Imaging macaque cortical myeloarchitecture

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Target Audience: Researchers interested in cortical myeloarchitechture, parcellation, and plasticity.

Background: T1 contrast is known to reflect myelination and can be used to image cortical myeloarchitechture (1-2). Direct T1 imaging is more quantitative than T1-weighted imaging and has recently been demonstrated in human studies for local myelination measurement (3). The current study was to optimize a high resolution T1 imaging protocol for rhesus monkey brain studies. Since the architectonic areas of the monkey brain have been well studied, it provides an excellent model to verify T1 mapping results.

Method: Anesthetized rhesus monkeys were imaged in a 40 cm bore Bruker 4.7T scanner, using a single loop coil (14 cm diameter) placed over the animal's head. Three-dimensional (3D) FLASH sequence was modified to implement the variable flip angle (VFA) method for T1 quantification. The actual flip-angle imaging (AFI) method is used to calibrate the flip angle. Following Yarnykh's recommendations (4), long and strong spoiler gradient pulses were used in both VFA (32ms x 60mT/m) and AFI (9ms x 48.5mT/m) sequences to minimize T1 errors. The 3D field of view was 56x82x96 mm^3, and spatial resolution was 0.5 mm isotropic. In VFA experiments, TR=40ms, TE=3.8ms, and eight volumes were acquired with flip angle values of 5.9, 33.2, 5.5, 31.0, 6.6, 36.6, 5.9, 33.2 degrees. Total VFA scan time was 170 minutes. In AFI experiments, TR1=20ms, TR2=100ms, flip angle=60^o, and RF phase increment =39^o. AFI experiment was repeated three times and total scan time was 22 minutes. The accuracy of this T1 mapping implementation was validated by comparing with standard inversion-recovery (IR) T1 measurements in water phantoms doped with $MnCl_2$ (0.05 to 0.3 mM concentration).

FreeSurfer (v5.3) was employed to reconstruct cortical surface from quantitative R1 (1/T1) with extensive manual editing, which ensure precise white and gray matter boundary. R1 data were sampled along the normal to each gray-white matter surface vertex.

Results: In the phantom experiments, T1 values determined by the combined AFI-VFA protocol agreed very well with values determined by the IR T1 measurement; the absolute differences were all smaller than 2%.

The cortical surface T1 map clearly highlighted cortical regions of known high myelin content, such as early visual areas, central sulcus, superior temporal sulcus, and auditory cortex. (Fig. 1), in agreement with previous studies.

Moreover, the sensitivity and resolution provided by our implementation afforded us to observe the V2 CO stripes (Fig. 1), a known architectonic features that had been visible in histology but had not been observed previously using MRI in a living brain (5). The inter-stripe distance was around ~3.8 millimeter, in good agreement with histological observations (5).

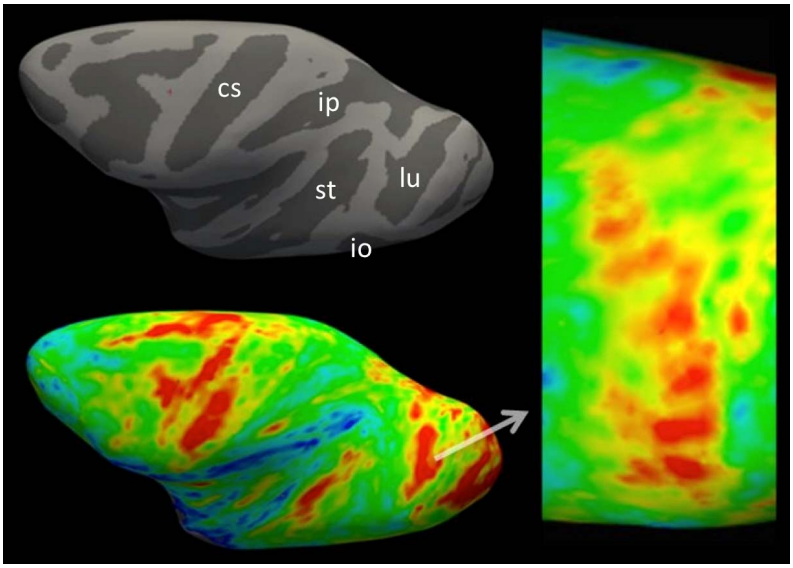

Figure 1. The myelination map calculated from quantitative R1 (bottom left panel) was projected onto the inflated monkey brain (top left panel), showing in left hemisphere. The V2 CO-rich strips were visible in the magnified view (right panel, orientation and spatial filter were adjusted for best viewing). Major sulci are labeled in lowercase letters: cs, central sulcus; io inferior occipital sulcus; ip, intraparietal sulcus; lu, lunate sulcus; st, superior temporal sulcus.

Conclusions and discussions: The high-resolution T1 imaging protocol presented in this study proved to be excellent for mapping cortical myelination in rhesus brains. Strong gradient spoiler, as recommended in (4), is necessary for accurate T1 mapping. The demonstrated high sensitivity to fine cortical myelination features (such as V2 stripes) opens the possibility for precise analysis of cortical myelination in healthy and diseased brains.

References: **1**. Bock, et al. (2011). Visualizing myeloarchitecture in with magnetic resonance imaging in primates. Ann. N. Y. Acad. Sci., 1225, E171-181. **2**. Glasser, et al. (2011). Mapping human cortical areas in vivo based on myelin content as revealed by T1- and T2-weighted MRI. J. Neurosci., 31, 11597–11616. **3**. Sereno, et al. (2013). Mapping the human cortical surface by combining quantitative T1 with retinotopy. Cerebral Cortex, 23, 2261-2268. **4**. Yarnykh (2010). Optimal RF and gradient spoiling for improved accuracy of T1 and B1 measurement using fast steady-state techniques. Magn. Reson. Med. 63, 1610-1626. **5**. Nakamura, et al. (1993). The modular organization of projections from areas V1 and V2 to area V4 and TEO in macaques. J. Neurosci. 13,3681-3691.