

T1 and T2 template of the human brainstem and spinal cord

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Purpose. MRI of the spinal cord has important applications for the diagnosis and prognosis of several neurodegenerative and traumatic diseases. However, processing of MRI data is challenging due to the lack of standard tools and guidelines [1]. Notably, a standard reference space (template) is needed to avoid user bias to quantify multi-parametric data and to facilitate multi-center studies. Recently, the MNI-Poly-AMU template was introduced as the first unbiased template of the human cervical spinal cord [2]. This template was based on T₂-weighted data from 16 subjects and spanned C1 to T8 vertebral levels. In this study we further these developments and introduce a T₁-weighted and T₂-weighted template of the full spinal cord and brainstem, based on 36 adult subjects acquired at two sites. A probabilistic white and gray matter atlas [3] is also merged to the template.

Methods. Subjects and acquisition: 36 healthy subjects were scanned in Montreal (n=22) and Marseille (n=14) on a 3T system (TIM Trio and Verio, Siemens Healthcare) using the standard head, neck and spine coils. Each subject had a 3D T₁- and T₂-weighted scan covering the full spinal cord and brainstem. This large coverage was achieved by acquiring two FOVs per contrast, one including the head and cervical spine and the other including part of the cervical, thoracic and lumbar cord. The two volumes were then stitched together using the off-line console tools after correcting for image bias field (signal non-uniformity). Parameters for the T₁-weighted scan were: MPRAGE sequence, TR = 2260 ms, TE = 2.09 ms, TI = 1200 ms, flip angle = 7°, bandwidth = 651 Hz/voxel, voxel size = 1x1x1 mm³. Parameters for the T₂-weighted scan were: slab-selective fast spin echo, TR = 1500 ms, TE = 119 ms, flip angle = 140°, bandwidth = 723 Hz/voxel, voxel size = 1x1x1 mm³. Total acquisition time was 22 min. **Pre-processing** is illustrated in Figure 1 and included (i) stitching of images, (ii) cropping to include brainstem down to L2/L3 level, (iii) extraction of spinal cord centerline using PropSeg [4], (iv) straightening the volume image using thin plate spline interpolation, (v) b-spline-based alignment of the vertebrae using an average model of vertebral distance [5] based on the manual labeling of the following landmarks: pontomedullary junction (PMJ), C3, T1, T7 and L1, (vi) normalization of spinal cord intensity (set to 1000). **Template creation:** The ANTs framework [6] was used for creating an unbiased template. Parameters were: diffeomorphic transformation (greedy SyN), cross correlation metric, 100x50x50 iterations. Following template creation, both T₁ and T₂ templates were co-registered, and the white and gray matter probabilistic atlases were merged to the template as in [2].

Results. Figure 2 shows the two generated templates as well as an overaly of the vertebral labeling and white and gray matter atlases. Each template has 200x200x1100 voxels of 0.5x0.5x0.5 mm³ resolution and is oriented as Right-to-Left/Posterior-to-Anterior/Inferior-to-Superior (RPI).

Discussion. We created an unbiased T₁- and T₂-weighted template of the brainstem and spinal cord. These templates provide a common framework for registering multi-parametric data and hence facilitate the conduction of multi-center studies. The associated white and gray matter atlases can be used for extracting metrics within specific regions of interest. The templates and registration tools are part of the Spinal Cord Toolbox [7].



Figure 1. Main pre-processing step before template construction: stitching 2-FOV images, cropping at pontomedullary junction and L2-L3 interface, segmentation and extraction of centerline, straightening using thin plate spline and normalization of spinal cord intensity (value set to 1000).

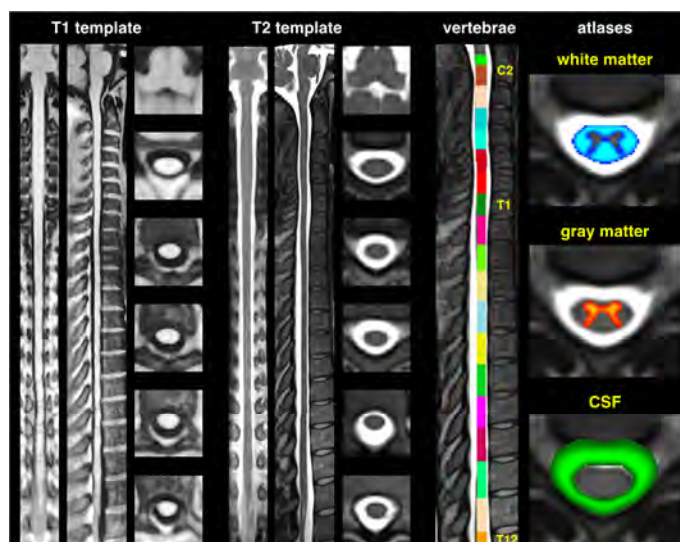


Figure 2. Generated T₁ and T₂ templates and overlay of vertebral labeling, white and gray matter probabilistic atlases and CSF mask. Resolution of the template is 0.5 mm isotropic. Size is 200x200x1100 voxels.

References. [1] Wheeler-Kingshott, *Neuroimage*, 2014. [2] Fonov, *Neuroimage*, 2014. [3] Taso, *MAGMA*, 2014. [4] De Leener, *Neuroimage*, 2014. [5] Ullmann, *Int J Biomed Imaging*, 2014. [6] Avants, *Neuroimage*, 2010. [7] Cohen-Adad, *Proc. OHBM*, 2014.

Acknowledgments. Study funded by NSERC, FRQS, QBIN, FRQNT, GRSTB and MEDITIS.