Learning Objectives
1) Describe the limitations for image-based targeting for functional neurosurgery in the thalamus
2) Understand the underlying concepts for multiband diffusion and track density imaging MRI techniques
3) Identify the future potential for new MRI methods to guide functional neurosurgery.

Introduction
Essential tremor can be treated by thalamic stimulation or ablation of the ventral intermediate nucleus (VIM) with good outcomes [1]. Routine MRI cannot distinguish between thalamic nuclei so targeting is based on anatomic atlas-based coordinates. Diffusion MRI-based track density imaging (TDI) can better depict internal thalamic structure [2], but previously has required high-field MRI or long acquisitions that are not clinically practical. We applied multiband diffusion MRI [3] to enable 3-T MRI TDI in patients with essential tremor.

Methods
Six patients with essential tremor underwent standard preoperative MRI with an additional multiband diffusion sequence that used 3-slice acceleration factor, 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. TDI data post-processing generated track density and direction-encoded color maps at 500-micron isotropic 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 and clinically feasible scan times. Results also were consistent for repeat imaging in the 3 volunteers. TDI with or without direction-encoding demonstrated some of the internal anatomy of the thalamus, but fiber-orientation maps derived from these data (Fig. 1) were preferred by the 2 participating functional neurosurgeons.

Conclusions
Multiband diffusion acquisition makes TDI-based parcellation of the thalamus feasible in elderly patients with essential tremor using 3-T MRI. 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]. While planning for gamma knife ablation of VIM for these initial 6 patients still relied on conventional methods, future efforts will focus on validation and careful introduction of TDI-derived thalamic maps to actual surgical planning.

References
Coregistered T2-weighted MRI (A) and 500-micron isotropic resolution TDI fiber-orientation maps (B) demonstrate the latter can identify many internal nuclei of the thalamus using different fiber orientations, including massa intermedia (1), VA (2), dorsomedial thalamus (3), VLa (4), centromedial thalamus (5), VLP or VIM (6), VPL (7) and pulvinar (8).