Automated White Matter Lesion Segmentation in Cranial MR Imaging

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Introduction

In the last decade many studies have focused on the prevalence of cerebral white matter lesions (WMLs) in the elderly population or in patients with cardiovascular risk factors. In both patient groups WMLs are a common finding on cranial MR imaging. Since WML patterns are very heterogeneous, ranging from punctuate lesions in the deep white matter till large confluent periventricular lesions, the scoring of WMLs is complicated and it has been shown that different visual rating scales lead to inconsistencies between WML studies [1]. In this respect it would be highly advantageous to use an automated segmentation method that detects WMLs with a high sensitivity and specificity that are demonstrated in a quantitative and objective way. Such methods have been developed for the detection of multiple sclerosis lesions, but not for the more complicated issue of WMLs in general. In this study a new method is presented for fully automated segmentation of WMLs on cranial MR imaging, based on a supervised KNN-classification technique using multi-spectral information.

Methods

The algorithm uses five types of regular MRI-scans: T1-weighted (TI-w), T1-weighted inversion recovery (IR), proton density-weighted (PD), T2-weighted (T2-w) and Fluid Attenuation Inversion Recovery (FLAIR) scans. Twenty patients with arterial vascular disease were included in this study. Manual segmentations of the WMLs were used for the learning of the system and considered as gold standard. Based on the manual segmentations the patients were divided into four categories: (1) all patients, (2) patients with small lesion load, (3) Patients with moderate lesion load and (4) patients with high lesion load. Three preprocessing steps were performed on the data: (1) Correction for MR inhomogeneities [2], (2) Rigid registration (intra patient) and (3) Brain segmentation (Mbrase) [3]. Voxels were classified by a KNN-classification method (K=100), which generates the lesion probability per voxel, with two types of features: (1) Voxel intensity values of the five different scans, (2) Spatial features: coordinates x, y or ρ, φ (polar coordinates) and z. Binary segmentations were generated by applying thresholds to the probability maps produced by the KNN-classification. Evaluation was performed by comparison of the segmentations with the manual segmentations. The similarity index (SI) over the binary segmentations was calculated, as well as the probabilistic similarity index (PSI) over the probability map. The SI and the PSI are defined by (Fig. 1): $SI = \frac{2\times(Ref \cap Seg)}{Ref + Seg}$, $PSI = \frac{2\times\sum P_{x,\,gs\,=\,1}}{\sum 1_{x,\,gs\,=\,1} + \sum P_x}$,

with: $\sum P_{x,\,gs\,=\,1}$: Sum over all voxel probabilities, where in the gold standard (= manual segmentation) the voxel value = 1; $\sum 1_{x,\,gs\,=\,1}$: Sum over all voxels in the gold standard; $\sum P_x$: Sum over all probabilities in the probability map.

Results

Figure 2 shows an example image of the classification result with the feature set including voxel intensities and spatial features x, y and z. Figure 3 shows the SIs for the segmentations, with thresholds running from 0 to 1, with the five feature sets: (1) F: only voxel intensities, (2) Fρφ: voxel intensities with ρ and φ, (3) Fρφz: voxel intensities with ρ, φ an z, (4) Fxy: voxel intensities with x and y, (5) Fxyz: voxel intensities with x, y and z. Table 1 shows the SI of the segmentation with threshold 0.3 and the PSI.

Discussion and conclusions

The combination of spatial information and intensity values of MR images in KNN-classification provides a strong technique for WML-segmentation with a high accuracy. The method produces a probability map, which contains more valuable information about the state of the lesions and the total lesion volume than a binary segmentation. At a proper threshold on the probability map the overall sensitivity of the binary segmentations of all patients is 0.9704, with a specificity of 0.9740.

The SI is a suitable measure to evaluate the segmentations in a quantitative and objective way. From the SI can be concluded that the method has better performance for large lesions then for small lesions. Furthermore, the SI shows that adding features containing spatial information improves the result substantially. The SI is also useful for determination of an optimal threshold. The PSI is a useful measure to evaluate the probability map directly without application of a threshold. Since the method has a general basis it is applicable to many other segmentation problems, for instance segmentation of atrophy, white matter, gray matter or CSF.

Table 1. Similarity index with threshold 0.3 (probabilistic similarity index)

Feature set	All patients	Few lesion	Moderate lesion	Large lesion
F	0.73 (0.62)	0.33 (0.25)	0.70 (0.57)	0.80 (0.70)
Fρφ	0.77 (0.65)	0.39 (0.28)	0.73 (0.60)	0.83 (0.72)
Fρφz	0.80 (0.69)	0.49 (0.35)	0.75 (0.63)	0.85 (0.75)
Fxy	0.77 (0.65)	0.40 (0.29)	0.73 (0.60)	0.83 (0.73)
Fxyz	0.80 (0.69)	0.50 (0.36)	0.75 (0.64)	0.85 (0.76)

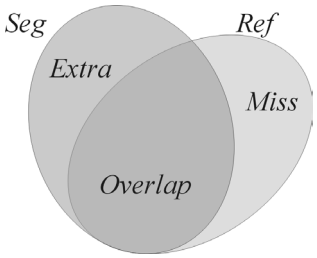

Figure 1: Comparison of a binary segmentation (*Seg*) with the reference image (*Ref*), with (*Overlap)* the correctly classified voxels, (*Extra*) the false positives and (*Miss*) the false negatives.

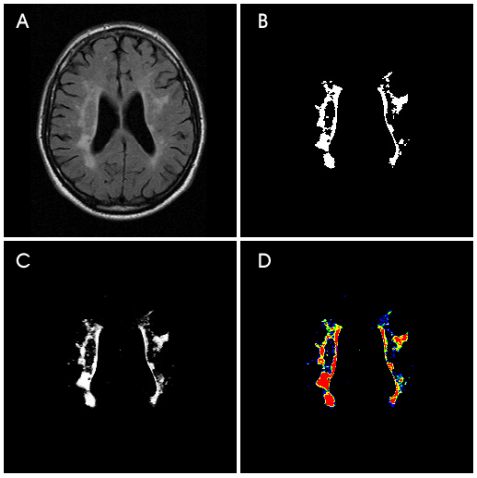

Figure 2: Classification with probabilistic similarity index:0.76.(A)FLAIR image,(B) manual segmentation, (C) probability map, (D) segmentations derived from probability map with different thresholds: black: probability (p) = 0, blue: 0 < p <= 0.3, green: 0.3 < p <= 0.5, yellow: 0.5 < p <= 0.8, red: 0.8 < p <= 1.

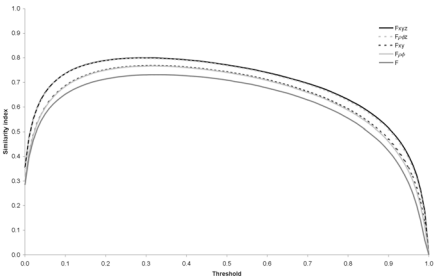

Figure 3: Similarity index of binary WML segmentations of all patients as function of the threshold with different feature sets: (Fxyz) voxel intensity features and spatial features x, y and z, (Fρφz) voxel intensities and ρ, φ and z, (Fxy) voxel intensities and x and y, (Fρφ) voxel intensities and ρ and φ, (F) only voxel intensities.

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