Delineation of the subthalamic nucleus (STN) on high-resolution maps of R2*

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Introduction:

The subthalamic nucleus (STN) is the target structure for deep brain stimulation for neurosurgical treatment of Parkinson's disease. It is notoriously difficult to detect on T1-w(eighted) stereotactic MRI, but may be seen on multi-slice T2-weighted turbo-spin-echo images due to its high content of intra-cellular iron (1). Recently, we demonstrated the visibility of the STN on gradient-echoes (GE) at echo times (TE) of 20 ms or longer. These can be incorporated into T1-w spoiled gradient-echo sequences (FLASH) providing stereotactic resolution and spatial congruence (2). Here, we report on the use of quantitative 1/T2* maps for improved delineation of iron rich structures, in particular the STN and substantia nigra (SN).

Methods:

3D multi-echo FLASH MRI with non-selective excitation was performed at 3 Tesla (Siemens Magnetom Trio; 8-channel receive headcoil) on 20 healthy adult volunteers. Eight bipolar gradient echoes at TE between 2.2 ms and 23.2 ms (370 Hz/pixel bandwidth) yielded separate 3D volumes (256*256*176) of increasing T2*-weighting. This added to the predominant T1-weighting of the steady state (TR/α = 30 ms/20°). The sagittal measurement took 7:06 minutes with partial parallel (GRAPPA, 2x, 24 reference lines) and 6/8 partial Fourier acquisition in phase and slice.

After conversion to nifti format, FSL 3.2 (www.fmrib.ox.ac.uk/fsl) was used to calculate R2* = 1/T2* by regression of the log signals. Then, the T1-w volumes and the R2*-maps were co-registered by a rigid-body transform (6 dof) to a modified MNI standard brain (resampled at 0.5 mm resolution and tilted to the Schaltenbrand-Wahren (SW) (3) coordinate system). The MRIcro viewer (www.edu/crorden/mricro.htm) was used for display and evaluation. The STN was depicted by overlays of thresholded R2* maps onto T1-w images. "Pixel coordinates" were transformed to cartesian SW coordinate system with the origin at half the intercommissural (ACPC) distance. The center, poles and the lateral position of both STN were determined from the R2* maps, as well as the intercommissural (ACPC) distance commonly used to normalize the SW-coordinate space.

Results:

The STN was well delineated at individual thresholds of 25.9±1.5 s^{-1} (**Fig. 1**). The border to the SN was occasionally seen, but more reliably determined by means of the T1-hypointensity of the SN. The R2* in the center of the STN was 37.0±4.4 s^{-1}. The T2* in the midbrain region was hardly affected by residual B0-inhomogenities, except close to major vessels and at the inferior pons, as controlled by B0 field mapping. This is further supported indicated by absence of lateral differences. In particular, the displacement of the odd and even echoes was less than 0.5 pixels, so no unwarping was performed. The position of central STN in the cohort differed markedly from the one commonly accepted for neurosurgical planning. In particular, there was no significant correlation of distance of the STN to the ACPC distance (**Fig. 2**).

Discussion:

The proposed method provides a mapping of the STN of "diagnostic quality" in clinically feasible time. The 3D shim is sufficient. R2* may also provide information about the involvement of the STN in pathology, since higher iron content has been reported to correlate with symptoms in Parkinson's disease.

The scatter shows the limitation of the common approach of co-registering a reference map to individual anatomy. It thus needs to be tested whether individual mapping of the STN provides a better accuracy. The proposed multi-echo approach may be used for this purpose, as it provides R2* maps at a stereotactic resolution that are inherently co-registered to the T1-w data sets. Other brain structures containing iron – like the red nuclei, the globus pallidus and the dentate nuclei - can be identified as well.

References:

(1) Dormont, et al. AJNR 25(2004) (2) Elolf, et al. AJNR 28(2007) (3) Schaltenbrand, Wahren. *Atlas for Stereotaxy of the Human Brain*. (1977)

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Figure 1: R2*-overlay thresholded 26-45 s^{-1}

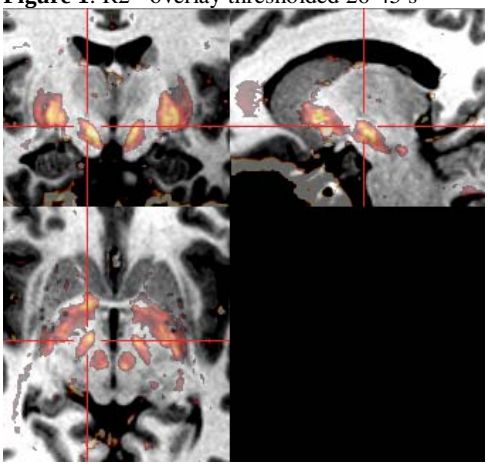

Figure 2: Scatterplot of STN positions versus the intercommisural distance