Cortical layers one by one: diffusion properties at 160µm resolution

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Introduction: The steadily increasing number of ultra-high field scanners (7T and above) and substantial advances in coil technology at lower fields have brought our acquaintance with the living brain to the sub-millimetre domain. Ambitious applications aim at using this new level of detail for cortical parcellation *in vivo* based on both structural and functional aspects. In the process, evidence is accumulating about the important role played by the presence of myelin in generating intra-cortical MRI contrast. A recent study of the most conspicuous myelinated cortical layer, the stria of Gennari, have highlighted its distinct diffusion properties [1]. In this study we extend our investigation of the structural and diffusion properties of cortical layers to the motor cortex. An important result of this work is a clear visualisation of two intracortical bands with MR contrast dramatically different from that of the surrounding cortex.

Materials and methods: Measurements were performed on a home-built 9.4T animal scanner comprising a 21cm horizontal bore Magnex magnet equipped with a 12cm ID, 600mT/m, 100µs rise time Agilent gradient coil and interfaced to a Siemens Tim Trio console running on the syngo™ platform. A 7cm surface coil was used for both RF excitation and signal reception. Studies were performed of a block of cortical tissue containing the central sulcus and, thus, primary motor as well as sensory cortex. The tissue had been obtained 6 hrs post mortem from the left hemisphere of a female subject, aged 38, without known neurological disorders. The tissue was fixated using 2.6% phosphate buffered paraformaldehyde and MR-scans were performed after about 1 year of fixation. All procedures had been approved by the local ethics committee in Frankfurt. A 2D spin-echo sequence was modified to include a diffusion preparation module. The measurement parameters included: FOV 52x52mm^2, matrix 320x320 (in plane resolution of 160µm^2), 0.3mm slice thickness, 97 contiguous slices, TR=10000ms, TE=45ms, Δ=22.5ms, δ=3ms, α=90^o, 8 averages, b=3000mm^{-2}s. We used 12 diffusion encoding directions (Jones's scheme [2]) and two b=0 acquisitions. The temperature in the scanner bore before the measurements was approximately 15C and kept constant due to water cooling of the gradient coil. The data were evaluated using Matlab (Mathworks Inc) and the freely available software packages ImageJ [3] and fsl [4] .

Results and Discussion: The striking presence of two dark bands inside the cortex is best visualised in Figure 1, and magnified in the right zoomed images. The contrast in Fig. 1a is obtained by summing up all diffusion weighted scans. Regional changes in the intensity patterns are observed (left zoomed images). The dark bands are also visible in the non-diffusion weighted scans (Fig.1b) where T_2 contrast dominates. Enhancement of T_2 contrast by incidental MT effects on M_0 [5,6] might play a role in multi-slice sequences with many 180^o pulses. Maps of the apparent diffusion coefficient (ADC) and fractional anisotropy (FA) are shown in Fig. 2a and b for the same slice, together with the histograms of ADC and FA values over the whole sample. As observed before for the visual cortex [1], the ADC values are lower than *in vivo*, due at least partly to the low temperature. The mean diffusivity of grey matter (3.89x10^{-4} s/mm^2) is about 70% higher than that of white matter (2.28x10^{-4} s/mm^2). This ratio is identical to the one obtained for the visual cortex using STEAM diffusion [1] and comparable to values obtained in vivo [7,8]. The mean FA values (0.31 for WM and 0.17 for GM) are also nearly identical to the values reported for the fixed visual cortex but smaller than the in vivo values [8]. While some intracortical structure is visible in the ADC map (zoom), its visibility is reduced in comparison to the contrast seen in either the summed diffusion-weighted or the b0 scans.

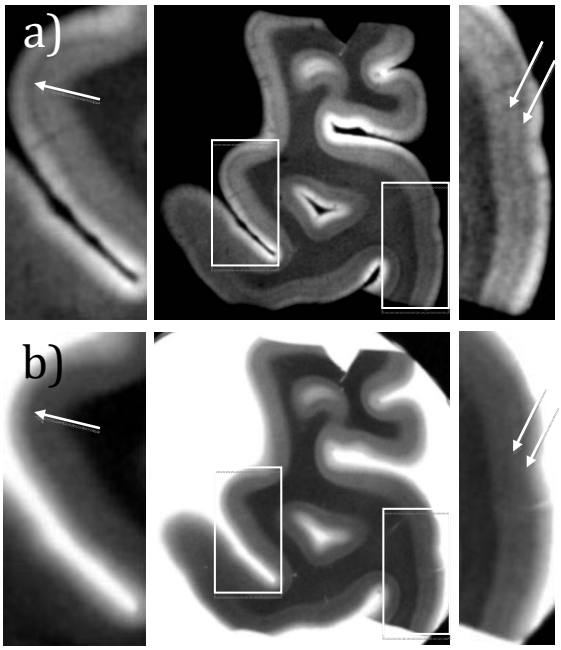

Figure 1: a) Sum of all diffusion-weighted scans; b) T2-contrast (b=0).

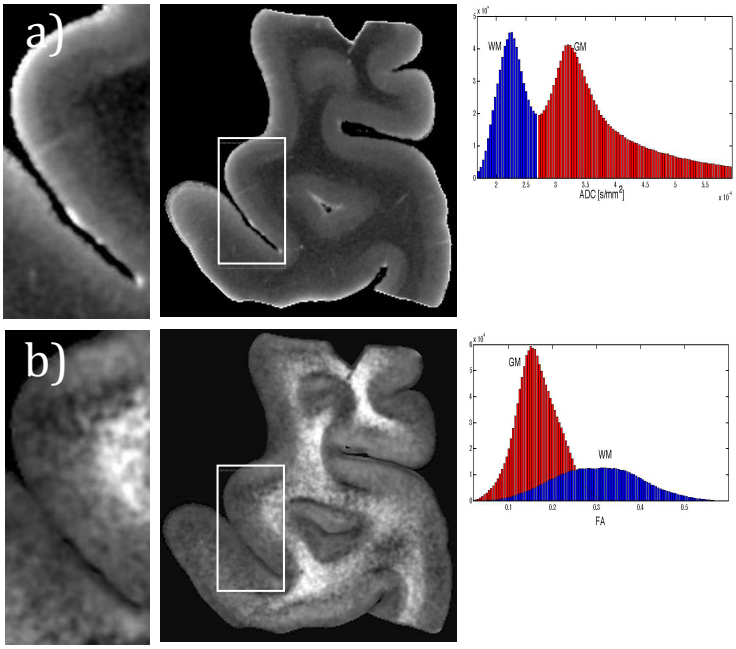

Figure 2: a) ADC map and histogram; b) FA map and histogram.

No cortical substructure can be clearly identified in the FA map (Fig 2B and zoom). From the present data, a significant source of contrast for the visualisation of the cortical substructures with MRI appears to be T_2 (with a possible MT contribution), as identified in the b0 images. Since the better visualisation is offered by the summed diffusion images, diffusion contrast is also present and enhances the inter-layer discrimination. The cyto and myeloarchitectonic origin of the two dark bands visualised by high-resolution MRI and DWI and their usefulness for cortical parcellation is currently examined by comparison of MR data to the actual histological organization of the tissue, results are still pending. At this stage, speculations regarding their nature and contrast mechanism might prove misleading. We mention tentatively, however, that both myelin and cell density and packing are factors which influence both T_2 and diffusion, and observation of the stria of Gennari and the granular layer (also in hippocampus) based on such microscopic contrast has been reported in several studies (e.g. [9]). To the best of our knowledge, such a clear identification by MRI of two intracortical bands, as reported here, is unprecedented.

References

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