine detail even with isotropic voxels. Furthermore, Duyn et al. [6] have shown that the phase images produced by gradient echo (GRE) MRI sequences provide enhanced contrast to noise (CNR) to display intra-cortical structures. In order to visualise intra-cortical layer structure within the human cingulate gyrus we use the phase images of the FLASH sequence.

Methods: A formalin-fixed post-mortem human brain was scanned at a 7 Tesla scanner (Siemens Medical, Erlangen, Germany) using a 24 channel head coil (Nova Medical, Wilmington, USA). Magnitude and phase images of high-resolution coronal 2D FLASH data (TR/TE=2800/23 ms; flip angle 90°; voxel size=0.3x0.3x0.3mm³; 4 averages) were reconstructed using Siemens product software. The phase images were high-pass filtered using a gaussian kernel of 10 voxels. An in vivo study was carried out with ethical approval from the local university, and informed consent was obtained from 9 subjects. The subjects were scanned in-vivo with a high-resolution 3D FLASH sequence (TR/TE=30/15ms; flip angle 11°; single acquisition). To accommodate the length of the cingulate gyrus in the AP direction, an axial slab with 88 slices of 0.3 mm thickness was placed just above the Corpus Callosum to cover the entire cingulate gyrus. To decrease acquisition time the phase encoding direction was chosen as the AP direction and the phase resolution was set to 75% of the base resolution. The actual spatial resolution was thus 0.3x0.3x0.4 mm³.

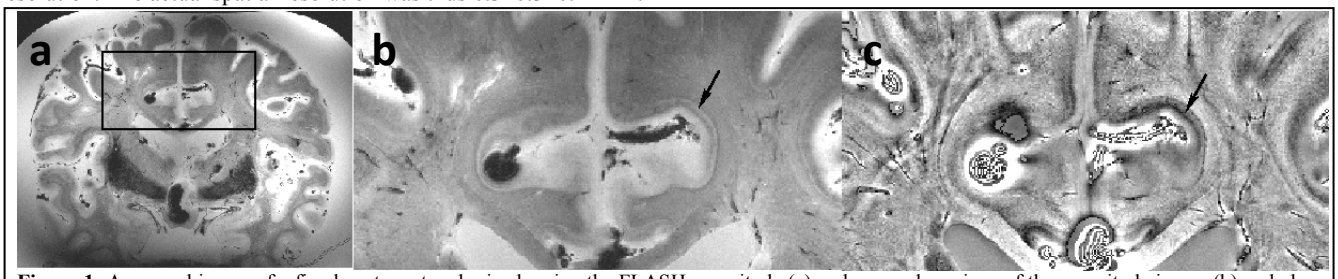

Figure 1: A coronal image of a fixed post-mortem brain showing the FLASH magnitude (a) and zoomed versions of the magnitude image (b) and phase image (c). The zoomed images display intra-cortical layer in the cingulate gyrus (arrows).

Results and Discussion: Figure 1 shows coronal views of the magnitude (a,b) and phase (c) images for the post-mortem dataset. Both show a dark intra-cortical line parallel to the cortical surface of the cingulate gyrus, in accordance with the cytoarchitecture of excised human brain tissue [2,7]. The MR contrast is similar to that of the Stria of Gennari within the primary visual cortex. To test the resolution required to visualise this structure in vivo, we re-sampled the data to a range of different coarser resolutions. We found that an isotropic resolution of 0.4 mm or better is necessary to image this intra-cortical structure, probably due to the smaller thickness of this intra-cortical layer compared to the Stria of Gennari. A rather long in-vivo acquisition time (about 22 min) is needed for the large image matrix, and one subject was excluded from further analysis due to movement. The intra-cortical stripe in the cingulate gyrus was observable in the phase images of all the other eight subjects, but it could not always be detected in their magnitude images. This may be due to the higher CNR of phase images for visualising intra-cortical layer structure [6]. The images of one subject are shown in Figure 2. Furthermore, the layer structure was not seen within the entire cingulate gyrus. The next step will be to register the in vivo data with a probabilistic atlas, which may clarify the identity of this area. It is clear, however, that phase imaging at 7 Tesla reveals intra-cortical layer structure other than V1 and V5 in vivo.

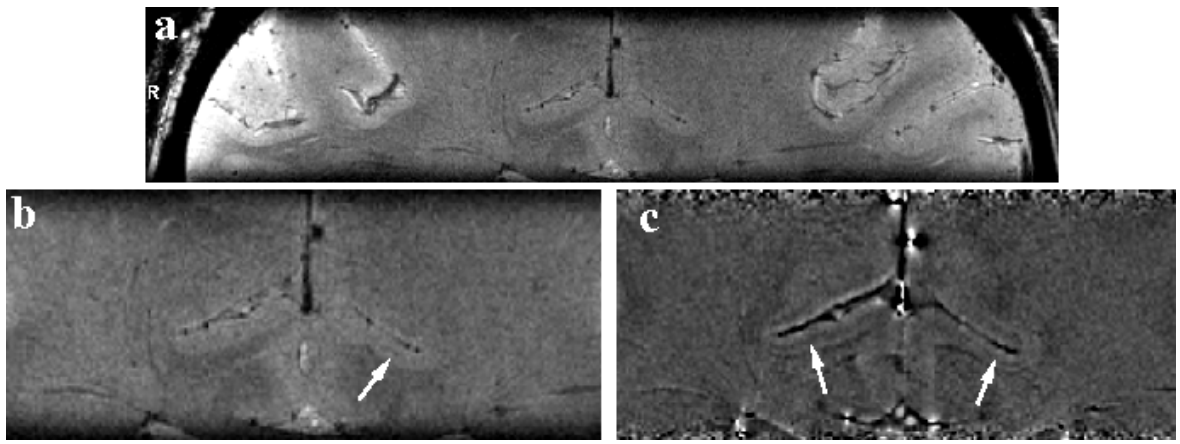

Figure 2: An in vivo coronal view of a healthy volunteer showing the FLASH magnitude (a) and zoomed versions of the magnitude image (b) and phase image (c). The phase image displays the intra-cortical layer in the cingulate gyrus (arrows) much stronger than the magnitude image.

References: **[1]** Vogt *et al.* Cereb. Cortex, 435-443 (1992) ; **[2]** Vogt *et al.* J. Comp. Neurol, 490-506 (1995) ; **[3]** Beckmann *et al.* J. Neuroscience, 29(4):1175-1190 (2009); **[4]** Barbier *et al.* MRM 48:735-738 (2002); **[5]** Clare *et al.* Human Brain Mapping, 26:240-250 (2005); **[6]** Duyn *et al.* PNAS 104:11796-11801 (2007); **[7]** Vogt *et al.* European Journal of Neuroscience 3134-3144 (2003)