Human cortical surface maps of three quantitative imaging parameters:R_1, R_2^* and Magnetic Susceptibility

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TARGET AUDIENCE: researchers interested in cortical surface maps of quantitative contrasts; quantitative susceptibility mapping, R_1 and R^*_2.

PURPOSE: Longitudinal (R_1) and apparent transvrse (R^*_2) relaxivity rates have been used to study the cortical structure of the human brain [1, 2] and shown to reveal cortical cytoarchitecture, particularly enhancing the primary sensory cortices. As both these quantitative contrasts are sensitive to iron and myelin, the quantitative susceptibility mapping (QSM), which is sensitive to the same components but with opposite sign, might provide additional information regarding what is being observed. This study compares the ability of the different contrasts (R_1, R^*_2 and χ) to provide insights into the cortical structure.

METHODS: Data from six subjects were acquired on a 7T scanner (Siemens) according to a protocol accepted by the local ethics committee using the following sequences:

1. T1w imaging MP2RAGE: TR/TI_1/TI_2 = 6/0.8/2.7s, α_1/α_2 = 7°/5°, res= 0.6mm , T_{acq}=10min 25sec
2. B1 map Sa2RAGE:TR/TI_1/TI_2 = 2.4/0.045/1.8s, α_1/α_2 = 4°/10°, res= 2.0mm, iPAT=3x1, T_{acq}=1min 55sec
3. T2*w imageing 3D GRE: TR/TE_1-TE_5=42/4.97-37.77ms, α=10°, res= 0.66mm, iPAT=2x2, T_{acq}=11 mins. The scan was repeated 4 times with the subject's head oriented along different orientations.

Quantitative R_1 maps were calculated using the MP2RAGE and Sa2RAGE data and the processing protocol as described in [3]. The relative head positions were computed by co-registering using FSL-FLIRT. Field maps were computed as in [4] and χ maps were calculated with multiple orientation acquisitions (COSMOS) [5]. The magnitude T_2^*-w image was used to co-register the R*2 and χ volumes with the R_1 maps. The processing procedure for the cortical surface maps of quantitative contrasts (R_1, R^*_2 and χ) is shown in Fig.1.

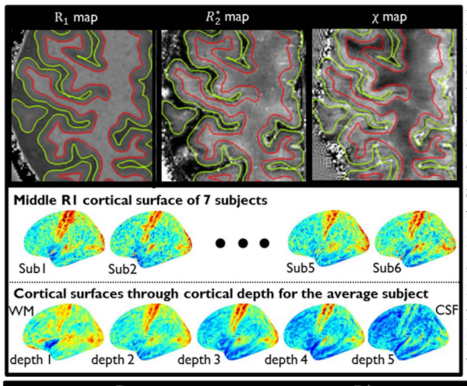

Fig. 1 shows the processing procedure for cortical surface maps: i) cortical surface models were reconstructed from R_1 maps using FreeSurfer and applied to R^*_2 and χ maps (detail of an axial slice of at the level of sensory cortex is shown), ii) all maps were sampled along the normal to gray-white matter (GM-WM) surface vertex in steps of 20% of cortical thickness across the entire cortical hemisphere, iii) an average dataset was calculated for all quantitative contrasts and the information on the different depths was kept (average R1 maps shown).

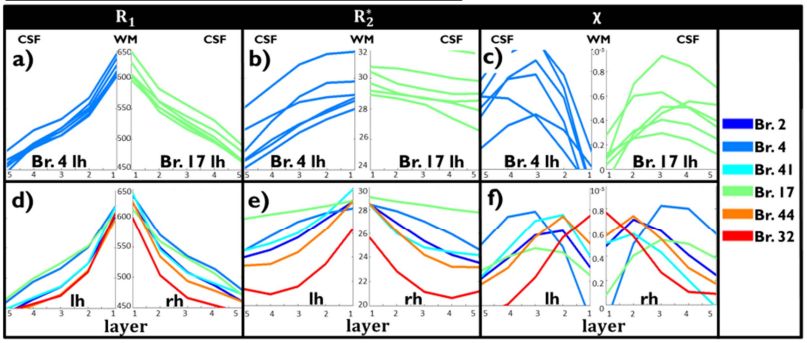

Fig. 2 Plots of the for different quantitative contrasts (R_1,R^*_2 and χ) as a function of the layer number (layer 1 being closest to the GM-WM surface and layer 5 closest to the pial). The first row (a-c) shows the left hemisphere (lh) of Brodmann 4 (left) and right hemisphere (rh) of Brodmann are 17 (right) for all 7 subjects. The second row (d-f) shows average subject where the different colors correspond to different Brodmann regions (Brodmann 2 somatosensory, 4 primary motor cortex, 17 primary visual cortex, 41 auditory cortex, 44 Broca's area and 32 cingulate region).

RESULTS: The quality of the used data is shown for one subject in Fig.1. The FreeSurfer [6] calculated cortical surfaces (green and red lines in Fig.1 i) correspond well to the underlying R_1 contrast (from which they were calculated), the R^*_2 and χ contrast reveal dissimilarities that are not attributed to poor co-registration. While in the outer layer (the pial surface) the χ contrast is significantly noisier due to the background removal, the mismatches in the grey white-matter surface for both the R^*_2 and χ is solely due to the different mechanisms generating the contrast.

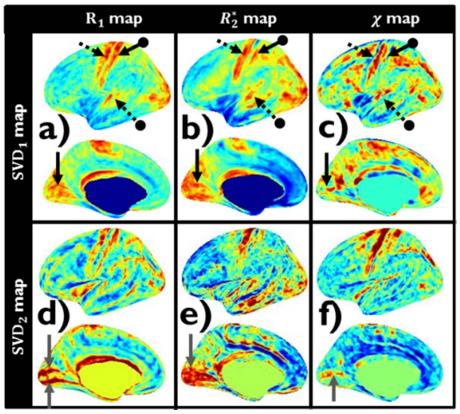

Fig. 3 shows on first, second and third column the surface maps of the left hemisphere for i) R_1, ii) R^*_2 and iii) χ contrast for the first component (a-c) and the second component (d-f) of the singular value decomposition. Black solid arrow points the visual cortex, the dashed arrow shows the motor cortex, the dot-ended solid arrow points the somatosensory cortex while the dot-ended dashed points the auditory cortex. The gray arrow shows the separation between primary and supplementary visual cortex.

Fig. 2 a-c) shows that for all contrasts the through layer behaviour on the R_1, R^*_2 and χ was in good agreement between the 6 subjects and varied between different brain regions. It should be noted that the variability of the χ curves is due to the arbitrary offset, but the shapes are maintained. Figure 2 d-f) shows for a wider set of ROIs, the behaviour of the contrasts when averaged over the subjects. While the behaviours are different between different ROI, they are coherent between left and right hemisphere.

To benefit from this information without the need to rely on segmentation, singular value decomposition (SVD) was performed for each contrast to separate cortical maps with different through layer behaviour. The first component of the SVD (SVD1) of R_1, and R^*_2 shows similar maps (enhancing all primary sensory regions, see Fig 3.a,b) and describes a relaxivity decay (as in Fig. 2d,e). The χ SVD1 has a curvature like behaviour (as in Fig. 2 c,f). While the R_1 contrast shows both the motor and somatosensory cortex, the R^*_2 and χ only enhance the motor cortex and show low contrast for the somatosensory cortex (dot-ended arrow in Fig. 3). SVD2 performs a separation of the primary visual cortex and the cortex variation is similar for all three contrasts (gray arrow in Fig. 3).

DISCUSSION/CONCLUSION: The cortical R_1 and R^*_2 maps shown show similar contrast to that reported by other groups [1,2]. The observation that χ, as opposed to R_1 maps and R^*_2, does not decrease monotonically from inner surfaces to outer surfaces, suggests that myelin and iron contributions are cancelling each other and might have distinguishable cortical distributions that could be studied using this data. This will be the object of future research. Furthermore, combination of information using different contrasts at different depths could provide useful information for cortical segmentation as is supported by the reproducibility of the single subject data.

REFERENCES

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