Optimized high-resolution mapping of magnetisation transfer at 3 Tesla reveals substructures in the human thalamus in clinically feasible measurement time

G. Helms[1], T. Gringel[1,2], E. Elolf[2], W. Schulz-Schaeffer[3], and P. Dechent[1]

[1]MR-Research in Neurology and Psychiatry, University of Göttingen, Faculty of Medicine, Göttingen, Germany, [2]Neuroradiology, University of Göttingen, Faculty of Medicine, Göttingen, Germany, [3]Neuropathology, University of Göttingen, Faculty of Medicine, Germany

Introduction:

The thalamus is a key structure in processing pathways due to its central role in linking sensory input signal with areas of higher cortical function. It is also a key target of neurosurgical treatment of functional deficits, e.g., in Parkinson's disease. Although sub-millimeter resolution has become feasible on modern high-field MR scanners, MRI of the thalamus is yet notorious for its low contrast. The high density of axonal connections results in an intrinsic loss of contrast; while its location in the centre of the skull impedes the signal gain from surface coil detection. The magnetisation transfer saturation (MTS), i.e. the additional degree of saturation in Mz created by an off-resonant saturation pulse during TR (1), are derived by correcting MT-weighted Flash MRI for effects of proton density (PD) and T1-relaxation. These maps are independent of B1-inhomogeneities and provide a high contrast between cerebro-spinal fluid (CSF), gray matter (GM) rich in neuronal cell bodies, and white matter (WM) rich in myelinated axons (2). This technique was optimized for high-resolution mapping of the human thalamus at 3 Tesla.

Methods:

Three 3D-Flash datasets with predominant MT-, PD-, and T1-w(eighting) was acquired on healthy volunteers (22-26 years, 5f/1m) at isotropic resolution of 1.25 to 0.9 mm on a 3 T clinical MR system (Siemens Trio, Erlangen, Germany) using the 8-channel receive-only head-coil. The SNR was increased by averaged multi-echo acquisition at TR = 30 ms for PD-w (7°) and T1-w (15°), and 48 ms for MT-w (10°). Partial Fourier acquisition was decreased as far as resolution remained unaffected. Total acquisition time was 29.5 minutes. MTS-, MTR-, T1-, and PD maps were calculated after realignment of the 3 datasets as described previously (2), up-sampled to 0.5 mm resolution and registered to a template in ac-pc orientation covering the central parts of the brain from the corpus callosum to the pons using FSL 3.2 (University of Oxford). Conspicuity of maps was rated by a physicist (GH), an experienced neuropathologist (WS), and a neuroradiologist (EE). The classification of Jones (3) was used for assignment of thalamic substructures. Comparison with anatomical atlases by an unbiased student (TG) was cross-checked against clinical expertise (WS).

Results:

MTS maps provided the highest contrast and largest number of identified sub-structures. The visibility of laminar structures was greatly enhanced by reducing the resolution below 1 mm. The mamillothalamic tract (MTT) and the internal medullary lamina (IML) served as major landmarks to distinguish the groups of medial, lateral and intralaminar nuclei, as well as those in the splitting of the IML. Histogram analysis confirmed an optimal resolution of 0.95 mm to minimize broadening due to noise and partial volume effects (Fig. 1). Assignment was based on visual contrast only, without resorting to additional stereotactic information (Fig. 2). 25 of 32 nuclei of the Jones classification could be assigned in the dorsal thalamus, besides epithalamus, subthalamic nucleus, and substantia nigra.

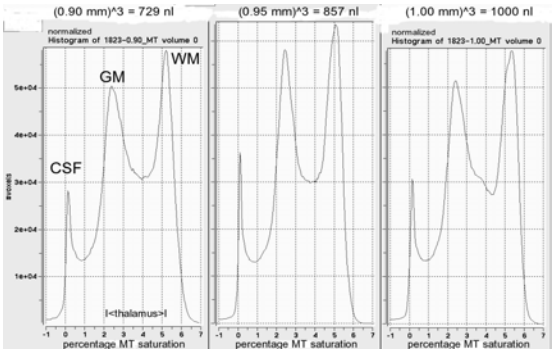

Figure 1: Normalized MTS histograms from central brain (Fig. 2) show high contrast and reveal broadening of modes by noise at 0.9 mm and partial volume at 1.0 mm resolution.

Discussion:

The optimized acquisition protocol yielded MTS maps of sufficient resolution and contrast-to-noise to allow the direct assignment of thalamic nuclei. So far, segmentation of the thalamus has been mainly based on diffusion-tensor data (4,5) with compromised spatial resolution. Multi-session averaging of high-resolution T1- and T2-maps at 1.5 T is unfeasible for clinical purposes (6). As maps of MTS were deemed most conspicuous, the other parameters were not regarded further. This may be due to the high specificity of MTS to the presence of structural material and myelin. In a Cuprizone model of reversible demyelination (7), the MTS showed a higher sensitivity to myelin than T1, PD, or the commonly used MT-ratio. Since heat deposition was around 30% of the SAR limit, the method imposes no immediate limits on application at higher field strength.

Conclusion:

The intrinsic MR-contrast of the thalamus was improved by a combination of high resolution, efficient signal averaging, and use of MTS maps. This made it feasible to assign thalamic substructures in individual subjects without prior information.

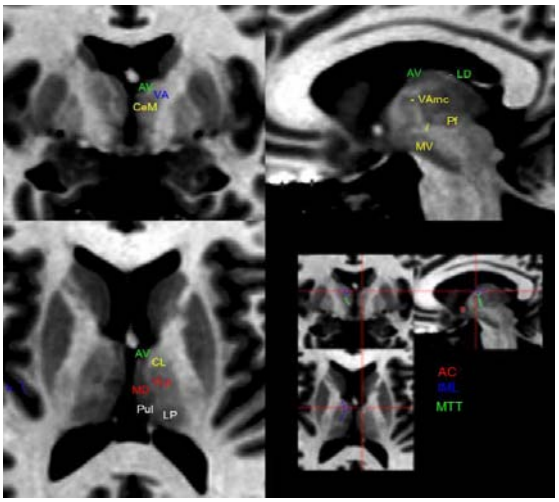

Figure 2: MTS-map - thalamic nuclei assigned on a selected orthogonal view; main WM tracts depicted on scout insert.

References:

1. Helms G, Piringer A. NMR Biomed (2005) 18:44-50 **2.** Helms G, Dathe H, et al. Proc. ISMRM 14, 2006, 2491 **3.** Hirai T, Jones EG. Brain Res Rev (1989) 14:1-34 **4.** Wiegell MR, et al. NeuroImage (2003) 19:391-401 **5.** Johansen-Berg H et al. Cereb Cortex (2005) 15:31-39 **6.** Deoni SCL, et al. Hum Brain Mapp (2005) 25:353.359. **7.** Boretius S, et al. Myelin Imaging Conf, abstr. Vancouver, 2006.

Acknowledgements: Dr. G. Krüger, Siemens, for providing the me-Flash sequence. Grant support by the Volkswagen Foundation of Lower Saxony.