Diffusion-Based Filling and Synthesis of Multiple Sclerosis Lesions

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Introduction

White matter (WM) lesions, common in neurological conditions like multiple sclerosis (MS), can significantly distort cortical thickness measurements derived from magnetic resonance imaging (MRI). Traditional methods often rely on lesion filling techniques to mitigate this issue. This thesis explores the potential of deep learning to improve the accuracy and efficiency of cortical thickness measurement in the presence of WM lesions. Additionally, it compares the robustness of various computational methods for cortical thickness measurement in the presence of WM lesions. A major challenge in deep learning projects for medical images is the scarcity of large datasets. To address this limitation, this thesis investigates the generation of synthetic data.

Materials and Methods

We explored different techniques and architectures for filling and synthesizing MS lesions in MRI images using noise diffusion models. We compared 2D and pseudo-3D architectures, as well as conditional and unconditional approaches. Additionally, we investigated the use of a synthetic mask distribution for training. To evaluate the robustness of various processing tools, we calculated the average absolute changes relative to the mean (%) when comparing with and without lesion filling. To assess the quality of the generated synthetic lesions, two trained neurosurgeons were asked to identify the synthetically added lesions among other lesions in 20 patients.

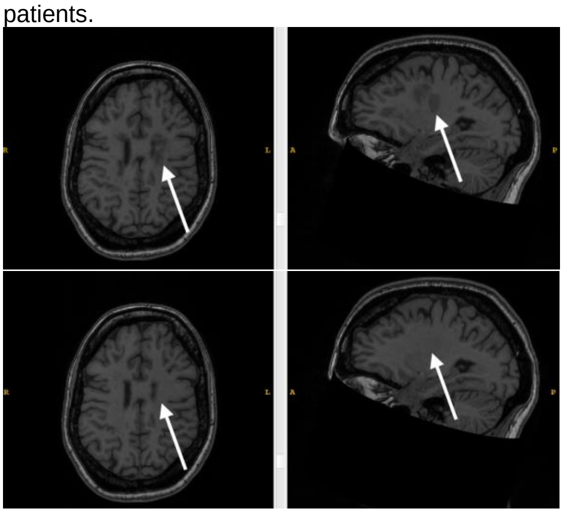

Fig. 1 T1w before (top) and after (bottom) lesion filling.

Results

The most effective model for lesion filling was a diffusion model using a pseudo-3D U-Net architecture conditioned on binary masks. This model was trained with a combination of real lesion masks and synthetic random circle masks. The best model for lesion synthesis was also a conditional model with the same pseudo-3D U-Net architecture. In the neurosurgeon evaluation, only three synthetic lesions were correctly identified out of 20. When comparing the robustness of different computational methods for cortical thickness, newer deep learning-based approaches exhibited superior performance.

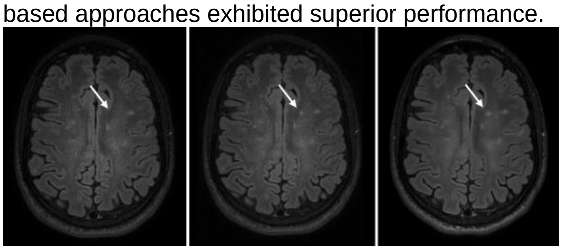

Fig. 2 Comparison of a patient's brain scans: (1) before adding a synthetic lesion to healthy tissue, (2) after adding the synthetic lesion, and (3) at a later timepoint with a natural new lesion at the same location.

Discussion

The trained models exhibited high-quality performance in lesion filling and lesion synthesis. A qualitative evaluation by two neuroradiologists confirmed the authenticity of the synthetic lesions. The superior performance of newer deep learning-based models for cortical thickness measurements suggests that lesion filling techniques may become less essential as these tools evolve.

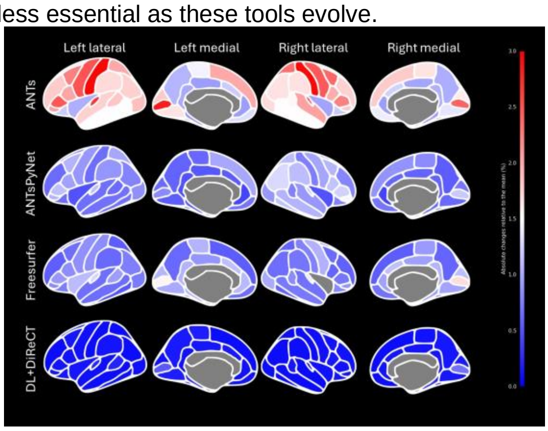

Fig. 3 Reproducibility errors of the ROI-wise average cortical thicknesses between different processing tools.