In vivo investigation of cortical layers in area V1 by high resolution MR imaging

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Introduction Much of the current work in the field of neuroscience is motivated by the quest to establish the correspondence between the functional organization of the neocortex and its cytoarchitectonic fields. The development of techniques which allow for the identification of cortical layers in the living cortex by MRI has made substantial progress in the recent years. The visual cortex occupies nearly one third of the surface of the human cortex and is divided in several regions according to their structure and function. The primary area V1 is characterised by an easily identifiable (after dissection) anatomical landmark: the stria of Gennari. A few MRI studies were able to identify Gennari's stripe *in vivo* by its myelination pattern, exploiting the grey-white matter T_1 contrast. Results were obtained at 1.5T [1,2] as well as at 3T [3,4]. An in-plane resolution of at least 300 µm was needed, and was achieved by greatly sacrificing the slice resolution (>1.5mm) and orienting the slices such that partial volume effects were kept to a minimum. Only the portions of the stripe were visualised for which partial volume effects coming from tilted orientation of the stripe with respect to the slice were avoided. A complete characterisation of the extent and boundaries of the area V1 is thus not possible or at best unreliable. Isotropic resolution is required for this aim. A whole-brain study at 1.5T with isotropic resolution of 0.61mm [5] allowed for the occasional visualisation of Gennari's stripe, but higher resolution is required for reliable characterisation because the cortical layer is actually less than 300 microns thick. Very recently, the stria of Gennari has been visualised *in vivo* using phase images [6], but a very high field of 7T was necessary to create the contrast. We present a method which provides reliable 3D characterisation of Gennari's stripe *in vivo*, using an affordable amount of measurement time at a widely available field strength of 3T.

Methods All the measurements were performed on a 3T scanner (Siemens Trio), equipped with a 40mT/m gradient coil, an RF body coil operated in the transmit mode and a head phased array RF coil with 12 elements for signal detection. Images of six volunteers (4 male and 2 female, mean age 32 years) were acquired. A volume perpendicular to the calcarine sulcus was investigated with high resolution using a 3D magnetisation-prepared turbo spin echo sequence. Besides offering high SNR per unit time, the sequence provides contrast weighted by T1(inversion recovery preparation), T2 (echo time, turbo factor) and magnetisation transfer (slab selective 180deg pulses). The repetition time, inversion time and turbo factor were optimised for signal, contrast and resolution [7]. The original sequence was modified to output phase images in addition to the standard magnitude images. Two measurements with interleaved slab settings were combined to produce a contiguous volume. In order to check the quality of coregistration of the two interleaved sets of slabs, an identical fiducial slab (defined as a second slab group in the parameter card of the sequence) was acquired every time. The fiducial slab was placed in a different orientation than the interleaved slabs, approximately in coronal orientation through the middle of the brain. The TSE measurement parameters include: TR=1880 ms, TE=17ms, TI=150ms, flip=180, turbo factor=15, FOV=160x135x0.5 mm, matrix size 384x324, 10 slices/slab, 5+1 slabs (4+1 slabs, respectively). The highest nearly isotropic resolution (0.4x0.4x0.5mm) was chosen such that the SNR in the scans still allowed for a good coregistration with one average. An acceleration factor of 2 was crucial to keeping the total acquisition time per scan to 8 mins. Each saved scan consisted of a magnitude and a phase image in DICOM format. Between three and five sets of identical volumes consisting of two interleaves (5+4 slabs) were reconstructed for each volunteer and averaged [5]. 3D volumes, both magnitude and phase, were reconstructed and saved in Analyze format; the magnitude images were coregistered with the first scan of the series, and the magnitude, real and imaginary 3D data sets were resliced. All these operations were performed using MATLAB, based on functions from the SPM2 software package [8]. In contrast to the commonly used averaging method, where only magnitude images are summed, we use the resliced complex matrices for averaging [5]. This ensures incoherent summation of the random noise and maximizes the gain in SNR especially for initial images with low SNR.

Results and discussion The dependence of the contrast between grey and white matter on the inversion time was investigated experimentally and modelled as a function of TR, and tissue characteristic T1, T2 and M0 [7,9]. The inversion time TI=150ms was chosen as a compromise between contrast (quite flat between 150 and 350ms) and signal (strongly decreasing). An example of the *in vivo* visualisation of the area V1 via its stria of Gennari is shown in Fig. 1 for three volunteers. The stria of Gennari could be identified in all volunteers, irrespective of the sinuousity of their calcarine sulcus. Using the 3D data, slices perpendicular to the calcarine sulcus can be obtained at every point along the sulcus. The stria can be visualised in the perpendicular sections and followed over several slices before a new reslicing becomes necessary. For a better visualisation, a few consecutive slices can be summed up without introducing substantial blurring due to partial volume effects.

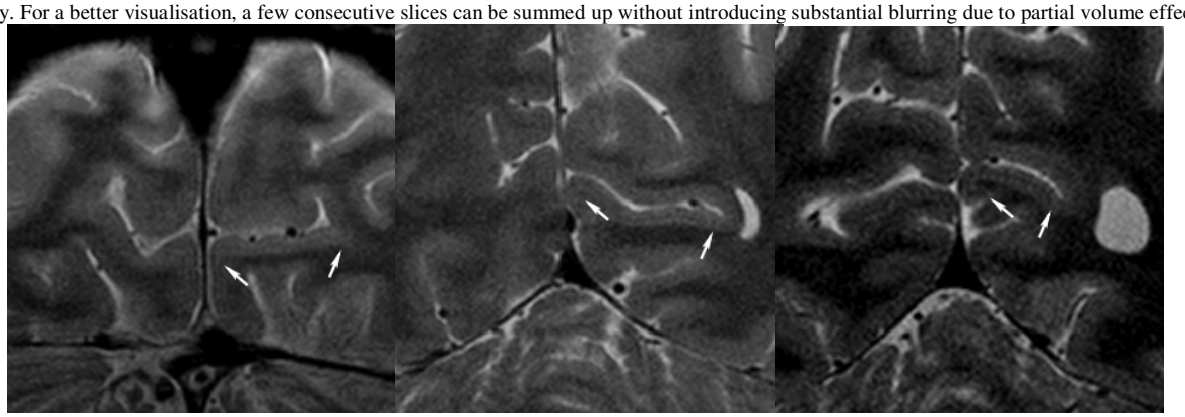

Fig. 1

Conclusions We show optimized, high-resolution MRI results obtained on a 3T scanner which allow visualisation of Gennari's stripe *in vivo* in each slice over a certain volume and for every volunteer. Besides optimisation of the white-grey matter contrast with the magnetisation prepared TSE, coregistration, complex averaging and parallel imaging turn out to be very important in the detection of myelination patterns *in vivo*. Using complex averaging instead of summing only magnitude images leads to a significant increase in the final SNR, given the low SNR values of the magnetisation-prepared images. The data quality is high enough to allow one to investigate the three-dimensional extension of Gennari's stripe. For an automatic segmentation, however, the endeavour would greatly benefit from measurements at a higher field strength. In this respect 4T might be an optimal field value, providing increased SNR without prohibitive SAR limitations.

References: [1] V.P. Clark et al., Cereb Cortex 2, 417-424 (1992); [2] N.B. Walters et al., Proc Natl Acad Sci USA 100, 2981-2986 (2003); [3] E.L. Barbier et al., Magn Reson Med 48, 735-738 (2002); [4] H.Bridge et al., J.Vision 5, 93-102(2005); [5] A.M. Oros-Peusquens et al.,ISMRM 2005, abstract 630 and NeuroImage, in revision; [6] J. Duyn et al., Proc Natl Acad Sci USA 104, 11796-801 (2007); [7] A.M. Oros-Peusquens et al., submitted to present proceedings; [8] SPM2,http://www.fil.ion.ucl.ac.uk/spm; [9] S.J. Meara and G.J. Barker, Magn Reson Med 54, 241-5 (2005).