Automated Segmentation of Multiple Sclerosis Brain Lesions at 7T

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Target Audience: Radiologists, neurologists, imaging and MR scientists (especially ultra-high-field MR)

Purpose: To test at ultra-high-field (7T) the viability of an automated lesion segmentation algorithm (LesionTOADS) in the analysis and quantification of white matter lesions in multiple sclerosis.

Methods: This feasibility study was conducted under an Institutional Review Board-approved natural history study. Five participants with MS provided informed consent and underwent MRI study at 7T (Siemens Magnetom) equipped with 1TX/32RX head coil (Nova Medical). Two images were acquired as part of a standardized protocol: 3D T_1-weigthed magnetization-prepared rapid gradient-echo (MPRAGE) (FA = 7°, TR = 2200ms, TI = 1050ms, TE = 2.96ms, 0.7 mm isotropic resolution, AT = 6 min) and 3D T_2-weighted FLAIR (TR = 8000ms, TI = 2150ms, TE = 399ms, 0.8 mm isotropic resolution, AT = 6 min). These images were first transferred to the NIFTI file format (Neuroimaging Informatics Technology Initiative, National Institutes of Health, Maryland, USA) for use in an in-house image-processing pipeline utilizing JIST [1]. Images were first reoriented into the axial plane to ensure similar orientation, and N4 bias correction [2] was applied to reduce image bias (caused by B1 field inhomogeneity, etc.). The FLAIR image was co-registered to the MPRAGE image, and the MPRAGE image was then registered to an up-sampled version of the MNI-152 atlas [3] to allow for a shared image space between subjects. The coregistration resulted in a common image resolution of 0.7 mm isotropic. SPECTRE (Simple Paradigm for Extra-Cranial Tissue REmoval) [4] was then applied to remove the skull from the MPRAGE image, and the resulting mask was applied to the FLAIR image. After skull stripping, another round of N4 correction was used to reduce any remaining image bias. A second round of registration was then used between the brain-masked images (and the MNI-152 brain-only atlas) to improve the correspondence. Following image preprocessing, the LesionTOADS algorithm [5] was used to provide an initial estimation of the brain tissue segmentation (including lesions). The parameters for LesionTOADS (maximum distance for gray matter, ventricles, etc.) were adjusted from the defaults to account for the 0.7 mm resolution. The dura was then removed using tissue classifications, and a more defined "dura mask" was used to create dura-stripped images. The LesionTOADS algorithm was then applied to these dura-stripped images, allowing for a more exact implementation of the algorithm by eliminating any excess extra cerebral tissue. For quantitative analysis, the lesions voxels were clustered and labeled by connecting component voxels on both a manually segmented mask and the mask from our LesionTOADS analysis. These lesions were compared to determine false positive and false negative findings.

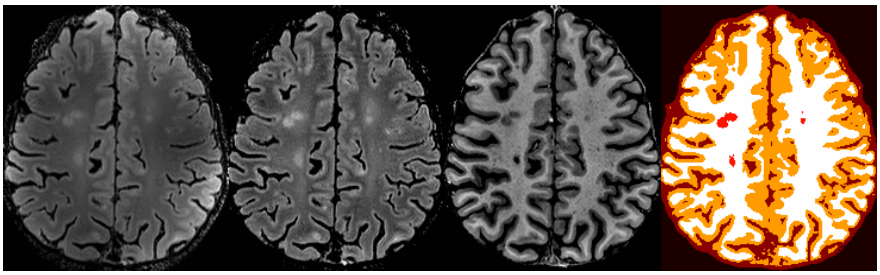

Figure 1: Typical "dura-stripped" 7T images of an MS patient. From left to right: FLAIR without N4-correction, N4-corrected FLAIR, N4-corrected, MPRAGE and final segmentation (white –white matter, orange – gray matter, light red – lesions, and dark red – cerebrospinal

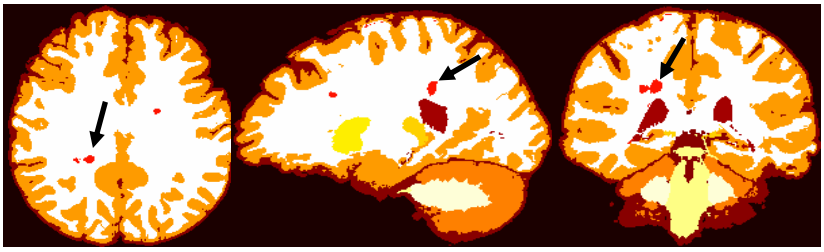

Figure 2: Segmentation displayed in three different orientations (from left to right: axial, sagittal, coronal) from another MS patient (lesions displayed in light red).

Results/Discussion: The output of the image-processing pipeline applied to a patient brain is shown in Figure 1. T1-weighted MPRAGE and T2-weighted FLAIR images show significantly reduced image bias after correction with the N4 algorithm. The segmented image shows proper gray-white matter distinction with well-defined cerebrospinal fluid spaces and white matter lesions. Note that this segmentation mask is calculated in native 0.7 mm isotropic resolution, corresponding to a three-time increase in volume resolution compared to standard 1 mm isotropic images. In Figure 2, the segmented image of another patient is presented in three different orientations. Parenchymal tissues are properly segmented throughout the brain, allowing for visualization of the lesions in each orientation (black arrows). The results of the quantitative analysis for the five patients are outlined in Table 1. An average of 10.9% false negative by volume was measured. These false negative lesions were mainly distributed in areas close to the cortex and ventricles. Note that the average size of the false negative lesions (measured at 24 mm^3) was substantially smaller than the average size of true positive lesions (measured at 113 mm^3). Regarding the false positive, an average of 24.2% by volume was measured. Note the non-negligible patient-to-patient variability in this case. Here, the areas of concern are portions of the brain where the N4 correction was not efficient. By excluding those areas (i.e. infratentorial brain with poor contrast and low signal), one can actually reduce the false positive percentage down to 15%. Therefore, although further improvements are under investigation, our automated pipeline can already perform acceptable lesion segmentation in MS patient brains.

Conclusions: High-resolution brain tissue segmentation (including lesion segmentation) can be performed on 7T MPRAGE and FLAIR images from MS patients using a fully-automated image-processing pipeline which includes N4 bias correction and an optimized version of the LesionTOADS algorithm.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	**Average**
False Negative (%Vol)	15.7%	5.4%	14.6%	4.3%	14.5%	**10.9%**
False Positive (% Vol)	40.7%	12.1%	5.8%	39.3%	23.2%	**24.2%**
Lesion Volume (mm^3)	680.9	1311.3	7679.1	751.1	2130.7	**2510.6**

Table 1: Segmentation evaluation results from five patients with MS

References: [1] Lucas BC et al., Neuroinformatics (2010); [2] Tustison NJ et al., IEEE Trans Med Imaging (2010); [3] Grabner G et al., MICCAI (2006); [4] Carass A et al., Neuroimage (2011); [5] Shiee N et al., Neuroimage (2010).