Automated Detection, Segmentation, and Longitudinal Tracking of Active MS Lesions Via Subtraction MRI

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Purpose

Lesion activity on brain MRI is a sensitive tool in monitoring biological processes in Multiple Sclerosis (MS). Studies have shown that subtraction imaging improves conspicuity and detection of new lesions in the context of treatment trials, and that new lesion activity on subtraction MRI is more predictive of disease progression and more sensitive in the assessment of disease activity and treatment efficacy than contrast enhancing lesions or change in total lesion load on T2-weighted scans. In order to study the spatiotemporal dynamics of MS lesions in large-scale longitudinal datasets, we developed an automated procedure called Subtraction-Enhanced segmentatioN and Tracking of Individual New and Evolving Lesions (SENTINEL) to detect, delineate, and track new and changing MS lesions.

Methods

A sample of 92 subjects (44M,48F) were randomly selected from an existing longitudinal dataset of individuals with MS who had T1-, T2-, proton density (PD)-, and T2-FLAIR-weighted scans from a 3 Tesla scanner during at least two time points. All image processing was performed using the Java Image Science Toolkit (JIST) with Medical Image Processing and Visualization (MIPAV, CIT, NIH, Bethesda, MD). For each individual, volumes were coregistered through a longitudinal registration scheme. For each time point, the T1- and T2-FLAIR-weighted scans were input into the LesionTOADS classification algorithm to generate brain tissue masks. Each scan was normalized relative to its normal appearing white matter (NAWM) intensity. Images were compared in chronological pairwise fashion by subtracting the most recent previous scan. Hyperintense lesions were distinguished from noise and artifacts based on intensity on the subtraction images, brain tissue classification, and object size. Lesion masks were combined across time points using a joining algorithm to maintain consistent lesion ID values, including in cases where newly appearing lesions overlapped previously existing lesions. The size of each lesion at each follow-up time point was delineated by thresholding the geometric mean intensity of each voxel on the normalized images within each lesion mask.

Results

Across all subjects, a total of 206 time points were analyzed with a median scan interval of 160 days. MS patients had a median age of 47 years and median disease duration of 5.17 years at baseline. 307 lesions were visually identified and manually segmented to validate the algorithm. The automated SENTINEL segmentations had a voxelwise sensitivity of 90.73% and specificity of 99.99% for detecting new and expanding lesions. Visual comparison of the longitudinal lesion masks showed consistent agreement between segmented lesions and the corresponding normalized images. ID values were preserved, allowing longitudinal analysis of image-derived measures within individual lesions.

Conclusion

We propose a robust automated method for segmenting and tracking MS lesions. This enables the study of spatiotemporal dynamics in individual lesions at a level of detail and on a scale that was previously unfeasible with previous techniques.

Fig. 1 Subtraction-enhanced segmentation and tracking of individual new and evolving lesions. Top row: Normalized and coregistered consecutive T2-FLAIR images. Second row: Pairwise mean subtraction images. Third row: SENTINEL new lesion binary segmentations. Bottom row: SENTINEL lesion tracking masks for each time point. Blue arrows indicate expansion of an existing lesion. Green arrows indicate new lesion. Red arrows indicate shrinking lesion.