

Multiband Acquisitions for Clinically-Feasible 3-T MRI Track Density Imaging to Parcellate Thalamic Nuclei for Functional Neurosurgery

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TARGET AUDIENCE: Radiologists, neurologists, neurosurgeons and researchers involved in functional neurosurgery of the thalamus.

PURPOSE: Essential tremor is the most common movement disorder and can be treated by gamma knife ablation or deep brain stimulation (DBS) of the ventral intermediate nucleus (VIM) contralateral to the dominant affected extremity with good outcomes [1]. The internal structure of the thalamus lacks internal contrast on routine MRI and targeting is based on coordinates from anatomic atlases with less consideration for individual variability or left-right asymmetries. Track density imaging (TDI), based on super-resolution derived from probabilistic diffusion tractography, may better depict internal thalamic structure in individual patients [2], but has required high-field MRI or long acquisitions that may not be practical in most clinical settings. We applied multiband diffusion MRI [3] at 3-T to accelerate TDI acquisitions in clinical patients with essential tremor.

METHODS: Three patients with essential tremor consented to 3-T MRI (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) with TDI prior to undergoing gamma knife ablation of their left VIM. 3 additional healthy volunteers were scanned to assess reproducibility. Subjects underwent standard preoperative MRI with an additional multiband diffusion sequence that used multiband factor of 3, 3-mm isotropic image resolution, whole-brain coverage (45 slices) and 256 diffusion gradient directions ($b = 2500 \text{ s/mm}^2$) acquired in 11 min (TR/TE = 2400/98 ms, NEX = 1, GRAPPA acceleration = 2). TDI data processing included 400,000 probabilistic tractography seeds to generate constrained spherical deconvolution, track density and direction-encoded color maps at 500-micron super-resolution [2].

RESULTS: Combining TDI and multiband diffusion acquisitions resulted in high-quality images of the human thalamus in typical elderly essential tremor patients using 3-T MRI. Results also were consistent for repeat imaging in the same subject. Track density with or without direction-encoding demonstrated some of the internal anatomy of the thalamus, but fiber-orientation maps derived from these data overlaid on conventional T2 images (Fig. 1) were preferred by the 2 functional neurosurgeons participating in the study.

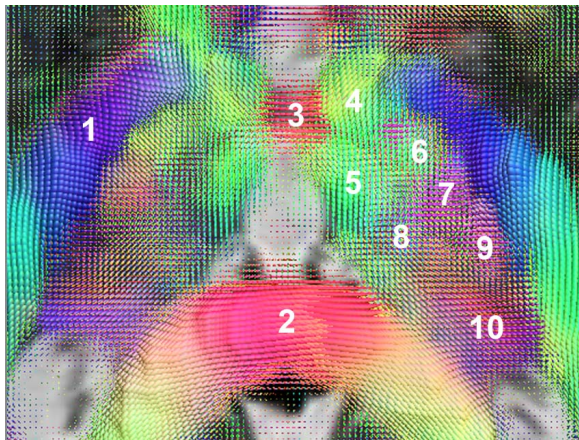


Fig. 1 – Constrained spherical deconvolution fiber-orientation map of the thalamus overlaid on an axial T2 image with 570-micron in-plane resolution in a 70 year old man with essential tremor. Besides the internal capsule (1) and corpus callosum (2), most of the internal nuclei of the thalamus can be identified using different fiber orientations, including massa intermedia (3), VA (4), dorsomedial thalamus (5), VLd (6), VLp (7), centromedial thalamus (8), VPL (9) and pulvinar (10). The VLp (or VIM) (7) is the most common target used to treat essential tremor via DBS placement, gamma knife or radiofrequency ablation.

DISCUSSION: TDI of the thalamus using 3-T MRI and recently developed multiband acceleration [3] represents practical translation of a research tool into a clinically feasible technology. This approach provides at least equivalent data to previous diffusion tractography or TDI approaches for thalamus parcellation, but without long scan times or a 7-T MRI system [4-6]. The planning for gamma knife ablation of VIM for these initial 3 patients still relied on conventional indirect targeting based on T2 images that lack intrinsic contrast in the thalamus. However, we are slowly integrating TDI parcellation of the thalamus into primary planning of functional neurosurgeries with caution for potential spatial misregistration from diffusion acquisitions.

CONCLUSION: Multiband diffusion acquisitions make TDI-based parcellation of the thalamus feasible in elderly patients with essential tremor using 3-T MRI. Future efforts will focus on 1) validation of some anatomic assignments with DBS microelectrode recording and/or stimulation, and 2) assessing the impact of this approach on treatment outcomes after functional neurosurgery.

REFERENCES: [1] Kondziolka et al. J Neurosurg 2008;108:111-7. [2] Calamante et al. Neuroimage 2010;53:1233-43. [3] Setsompop et al MRM 2012;67(5):1210-1224. [4] Behrens et al. Nat Neuro 2003;6(7):750-757. [5] Wiegell et al. Neuroimage 2003;19:391-401. [6] Calamante et al. HBM 2013;34:2538-48.