Exploring the laminar components of the human cortex using ultra-high resolution Inversion Recovery and diffusion

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Purpose and Target:

The six-layered arrangement of cell bodies (i.e., cytoarchitecture) in the human cerebral neocortex is an intriguing feature of the CNS that holds within information about structural-functional organization of the cerebral cortex, as well as potential impairment of its development. This microstructural measure is used for brain mapping and for neuroanatomical parcellation [1,2,3]. Recently, we showed that inversion recovery (IR) MRI [4,5] can be utilized to provide image contrasts that enable division of the neocortex into laminar components (i.e., IR-layers) in vivo and in 3D both in human and rat brains. The IR-layers of the rat brain were validated by cytoarchitectonic histological analysis, and accordance was obtained. In this work, several tissue blocks of fixed human cortex were scanned at ultra-high resolution to visualize their IR layers and to explore the suitability of this feature for parcellation of the cortex. In addition, we also acquired diffusion MRI (e.g., DTI [6] and CHARMED [7]) that is considered as microstructural probe, and allow detection of connectivity pattern. With this setup, we wished to explore the diffusion characteristics of the IR-layers.

Methods:

6 fixed human brain samples that are known to have distinct cytoarchitecture were chosen for this work: Area striata (BA17); Gyrus postcentralis (BA3); primary acoustic cortex (BA41); orbito-frontal (BA10/11) and cingulate cortex (BA24). The samples were scanned in a 7T/30 Bruker biospec, equipped with a 400mT/m gradient unit. The scan protocol includes a set of IR-FSE scans (7 inversion times between 250 to 650ms at 150x150x225µm^3), DTI (15 directions, B values of 1000 s/mm^2, 225 µm^3 isotropically) and CHARMED scans (30 directions each shell, 3 B values of 1000, 2000 and 4000 s/mm^2, 312.5 µm^3 isotropically).

Results:

The IR-MRI dataset was used for calculation of T_1 maps and cluster analysis (Fig. 1A and B respectively) to define the cortical components, IR-layers. Cluster analysis was employed according to previous procedure [4] on all areas simultaneously, to discover clusters with shared characteristics. Six clusters were found, having distinct intensity profiles, each with a specific laminar shape. T_1 histograms (Fig. 2) exposed multi-peak pattern for the examined areas, which proves that the separation of the cortex to subcomponents is based on the intrinsic T_1 property of the tissue and does not stem from partial volume effects. The variation between the histograms is reflected in the measured IR-layers assembly. DTI and CHARMED were analyzed to extract the following quantitative maps: Fractional anisotropy (FA), axial and radial diffusivities (AD and RD) and fraction volume of restricted component (Fr, also known as a marker for axonal density). Fr and FA indices, which are mainly related to white matter, also show variation throughout the cortex (Fig. 3A). Fig. 3B shows that the IR-layers have unique diffusion properties, and that FA/Fr indices provide different information. DTI dataset was analyzed for tractography [8], where IR-layers were used as seed points to examine the laminar connectivity pattern (Fig. 3C). Two connectivity patterns were dominated of 1) U-fibers originating from IR-layers 2-3 to similar layers of adjacent cortex, 2) columnar fibers originating from IR-layer 1 towards IR-layer 4-5 of the same cortical area.

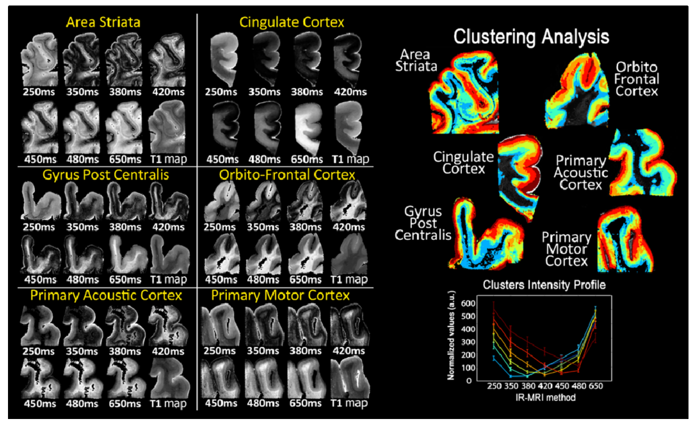

Fig.1:(A) Set of IR-MRI and T_1 maps of different human cortical areas

T_1 maps of some areas (area striata) show fine microstructural features at the cortex depth, which barely exist in others (cingulate cortex).

(B) IR-layers of the cortical areas and their intensity profile

Note that similar IR-layers were found for different areas; each having different laminar width.

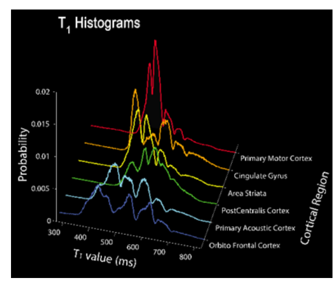

Fig.2: T_1 histograms of cortical areas

Conclusions and Summary:

IR-MRI of the human cortex provides image contrasts that allow its segmentation to subcomponents. Similar information was resolved at higher resolution IR-MRI (115µm) than in previous findings [4] (390µm), concluding that the information is existing within the T_1 properties of the tissue. Diffusion MRI can provide additional structural information, and indeed we found that the IR-layers have distinct diffusion characteristics. Incorporating IR-layers with tractography can elucidate the connectivity pattern and types of connections on a laminar scale.

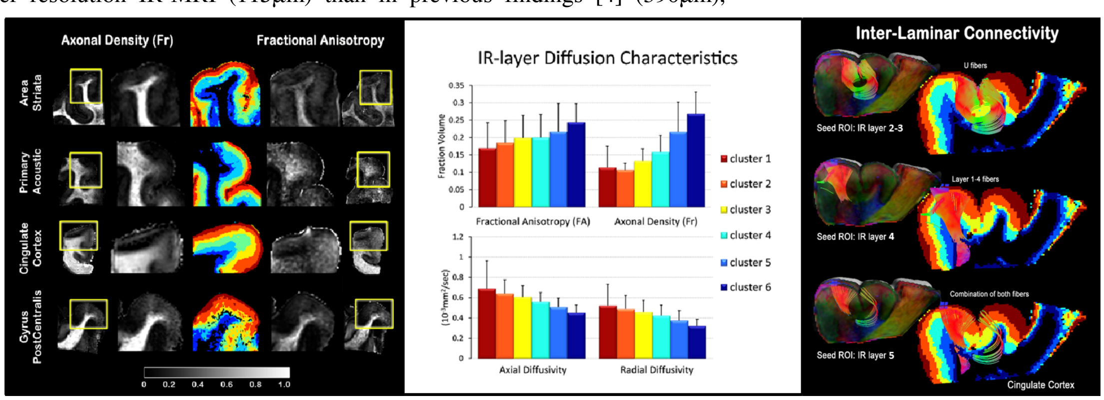

Fig. 3: (A) Examination of FA and FR maps along the cortex

(B) The diffusion properties of IR-layers

(C) The cortical connectivity pattern based on IR-layers

References:

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