An automated assessment of White Matter Lesions based on regional FLAIR intensity evaluation

J. F. Jansen[1], P. A. Hofman[1], and W. H. Backes[1]

[1]Department of Radiology, Maastricht University Hospital, Maastricht, Netherlands

Introduction

White matter lesions (WML) are areas of bright, high signal intensity in the white matter depicted on T2-weighted MRI. A high-resolution MRI examination was performed at 3.0 T, comprising T1-weighted, T2 relaxometry and FLAIR sequences, on a population with relatively mild WML, namely patients with localization-related, cryptogenic epilepsy and healthy volunteers. The WML were examined in two ways: i) visually, by an experienced neuroradiologist and ii) with a automated WML detection technique using regional intensity evaluation. A fully automated quantitative WML detection technique can be beneficial, as it may provide a more objective assessment than visual rating [1]. We have chosen to analyze FLAIR intensities on a regional level. This is in agreement with clinical practice, where a neuroradiologist examines brain images by looking for local signal intensity alterations. Furthermore, our method differentiates between subcortical WML (sWML) and periventricular WML. The aim of this investigation was to assess the performance of the automated WML detection algorithm.

Material and Methods

Patients The study population included 32 patients with localization-related, cryptogenic epilepsy (18F, 14 M, age 43±12) with or without secondarily generalized seizures, and 16 healthy volunteers (10F, 6 M, age 40±13) ***MRI*** Imaging was performed with a 3.0-Tesla whole-body unit (Philips Achieva [software release 1.5.4.0], Philips Medical Systems, Best, The Netherlands). For anatomic reference, first T1-weigthed three-dimensional (3D) turbo field echo (TFE) images were acquired with the following parameters: repetition time (TR) 9.91 ms, echo time (TE) 4.6 ms, inversion time (TI) 3 s, flip angle 8°, matrix 256x256x160, field of view (FOV) 256x256x160 mm^3, 1 mm adjacent coronal slices. For T2 quantification 3D dual-echo turbo spin echo (TSE-Dual) imaging was performed, using the following parameters: TR 2500 ms, TE1 10 ms, TE2 110 ms, matrix 256x256x100, FOV 256x256x200 mm^3, 2.0 mm adjacent coronal slices, acceleration (i.e. SENSE reduction) factor 1.5 in the left-right direction, k-space segmentation 6 shots per image. T2-weigthed turbo spin echo FLAIR images were acquired with the following parameters: TR 11 s, TE 125 ms, inversion delay 2.8 s, matrix 512x512x90, FOV 256x256x180 mm^3, 2 mm adjacent coronal slices. ***Visual Analysis*** Images were analyzed by an experienced neuroradiologist to obtain estimates of the total volume of subcortical WML (sWML) and the extent of periventricular WML (pWML). WML were scored according to the criteria by Achten et al. [2]. For this purpose, FLAIR image stacks were analyzed using custom software, which allowed systematic inspection and manual demarcation of regions of interest (ROIs). Lesions were identified on the FLAIR image, and a mask that matched the ROI best was fitted over the lesion. After inspection and delineation of all sWML the program yielded a total sWML volume for each patient. Periventricular WML severity, ranging between 0 and 3, was scored for frontal and occipital regions ("caps") and the medial periventricular lining ("bands") separately, which were then summed to an overall periventricular WML score. ***Automated Analyis*** Image preprocessing included: (1) A percentile volume CSF map was created by attributing to each pixel a CSF percentage (λ_{CSF}) on a scale of 0-100%, based on their T2 relaxation times calculated from the dual-echo images. Tissue was segmented from CSF by incorporating the cut-off $\lambda_{CSF} \leq 5\%$. (2) Brain tissue was segmented from non-brain tissue using BET skull stripping (3) The FLAIR, λ_{CSF}, and T2 map were spatially transformed into common coordinates (dimension 181×217×181, 1×1×1 mm^3) along with the spatial normalization procedure of the TE=110 ms image into the standard MNI space. Also, the T1-weigthed image was spatially normalized. (4) The normalized T1-weigthed images were segmented to yield a gray matter (GM), a white matter (WM) and a CSF map. (5) Based on the whole cerebrum maps created with WFU-Pickatlas, and the skull-stripped normalized T2 weighted image, for each patient a specific whole cerebrum map was created. (6) Using the obtained λCSF map, and the ventricle masks from the WFU-Pickatlas, individual ventricle maps could be created. Automated WML volumetric estimation included: (1) For each pixel within the person-specific whole cerebrum mask for the FLAIR image, a Z-score was derived based on the mean and standard deviation of the intensities of all pixels within a sphere with diameter 2 cm around the pixel. (2) All pixels, with a Z-score higher than 2 were selected. Subsequently, only clusters of with a clustersize of more than 26 pixels were selected. Furthermore, clusters were excluded if the percentage of GM was higher than 50%. Then, pixels were either classified sWML or pWML, based the distance of each cluster to the ventricles which had to be more or less than 0.7 cm, respectively. For sWML clusters, the maximum Z-score had to exceed 4. Finally, the total number of both sWML and pWML voxels was counted to obtain volumes in mm^3. The level of agreement between the two different WML assessment methods was evaluated. using the intraclass correlation coefficient and the Spearman's rank correlation coefficient.

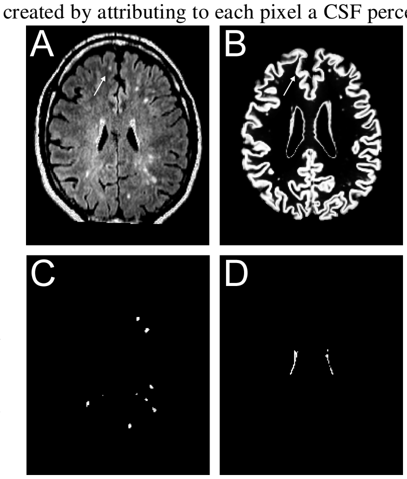

Figure 1 Example of automated white matter lesion detection in a 50 year old male patient with epilepsy. A) normalized FLAIR image. B) gray matter map, obtained from segmentation of the T1-weighted image. C) subcortical white matter lesions D) periventricular white matter lesions.

Results

The WML volumes from the automated segmentation method were found to be significantly correlated to the visual assessment (fig 2). Spearman's ρ for the sWML was 0.7 ($p < 0.001$). The intraclass correlation coefficient for the sWML was 0.92 ($p < 0.001$). The correlation between the overall visually obtained periventricular WML score and the automated pWML volume detection, as assessed using the Spearman's ρ, was 0.65 ($p < 0.001$).

Discussion

The relatively high correlation (ICC = 0.92) between the WML quantifications from the automated method and the neuroradiological grades demonstrated that this automated method can successfully segment and quantify the WML on FLAIR images. ICC values reported in the literature of the agreement of automated and visual assessed WML are: 0.98 (in 100 elderly patients, > 65 y) [3], 0.82-0.96 (in 6 MS patients, mean 40.5 y) [4]. However, the examined study population is only known to have relative mild WML. Populations consisting of asymptomatic elderly individuals, or patients with multiple sclerosis, can have much severe forms of WML [5], which is beneficial for the detection qualities of the proposed technique. It remains difficult to evaluate the merits of any WML detection method, without a gold standard as histopathology.

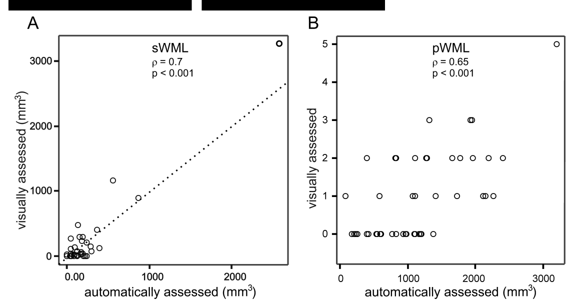

Figure 2 Comparison of visually assessed and fully-automatically obtained white matter lesion values. A) comparison for subcortical white matter lesion (sWML) volumes, and B) comparison for periventricular white matter lesion (pWML) scores. The dotted line in A is the identity line. ρ = Spearman's rank correlation coefficient.

Conclusion

The automated WML detection algorithm using a regional Z-score analysis can successfully segment and quantify the WML on FLAIR images, which was validated by a high correlation between the WML quantifications from the automated method and the visual grades.

References

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