Sub-millimeter diffusion MRI at 7T: Does resolution matter?

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Introduction: For tractography and connectivity analysis of the living human brain, diffusion MRI (dMRI) acquisitions with an isotropic resolution are necessary. Furthermore, to study small structures, such as the cortex and fine white matter structures, a high spatial resolution is important to minimize partial volume effects. Recently, it has been shown that dMRI with 1 mm isotropic resolution can be obtained at ultra-high field strength (7T) using a combination of zoomed imaging and parallel imaging, given the name ZOOPPA [1]. In this study, we demonstrate the benefits of the increased spatial resolution while decreasing the isotropic voxel size from 1.5 mm to 1.0 mm. The ZOOPPA approach in combination with a high performance gradient system enables the acquisition of dMRI images with an isotropic resolution of 800 µm showing detailed structures even in basal regions of the brain.

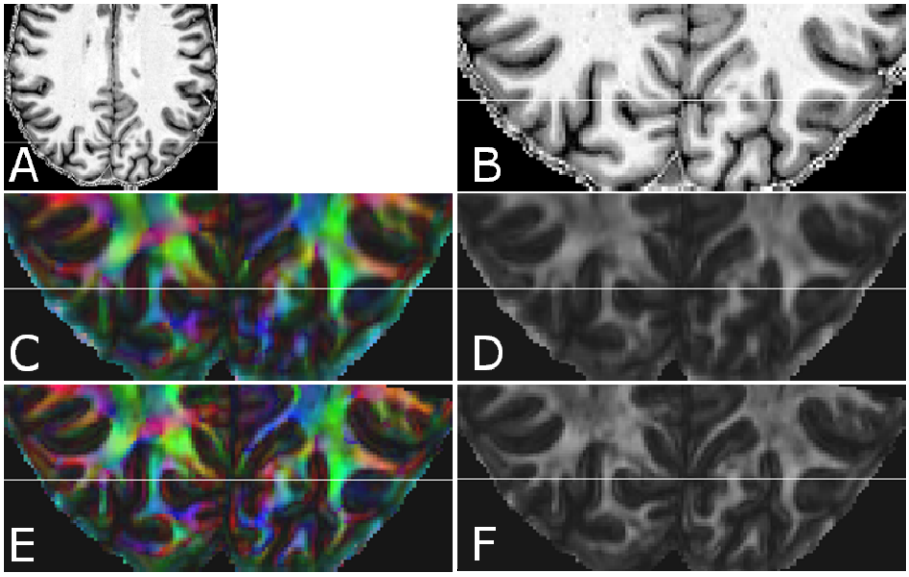

Fig 1: (A) T_1-weighted anatomical view, axial slice and (B) enlarged section. Color FA (left column) and FA (right column) with 1.5 mm isotropic resolution (C and D) and with 1.0 mm isotropic resolution (E and F) are shown. The white line indicates the same position in each image.

Methods: Experiments were performed on a 7T whole-body MR scanner with max. gradient amplitude 70 mT/m (Siemens AG, Germany) using a 24-element head coil (Nova Medical, USA). Scans were performed on healthy volunteers providing isotropic resolution of up to 800µm, with 91 slices, FOV 143x147 mm^2, TR 14.1 s, TE 65 ms, BW 1132 Hz/pixel, ZOOPPA accel. 4.6). 4 scans were performed with 60 directions with a b-value of 1000 s/mm^2. The total acquisition time was 65 min. A two-stage hybrid image restoration procedure [2] was applied to the raw data and the data was corrected for subject motion and registered to a T_1-weighted image of the same participant using a rigid-body transformation. For each voxel, multiple fiber orientations were modeled using constrained spherical deconvolution CSD [3] followed by probabilistic fiber-tracking and track density imaging (TDI) [4] using MRtrix.

Results and Discussion: The comparison of an acquisition with 1.5 mm isotropic resolution (see Fig. 1 C and D) and 1.0 mm isotropic resolution (see Fig. 1 E and F) shows that the increased spatial resolution unveils fine anatomical structures. This is due to reduced partial volume effects enabling a better differentiation between neighboring tissue types of different main orientation preference, such as fine white matter structures or the FA differences between the white matter and the cortex. With a nominal spatial resolution of 800 µm it is possible to track fine white and gray matter fiber bundles as exemplified in the thalamus and the brain stem (see Fig. 2). The TDI maps highlight the laminar structure within the thalamus and indicate fine structures with variable tissue directions, as shown in the sagittal section in Fig. 2. In the axial and coronal sections, the TDI maps differentiate various fiber bundles surrounding and crossing the nuclei of the brain stem.

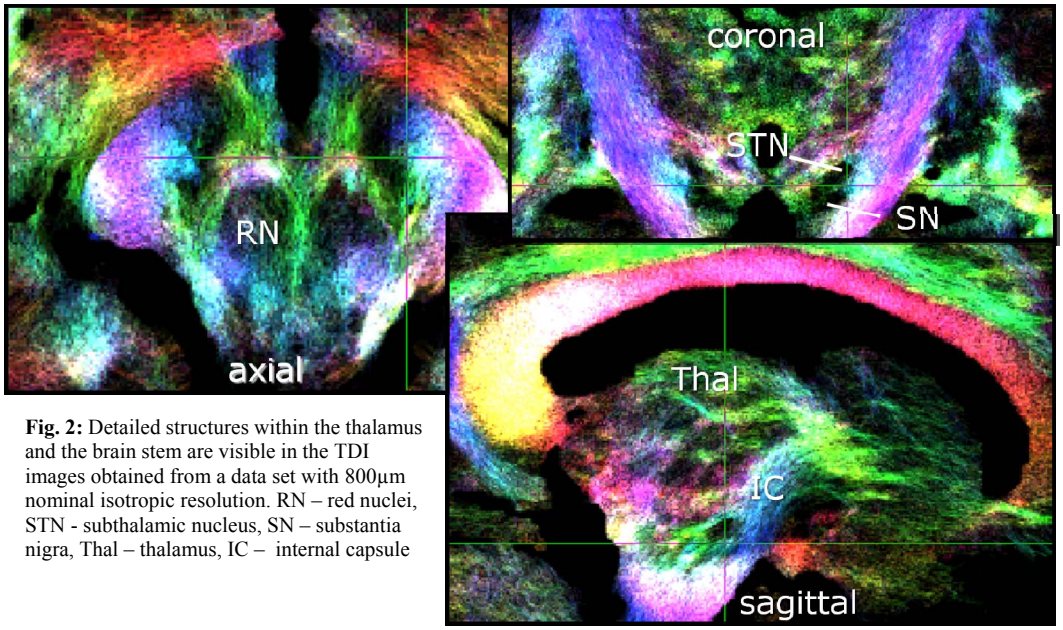

Fig. 2: Detailed structures within the thalamus and the brain stem are visible in the TDI images obtained from a data set with 800µm nominal isotropic resolution. RN – red nuclei, STN - subthalamic nucleus, SN – substantia nigra, Thal – thalamus, IC – internal capsule

References: [1] Heidemann RM, 2010, ISMRM. [2] Lohmann G, 2010, Magn Reson Med, 15-22. [3] Tournier JD, 2007, Neuroimage, 1459-1472. [4] Calamante F, 2011, Neuroimage, 1259-1266.