

B₀-orientation dependence can characterize cortical and sub-cortical fibers *in vivo* at 7T

Julien Cohen-Adad¹, Jonathan R Polimeni¹, Bruce R Rosen¹, Caterina Mainero¹, and Lawrence L Wald^{1,2}

¹A. A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Harvard Medical School, Charlestown, MA, United States, ²Harvard-MIT Division of Health Sciences and Technology, MIT, Cambridge, MA, United States

Introduction. Recent studies have shown a dependency between T₂* and orientation of white matter fibers with respect to the orientation of the main magnetic field B₀, relating a macroscopic effect to tissue microstructure [1-3]. Here we hypothesized whether this contrast mechanism can enable the characterization of cortical and sub-cortical fibers *in vivo* at 7T.

Methods. Acquisition. Eight healthy volunteers were scanned at 7T (Siemens Healthcare, Erlangen, Germany) using a head gradient (AC84) and a custom made 32-channel coil [4]. Protocol included a multiecho FLASH T₂*-weighted spoiled gradient-echo (two slabs covering the supratentorial brain, TR=2020ms, TE=6.34+3.2n [n=1..12], resolution = 0.33×0.33×1 mm³, 40 slices, matrix=576×504, BW=335Hz/Pix) and a T₁-weighted MPRAGE (TR/TI/TE=2600/1100/3.26ms, 0.60×0.60×1.5 mm³). Subjects were also scanned at 3T to obtain a multiecho MPRAGE used for surface reconstruction. **Processing.** 7T data were corrected for dephasing effects from background field gradient [5]. Then, T₂* was estimated using generalized linear least square fitting of the log of the signal. T₂* volumes were further corrected for distortions related to gradient non-linearities using the vendor-supplied specifications of the AC84 gradient fields. Volumes were then registered to the 3T surface as detailed in [6]. T₂* was mapped at the mid-depth of the cortical ribbon and 1 mm below the white/gray matter boundary (Fig1A) then smoothed tangential to the surface (FWHM=5mm) using FreeSurfer (http://surfer.nmr.mgh.harvard.edu). Orientation dependence was probed by relating T₂* to the angle θ_z between B₀ and the normal to the cortical surface (Fig1B). Instead of rotating the head of participants [1], we took advantage of the convoluted nature of the human cortical folding pattern to obtain a wide range of angles. **Cortical fibers.** T₂* sampled in the cortex was averaged within regions defined by the PALS-12 Brodmann atlas [7], then plotted against $\theta_z \in [0, \pi/2]$ and a nonlinear regression was conducted to test the presence of a B₀-dependency. Fitting equation was $R_2^* = c_0 + c_1 \cdot \sin(2 \cdot \theta_z + \varphi_0)$, where c₀ is the background portion of R₂* not affected by B₀ orientation, c₁ is the portion of R₂* that does depend on B₀ orientation, and φ_0 is a phase offset term [2]. The B₀-dependency was assessed by $\Delta R_2^* = 2 \cdot |c_1|$. **Sub-cortical fibers.** We tested whether the orientation of the sub-cortical fibers (i.e., radial or tangential to the cortical surface) is sensitive to B₀-dependency. A mask of gyri and sulci was created from curvature information. T₂* sampled at 1 mm below the cortex was averaged in sulci and gyri, then plotted against θ_z . A linear regression assessed the sign of the B₀-dependency, i.e., positive correlation between T₂* and θ_z would suggest that fibers are parallel to the cortical surface, radial otherwise [1, 2].

Results. Patterns of lower T₂* were detected in the sensorimotor (BA4,1), visual (BA19) and auditory cortices (BA42), likely reflecting higher myelin content (Fig2A). B₀ orientation dependence was 4× higher in the primary motor cortex (BA4) compared to the somatosensory cortex (BA2), as illustrated by the parameter c₁ in Fig2B. Mapping of B₀-dependence in 30 Brodmann areas is provided in Fig2C and further supports the stronger B₀-dependency in the motor cortex relative to other areas, likely due to the presence of highly coherent myelinated fibers. Analysis of B₀-dependency 1 mm below the cortex revealed negative correlations in gyri ($\beta = -0.49$, T=-19.9, p<0.001), suggesting radial orientation of fibers (i.e., orthogonal to the cortical surface) and positive correlation in sulci ($\beta = 2.29$, T=118.2, p<0.001), suggesting tangential orientation of fibers.

Discussion. This study suggests that B₀-orientation dependence can probe the coherency and orientation of cortical fibers, shedding light into the potential use of this type of contrast to characterize cyto-/myeloarchitecture *in vivo*. The B₀-orientation dependence of sub-cortical fibers revealed consistent anatomical features, reflecting U-fibers running tangentially to the sulci and penetrating radially in both contiguous gyri. As shown in the white matter [8], this technique could be used to supplement information given by diffusion tensor imaging to study the orientation of cortical and sub-cortical fibers [9].

References.

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→ Fig3. A mask of gyri and sulci was created from the signed mean curvature calculated from the surface geometry. T₂* sampled at 1 mm depth correlated negatively with θ_z in the gyri and positively in the sulci, consistent with the known anatomy of U-fibers. Source of the histology picture: Ellison & Love: *Neuropathology 2e*, 2004 Elsevier Ltd.

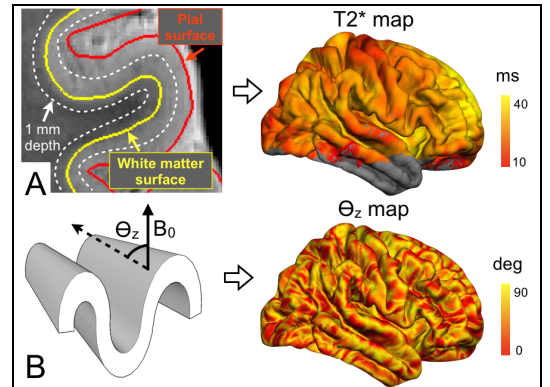


Fig1. A: Method for T₂* mapping along the midline of the cortex (between pial and white matter surfaces) and at 1 mm depth. **B:** Method to probe B₀-dependency by computing the angle between the normal of the cortical surface and B₀.

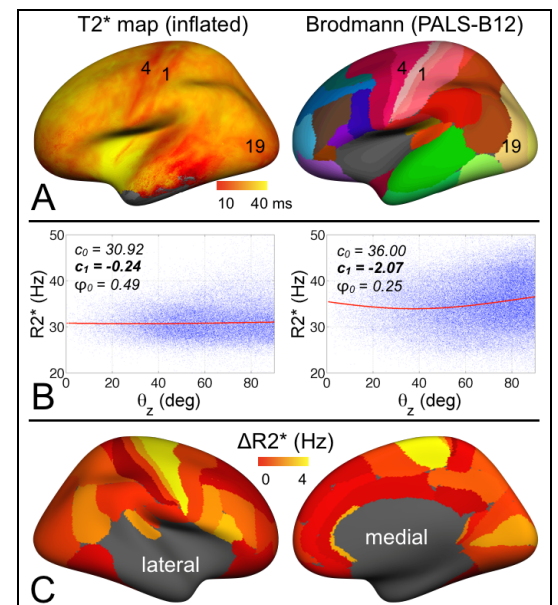


Fig2. A: T₂* map averaged across subjects (N=8) and compared to the Brodmann atlas. **B:** Fitting results in the somatosensory (BA2) and motor cortex (BA4), the latter exhibiting 4× stronger B₀-dependency. **C:** B₀-dependency mapping probed in 30 different Brodmann areas.

