Cortical layers one by one: the visual cortex in advanced qMRI

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Introduction The pursuit of understanding the structure of the human brain has much to gain from advances in MR microscopy on fixed tissue. At ultra-high fields (7T and above) small changes in the orientation and/or magnetic susceptibility of anatomical building blocks such as fibres, vessels, cell layers, become detectable by MRI and give rise to an extremely rich contrast which was not apparent at standard magnetic fields. There is a need to separate the contribution of different structural subunits of the tissue to the MR contrast. With this aim in mind, the present study investigates MR properties of cortical layers in the visual cortex using a battery of quantitative MRI methods. Among these, high-resolution q-space measurements, multi-shell HARDI data, very high temporal resolution Look-Locker acquisition for T1 mapping (TAPIR), T1-T2 correlated relaxometry and T2* and phase imaging of the visual cortex at 9.4T.

Materials and methods A piece of tissue with in-plane dimensions of 2x2.5cm^2 and 5.5mm thick was dissected from the left visual cortex of a fixed post mortem brain obtained from the brain donor programme of the University of Duesseldorf. All procedures were approved by the local ethics committee. Measurements were performed on a 9.4T animal scanner equipped with a 12cm ID, 600mT/m, 100μs rise time gradient coil and interfaced to a Siemens TIM Trio console. A birdcage coil with ID of 7cm was used for transmit and a 2-coil receiver array of 3cm diameter was used for signal reception. A 2D spin-echo sequence was modified to include a diffusion preparation module. Q-space data were acquired for a single diffusion gradient orientation and on a single slice for 128 b-values ranging between 0 and 40,000 s/mm^2 (giving equidistant q values). Each diffusion-weighted scan was accompanied by a b=0 reference scan. The measurement parameters included: FOV 20x26mm^2, matrix 192x148 (resolution of 136x136x400μm^3), TR=1000ms, TE=40ms, Δ=20ms, δ=10ms, α=90o, 4 averages. The total measurement time was 42 hrs. The data were denoised [1], fit with a biexponential model, extrapolated using the model to b of 128000 and Fourier transformed. The HARDI acquisition included 24 diffusion weighting directions and 29 b values equidistantly spaced up to 8000 s/mm^2. The spatial resolution was 200x200x400 μm^3. Mean diffusivity and fractional anisotropy were calculated with FSL. A Look-Locker-type sequence for T1 mapping, TAPIR [2] was used in a single-slice acquisition to measure 128 time points on the inversion recovery curve in steps of 10ms. The resolution of the T1 map was 80x80x400 μm^3. Data for T1-T2 correlated relaxometry were acquired with an inversion-prepared multiple-echo spin-echo sequence. A number of 32 equidistant spin echoes (echo spacing 6.7ms) and 37 logarithmically spaced inversion times between 20 and 2700ms were acquired and processed with 2D NNLS. A 3D multi-echo gradient echo sequence was used with parameters: FOV 20x26mm^2, matrix size=512x384x144, resolution of 50x50x52 μm^3, TR=120ms, α=20^o, BW=315Hz/px, TE_1=1.92ms, ΔTE=4.02ms, 7 echoes, 2 averages. The complex data were averaged off-line. M_0 and T_2* maps were obtained after monoexponential fitting of the magnitude data. The phase for each echo was unwrapped and the field map was calculated from the evolution of phase with echo time and filtered with a combination of low order polynomials, spherical harmonics and dipolar fields [3]. Unless otherwise specified, data processing was done with Matlab (Mathworks Inc).

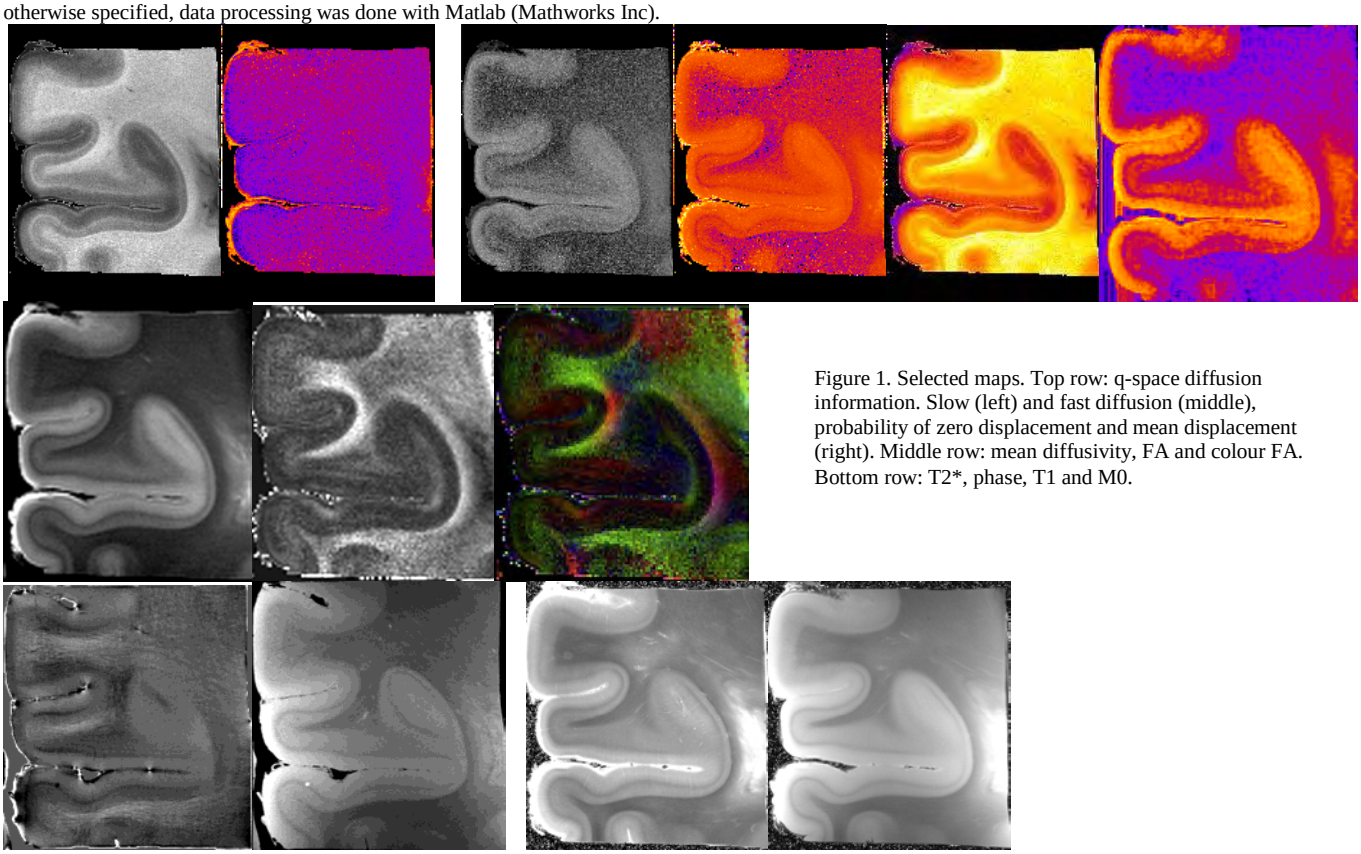

Figure 1. Selected maps. Top row: q-space diffusion information. Slow (left) and fast diffusion (middle), probability of zero displacement and mean displacement (right). Middle row: mean diffusivity, FA and colour FA. Bottom row: T2*, phase, T1 and M0.

Results and Discussion Selected maps are shown in Fig. 1. Interestingly, the slow diffusion shows practically the same value in the whole tissue, suggesting its origin in a featureless compartment (as opposed to intra/extracellular space which changes inside the cortex. The transition between areas V1 and V2 is visible in most contrasts. At least 4 regions are distinguishable in the cortex: superficial lamina, external lamina, internal lamina (stria of Gennari) and deep lamina, using the nomenclature of Ref. [4]. More structure is distibguishable in the T1 map, which displys the highest level of detail, and in phase contrast. From FA and diffusion tensor information, one can assign the presence of the additional band in phase images to the presence of a fibre sheet perpendicular on the imaging plane. Once more, the sensitivity of phase/susceptibility contrast to fibre orientation is confirmed.

References [1] A.M. Oros-Peusquens and N.J. Shah, Proc ISMRM 2013, 6706.; [2] N.J. Shah et al, MRM 2000; [3] J. Lindemeyer et al. Proc. ISMRM 2012; [4] C. Leuze et al., Cerebral Cortex 24, 318(2014).