Automatic Segmentation of White Matter Hyperintensities Based on Reaction Diffusion with Adaptive Threshold

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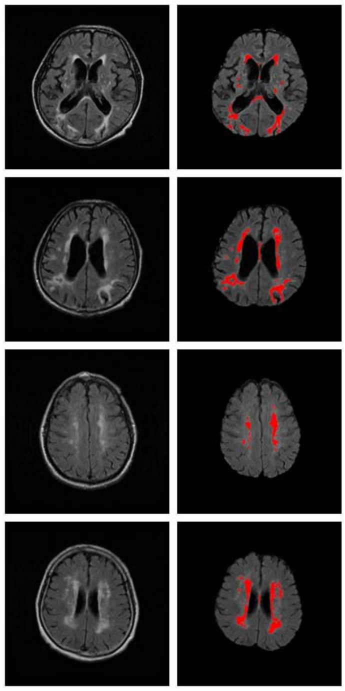
Introduction: White matter hyperintensities (WMH), commonly found on T2 weighed fast fluid-attenuated inversion-recovery (T2FLAIR) brain MR images in the elderly, were suggested to be associated with many central nervous system disorders, such as stroke, cognitive decline, dementia [1], and might be also seen in patients with Alzheimer's disease [2]. Quantitative analysis of WMH is critical for identifying risk factors and understanding pathogenesis. In this retrospective study, a novel MR image processing strategy based on the modified diffusion reaction model with adaptive threshold was proposed to automatically segment WMH MR images. The T2FLAIAR images of ten subjects aging from 52 to 75 years old were used for evaluating the validation of the proposed segmentation strategy.

Materials and Methods: T2flair images were acquired on a clinical MR system operating at 1.5 T field strength (General Electric, Milwaukee, WI) and have the following characteristics. T2FLAIR: TE =133 msec, TR = 9002 msec, slice thickness = 6 mm, matrix = 256×256, field of view (FOV) =24×24 cm^2. The image post processing was implemented in Matlab (MathWorks Inc.). For WMH segmentation, it mainly involved three steps. Firstly, the brain extraction tool (BET, Smith 2002) was used to remove skull in T2FALR images. Subsequently, an edge-preserving anisotropic diffusion filter [3] (fifteen iterations, time step = 1/5, conduction coefficient =30) was applied on the skull stripped T2flair images for noise reduction and smooth. Finally, a proposed approach based on the modified FitzHugh-Nagumo (FHN) reaction diffusion model with an adjustable parameter was introduced for WMH segmentation.

$$\begin{cases} \frac{\partial u}{\partial t} = D_u \Delta u + \frac{1}{\varepsilon}\left(u(u-a)(1-u) - v\right) \\ \frac{\partial v}{\partial t} = D_v \Delta u + u - bv \end{cases} \quad (1) \qquad \begin{cases} u(x,y,0) = I_0(x,y) \\ v(x,y,0) = 0 \end{cases} \quad (2) \qquad \begin{cases} \partial u / \partial n = 0 \\ \partial v / \partial n = 0 \end{cases} \quad (3)$$

In fact, the FHN model has been successfully used to describe the propagation of active electrical pulse along a nerve axon [4, 5], its form is taken by equations 1, where u and v are concentrations, D_u is diffusion coefficient of variable u and D_v is the diffusion coefficient of variable v, ε is small positive constant, a (0<a<1) and b (b>0) are constants. Ebihara et al [6] have proved that this model has two states: mono-stable state and bi-stable state, which depends on the values of a and b, and the bi-stable state can be used to represent background and foreground of a given image. For image segmentation, the initial conditions and Neumann boundary conditions for the two variables are given by equations 2 and 3 respectively, where $I_0(i,j)$ is the normalized skull stripped and filtered T2 grayscale image and the preset parameter a, reflects to the threshold value.

In this study, the parameter a in traditional FHN model is replaced with a parameter matrix a, which is adaptively changed according to the local intensity distribution of T2FLAIR images. We set $a(i,j)=k\times H(i,j)$, i=1...r; j=1...c, and r and c are the row and column of the image respectively. If $a(i,j) < s\times \text{std}(I_0)$, let $a(i,j) = s\times \text{std}(I_0)$. *Where* $H(i,j)$ is the average of $I_0(i,j)$ in its 3×3 neighborhood; $\text{std}(I_0)$ is the standard deviation of $I_0(x,y)$; k and s are constants. Subsequently, conventional finite difference scheme was used to solve the modified FHN model. After evolution, the converged matrix u finally became the expected segmentation result.



(a) (b)

Fig.1. Demonstration of WMH segmentation base on the modified FHN diffusion reaction model: (a) original typical WMH T2FLAIR images from different subjects.
(b) corresponding segmented results in red.

Results: WMH segmentation results by using the modified FHN model with adaptive threshold were demonstrated in Fig.1. Fig. 1(a) indicated four T2FAIR images chosen randomly from different subjects and different slices, Fig. 1(b) were the corresponding WMH segmentation results. Parameter values utilized in the finite difference scheme were: time step = 0.0001, space step = 0.6, Du=0.1, Dv=10, b=20, c=0.0001, k=0.95, s=6.5. Evaluated by three clinical doctors with more than 20 years experience, all the WMH segmentation results had a good agreement comparing with the size and location of the T2FLAIR images.

Conclusion: In this retrospective study, a modified FHN reaction diffusion model was introduced to locate the lesion of WHM. Comparing with traditional FHN model, it provided local intensity depended segmentation threshold adaptively, and the segmented results suggested the proposed approach could offer more convenient tool for WMH quantitative analysis.

Reference:[1] Ste´phanie Debette, et al. BMJ 2010;341:3666. [2] Hirono, N et al. Stroke 2000;31: 2182–2188. [3] Perona P, et al. IEEE Trans Pattern Anal Mach Intell 1990;12: 629–639. [4] R. FitzHugh, Biophys. J., 1961;1:445-466. [5] J. Nagumo, et al. Proc. I. R. E., 1962 ;50 :2061-2070. [6] M. Ebihara, et al. Proceedings of the 3rd IASTED International Conference on Visualization, Imaging, and Image Processing, 2003; 448-453.