Benchmarking and Explaining Deep Learning Cortical Lesion MRI Segmentation in Multiple Sclerosis

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Abstract

Cortical lesions (CLs) have emerged as valuable biomarkers in multiple sclerosis (MS), offering high diagnostic specificity and prognostic relevance. However, their routine clinical integration remains limited due to subtle magnetic resonance imaging (MRI) appearance, challenges in expert annotation, and a lack of standardized automated methods. We propose a comprehensive multi-centric benchmark of CL detection and segmentation in MRI. A total of 656 MRI scans, including clinical trial and research data from four institutions, were acquired at 3T and 7T using MP2RAGE and MPRAGE sequences with expert-consensus annotations. We rely on the self-configuring nnU-Net framework, designed for medical imaging segmentation, and propose adaptations tailored to the improved CL detection. We evaluated model generalization through out-of-distribution testing, demonstrating strong lesion detection capabilities with an F1-score of 0.64 and 0.5 in and out of the domain, respectively. We also analyze internal model features and model errors for a better understanding of AI decision-making. Our study examines how data variability, lesion ambiguity, and protocol differences impact model performance, offering future recommendations to address these barriers to clinical adoption. To reinforce the reproducibility, the implementation and models will be publicly accessible and ready to use at GitHub at Zenodo.

Keywords:
Multiple sclerosis, Cortical lesions, Segmentation, Detection, Magnetic Resonance Imaging, Brain, Deep learning, Trustworthy AI

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1. Introduction

Multiple sclerosis (MS) is a chronic inflammatory and neurodegenerative disease of the central nervous system, affecting over 2 million people worldwide [1, 2]. Magnetic resonance imaging (MRI) is central to the diagnosis and monitoring of MS, enabling the detection of characteristic brain lesions [3, 4, 5, 6]. White matter lesions (WMLs) have served as the primary radiological hallmark, guiding diagnosis and treatment decisions [3]. In recent years, additional imaging biomarkers—such as cortical lesions (CLs)[7, 8], paramagnetic rim lesions [9, 10], and the central vein sign [11, 8] — have gained recognition for their ability to support the diagnosis or to capture disease activity more comprehensively. CLs are of clinical interest due to their association with cognitive impairment, progressive disability, and early-stage