High-resolution 3T and 7T extension of the Colin27 atlas for deep-brain targeting

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Introduction:

Deep brain stimulation (DBS) for Parkinson's disease is an effective treatment however challenges remain in accurate targeting of the deep brain structures. Existing indirect DBS targeting relies on registration of 2D histological atlases [1] since many deep brain structures are not clearly visible in traditional images. Gradient echo images obtained with ultra-high-field 7 Tesla MRI can reveal superior contrast of deep-brain structures, with a degree of detail rivaling histology [2]. Although pre-surgical imaging of patients at 7T for direct targeting has been demonstrated [3], cost and availability limit its feasibility, thus, registration of high-resolution 3D atlases depicting structural targets could provide cost-effective and improved indirect targeting in DBS planning.

The Colin27 single-subject atlas [4], generated from 27 averaged 1.5T scans, has been a cornerstone of neuroimaging research for the past two decades, acting as a high-definition template for segmentation, MRI simulation [5], and stereotaxic normalization [6]. The objective of this work is to extend this single-subject atlas with additional high-resolution, quantitative, averaged scans at both 3T and 7T, enriching new and existing applications of this single-subject atlas.

Methods:

The same individual used to develop the Colin27 atlas was scanned multiple times at 3T and 7T to create high-resolution atlases with a number of different weighted and quantitative contrasts. Fast T1 mapping (0.75 mm isotropic) with the DESPOT1-HIFI technique [7] was performed on a 3T Discovery MR750 scanner (GE Medical Systems), employing two 3D SPGR images (flip angles=4,18) and an IR-SPGR for B1 mapping (total scan time=20:00, N=4 sets of scans). High-resolution T1-w MPRAGE scans (0.5mm isotropic, scan time=5:00, N=11 scans) were acquired on a 7T MRI scanner (Agilent, Siemens) using a 32 channel transmit-receive head coil array. Multi-echo gradient echo (T2*-w) images were also acquired at 7T (axial, 0.4mm in-plane, 1mm slice thickness, scan time=11:00, N=4 scans) and were used to compute maps of R2*, and local frequency shift (LFS) maps derived from the unwrapped phase images.

Affine registration with a block-matching technique (reg_aladin, [8]) was used to correct for motion between scans and align the scans to the original Colin27 atlas, composing the transformation matrices and resampling with spline interpolation. To account for distortions seen in the 7T images, non-rigid B-spline-based registration (NiftyReg, [9]) was performed between the 7T MPRAGE and Colin27 image (spline spacing 10mm, bending energy 0.005). The 7T MPRAGE was also corrected for intensity non-uniformities using the N4 tool [10].

Results:

Our atlases demonstrate significantly improved visualization of cortical and subcortical structures over the original Colin27, with the added benefit of providing quantitative T1 maps at 3T and R2* maps at 7T. Figure 1 shows the comparison between our 7T MPRAGE and 3T T1 map with the original T1-w atlas.

For investigating it's applicability for targeting of deep brain structures, in Figure 2 we have shown axial slices comparing the various images with overlaid delineations of anatomical landmarks commonly used for DBS, namely the red nucleus (RN) and subthalamic nucleus (STN). We see that the R2* and LFS maps reveal the best contrast for these and other surrounding deep brain structures. To quantify the contrast of the STN with respect to neighbouring structures we computed two-sample T-statistics between the intensities of the STN and prelemniscal radiations in Table 1.

We have made the 3T and 7T datasets are available to the community for download at: http://www.imaging.robarts.ca/petergrp-data/

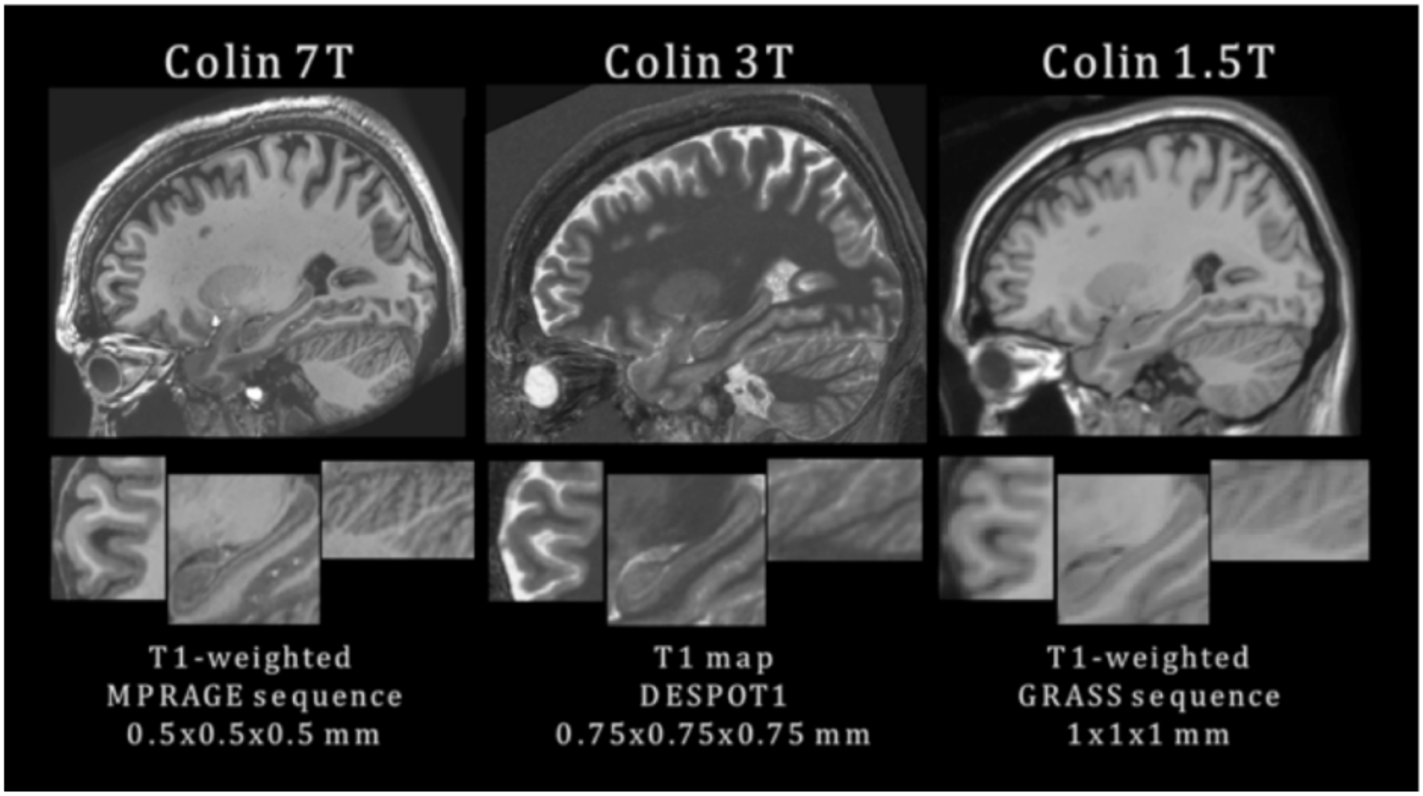

Figure 1: Comparison between: 1) Our T1-weighted average atlas, 2) our average T1 map (middle) and 3) the original T1-weighted atlas (right)

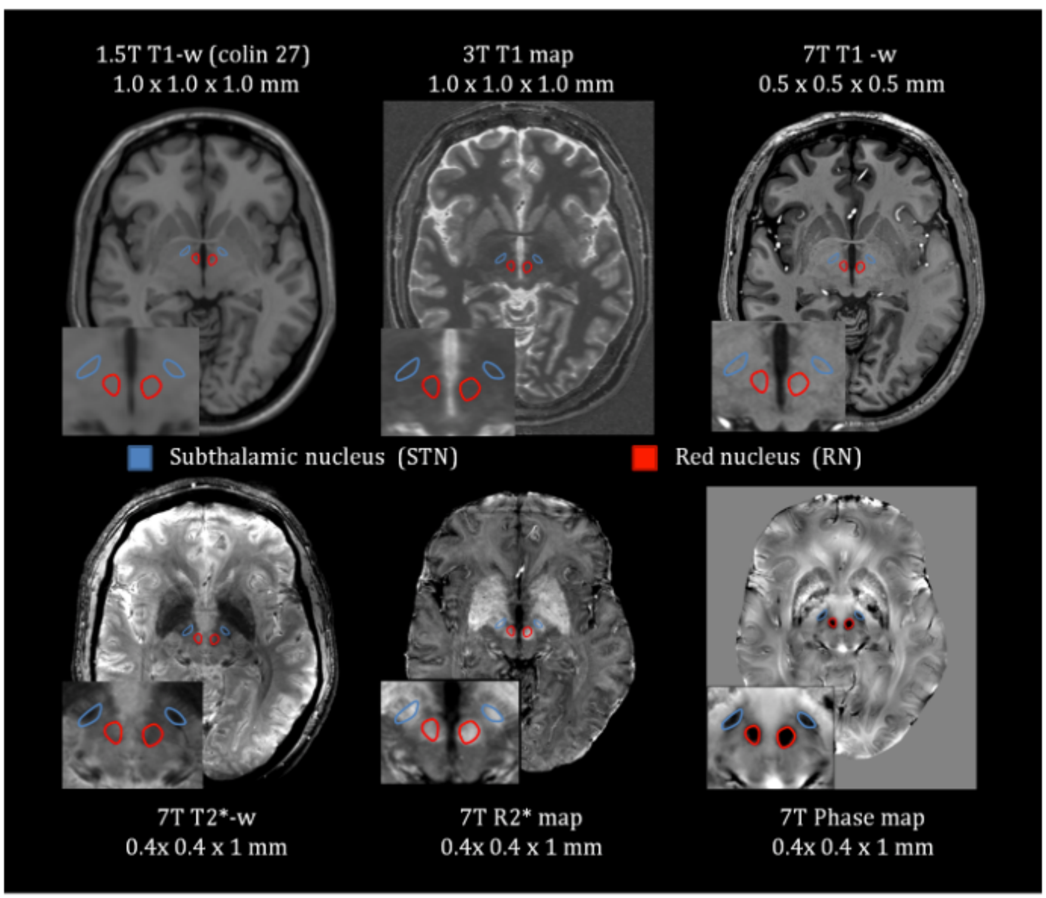

Figure 2: Comparison of contrast of deep brain structures in existing Colin27 atlas and our 3T and 7T extensions of the atlas.

	1.5T T_1-w	3T T_1 Map	7T T_1-w	7T R_2*	7T LFS
T-statistic	13.06	1.16	0.52	21.24	32.12
P-value	< 0.0001	0.59	0.24	< 0.0001	< 0.0001

Table 1: Evaluation of subthalamic nucleus (STN) contrast by two-sample *t*-test between STN and it's neighbouring structure (prelemniscal radiations), revealing best contrast in 7T R_2* and LFS (phase) maps.

Conclusions:

We have constructed a high-resolution and multi-contrast extension of the Colin27 brain that complements the original atlas and its annotations with a focus on deep brain targeting.

Informatics:

Atlases

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