Multi-stage segmentation of white matter hyperintensity, cortical and lacunar infarcts

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Abstract

Cerebral abnormalities such as white matter hyperintensity (WMH), cortical infarct (CI), and lacunar infarct (LI) are of clinical importance and frequently present in patients with stroke and dementia. Up to date, there are limited algorithms available to automatically delineate these cerebral abnormalities partially due to their complex appearance in MR images. In this paper, we describe an automated multi-stage segmentation approach for labeling the WMH, CI, and LI using multi-modal MR images. We first automatically segment brain tissues (white matter, gray matter, and CSF) based on the T1-weighted image and then identify hyperintense voxels based on the fluid attenuated inversion recovery (FLAIR) image. We finally label the WMH, CI, and LI based on the T1-weighted, T2-weighted, and FLAIR images. The segmentation accuracy is evaluated using a community-based sample of 272 old adults. Our results show that the automated segmentation of the WMH, CI, and LI is comparable with manual labeling in terms of spatial location, volume, and the number of lacunes. Additionally, the WMH volume is highly correlated with the visual grading score based on the Age-Related White Matter Changes (ARWMC) protocol. The evaluations against the manual labeling and ARWMC visual grading suggest that our algorithm provides reasonable segmentation accuracy for the WMH, CI, and LI.

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Introduction

Magnetic resonance imaging (MRI) has been widely used to detect a variety of cerebral abnormalities, such as white matter hyperintensity (WMH), cortical infarct (CI), and lacunar infarct (LI), that are of clinical importance. The WMH is thought to reflect small vessel cerebrovascular disease (Pantoni, 2002; Young et al., 2008), and may contribute to age-associated cognitive decline (Carmichael et al., 2010; He et al., 2010; Jokinen et al., 2009; Marquine et al., 2010; Ota et al., 2009; Vannorsdall et al., 2009), and increase the risk of dementia (Debette and Markus, 2010). CIs, as the name suggests, are infarcts in the cortical regions caused by cerebral artery occlusion most commonly by emboli, whereas LIs are subcortical infarcts due to the blockages of small penetrating arteries in the deep brain region with sizes up to approximately 15 mm (Ropper, 2005; Xavier et al., 2003). Previous studies suggest that both types of cerebral infarcts are associated with cognitive decline and increase the likelihood of dementia and stroke (Bennett et al., 2005; Carey et al., 2008; Jokinen et al., 2011; Jokinen et al., 2009; Schneider et al., 2004; Tripathi et al., 2011). Hence, it is of clinical importance to identify these cerebral abnormalities for potential early prevention, diagnosis, and treatment in cerebrovascular and neurodegenerative diseases.

Due to the complex mechanisms underlying cerebrovascular diseases, the appearance of the WMH, CI, and LI is heterogeneous in terms of their location, size, and image intensity on MRI. Up to now, visual inspection is still a common approach used to quantify the severity of these cerebral abnormalities. However, it is laborious and time consuming and therefore impractical in large-scale imaging studies. In addition, visual inspection is biased to raters and hence, highly dependent on inter and intra rater reliabilities (Kapeller et al., 2003; Prins et al., 2004; Vannorsdall et al., 2009), which in turn decrease the sensitivity in subsequent statistical analyses (Garrett et al., 2004; Van Straaten et al., 2006).

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