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Automated temperature calculation method for DWI-thermometry: the usefulness of LV probability map on healthy subjects *

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Abstract— **Diffusion-weight imaging (DWI) has already been incorporated as a regular sequence for patients. If DWI could indicate brain temperature without a complicated procedure, such information may greatly contribute to initial diagnosis. The temperature (T: °C) was calculated using the following equation form the diffusion coefficient (D): T= 2256.74/ln (4.39221/D) - 273.15. The cerebrospinal fluid region for automated temperature computation was segmented by lateral ventricle probability map which was constructed from 46 healthy volunteers. No significant differences were seen between temperatures using the proposed method and the manually segmented. The proposed method of fully automated deep brain temperature computation from DWI may prove feasible for application in MRI consoles.**

I. Introduction

Internal brain diseases are general comparably difficult to diagnose. Medical imaging modalities such as magnetic resonance imaging (MRI) mainly provide data on shape and spatial information. Although recent studies have revealed relationships between the functional information derived from MRI and pathological conditions, this information requires detailed studies based on each disease.

On the other hand, temperature is one of the most classical signs, and has been utilized for monitoring vital condition based on normal body temperature. Nevertheless, no direct, non-invasive methods of measuring temperature have been identified.

DWI-based methods have already been proposed and have shown the ability to measure temperature through clinical MRI scanners. This method has already been applied for measuring deep brain temperature in healthy volunteers [1], for determining the relationship between tympanic temperature and deep brain temperature [2], the age-dependence of deep brain temperature in healthy volunteers [3], and applications for Moya moya disease [4] ,head trauma [5], and idiopathic normal pressure hydrocephalus [6].

For DWI-thermometry, cerebrospinal fluid (CSF) in the lateral ventricle (LV), which shows relatively stable diffusion, needs to be extracted. Previous DWI-thermometry methods used manual extraction. DWI itself has already been routinely included in clinical acquisitions. Achieving automated DWI-thermometry through MRI would ideally achieve extraction of CSF in the LV on the MR console.

Given this background, the present study aimed to develop a method for fully automated determination of deep brain temperature by automatic extraction of the relevant CSF region from temperature maps for DWI thermometry. Some ventricle system extraction algorithms from MRI using empirical parameters [7] and spatial registration method [8] have been proposed. Although those algorithms successfully extracted the body of the LV, those requires complicated computation and special parameters. We therefore also aimed to create automatic extraction of the body of the LV, and calculate mean temperature in the LV.

II. Methods

A. Subjects

This study was approved by the institutional review board (the Ethics Committee of Kyoto Prefectural University of Medicine) and informed consent was obtained from all subjects. A total of 46 healthy volunteers (14 men, 32 women; mean (± standard deviation) age, 49 ± 19.1 years; range 22-85 years) underwent imaging.

B. Data acquisition

All images were obtained using a 1.5-T whole-body scanner (Gyroscan Intera; Philips Medical Systems, Best, Netherlands). Single-shot echo-planar imaging (EPI) was used for DTI (repetition time, 6000 ms; echo time, 71 ms) with a motion-probing gradient in 15 orientations, b-values of 1000 s/mm^2, and averaging of two images. The field of view was 230 mm. A parallel imaging technique (SENSE) was used to record 128 × 53 data points, which could be reconstructed to images equivalent to a 128 × 106 matrix. Data were zero-filled to generate images with a resolution of 128 × 128. A total of 20 slices with a thickness of 3 mm each were obtained without interslice gaps. All trans-axial slices were obtained using a plane parallel to the line which passes through the anterior and posterior commissures of the brain (AC-PC line).

C. Conversion of Diffusion coefficient to Temperature

The diffusion coefficient along the direction of motion probe gradient *i* was calculated by equation (1) and converted to a temperature [1];

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$$D_i = \frac{\ln(S_0 / S_i)}{b} \quad (1),$$

where D_i is the diffusion coefficient [mm^2/s] along a direction i, b is the applied diffusion weighting [s/mm^2], and S_0 and S_i are the voxel signal intensities of the reference and diffusion-weighted images along diffusion direction i, respectively. The D_i value was converted to the corresponding temperature using equation (2).

$$T_i = \frac{2256.74}{\ln\left(\frac{4.39221}{D_i}\right)} - 273.15 \quad (2),$$

where T_i is in unite of degree Celsius [°C]. Temperature within the LV was determined according to the following procedure described in subsection D.

D. Automated effective CSF area segmentation

The effective CSF area within the LV for temperature calculation was determined following procedure.

Step1: Construction of a CSF existing ratio map

a) Convert diffusion coefficient to temperature by equation (2).
b) Pixels > 20°C were selected as CSF area and set boundary box as effective region.
c) Resize the boundary box to 181 x 217 x 181 voxels.
d) Average the personal resized CSF areas as CSF existing ratio map.

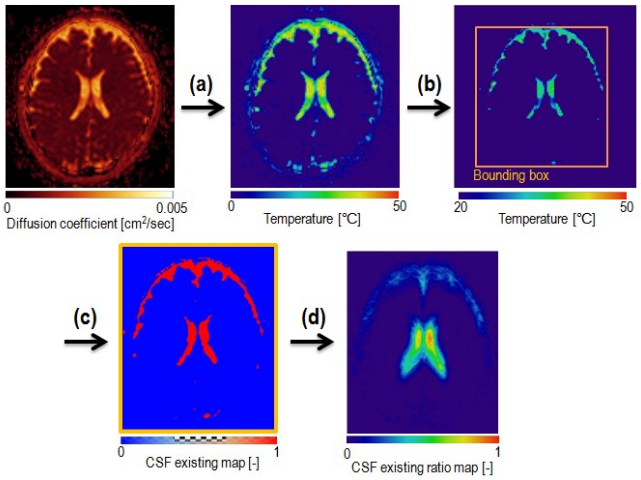

Figure1. The procedure of obtaining a CSF existing map: (a) convert diffusion coefficient to temperature; (b) set boundary box at temperature > 20°C; (c) resize the bounding box to 181x217x181 voxels; (d) averaging personal CSF areas.

Step2: Construction of a LV probability map

From the CSF existing ratio map, we segmented lateral ventricle area as a LV probability map (Figure 2a) by using region growing within the probability 0.1-1.0. Figure 2b, c, d showed representative views of segmented area from axitial, coronal, and sagittal, respectively.

Step3: AND operation between LV probability map and subject

Subjects LV area were extracted by using AND operation with the LV probability map (Figure 3). The mean temperature within the LV was determined by the previous paper [2].

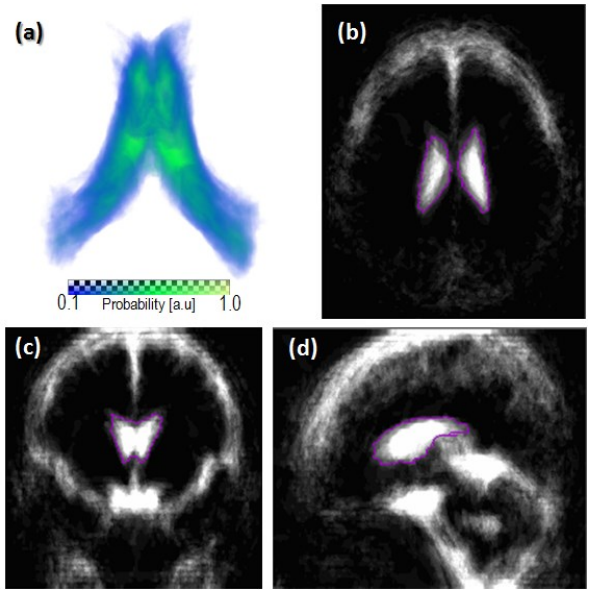

Figure2. The lateral ventricle (LV) probability map (a) and representative slices on axitial (b), coronal (c), and sagittal plane (d) *(inside of the purple line represent segmented LV area)*.

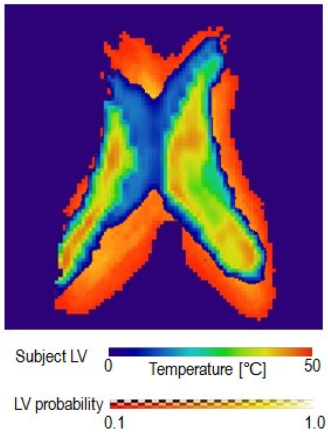

Figure3. The lateral ventricle (LV) probability map and a representative temperature map of a subject on an axitial plane.

E. Evaluation of proposed method

Bland-Altman analysis was employed to evaluate the proposed method. We performed Bland-Altman analysis between temperature of the manually segmented LV and the automatically segmented LV. The Wilcoxon signed rank test was also performed to evaluate differences between manual and automated methods using Matlab software (Mathworks, Natick, MA, USA). Values of $p < 0.05$ indicated statistically significant differences. As a reference, we used the sublingual temperature (electric thermometer, OMRON DALIAN CO LTD. MC-9018, Kyoto, Japan), which is known to be approximately 1ºC lower than the brain temperature [9, 10].

III. Results and Discussion

A. Comparison of tympanic membrane and DWI thermometry

Figure 4 shows the results of temperature measurements by both infrared thermometer on the tympanic membrane (A) and DWI thermometry with manual segmentation (B) and proposed method (C) of the LV, respectively. Mean differences of the two DWI thermometry analysis methods from tympanic membrane temperature were: 1.07 ± 0.98°C and 0.95 ± 0.76°C, respectively.

Because the gold standard of the core brain temperature was assumed to be approximately 1°C higher than the measured tympanic temperature [9,10], the proposed method appeared to yield temperatures closer to reality than the manual CSF area extraction method. Moreover, the proposed method showed a narrow SD than the manual CSF area extraction method.

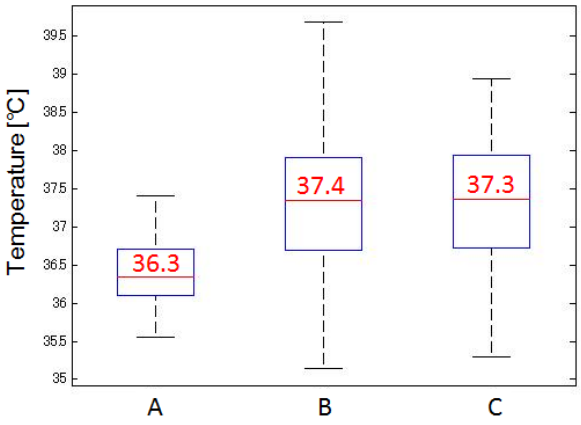

Figure4. Comparisons of the two DWI thermometry calculation methods and tympanic temperature [°C] *(A: tympanic membrane, B: manual segmentation of LV, C: proposed method)*

B. Bland-Altman analysis between DWI thermometry with manual and automated CSF area extraction

Figure 5 shows the Bland-Altman plot of the difference in DWI thermometry with manual and proposed methods with respect to the averaged temperatures by the two methods. Neither fixed nor proportional biases were evident between these two LV extraction methods. Additionally, there was no significant difference between the two (P=0.54, Wilcoxon signed rank test). We can therefore use the proposed LV area extraction method as an alternative method of manual extraction.

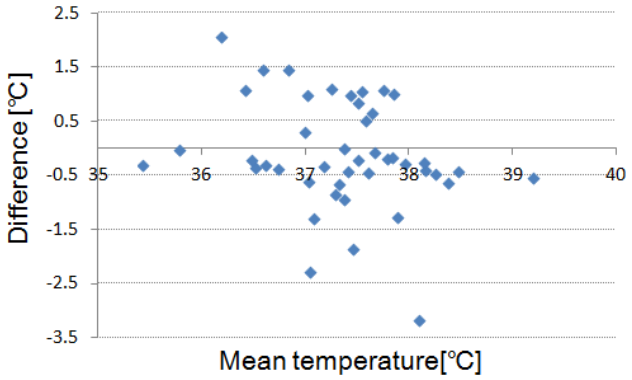

Figure5. Bland-Altman plot of differences in DWI thermometry with manual and automated LV area extraction methods with respect to mean values

C. The possibility of fully automated deep brain temperature estimation by DWI thermometry

To obtain mean temperature in the LV with DWI, the following two steps are needed: 1) extraction of the CSF area in the LV; 2) choice of the proper voxels with values close to the human body temperature. Previous papers [1-6] have employed manual extraction of the LV area. The method proposed in this paper allows the user to automatically extract the effective CSF region for DWI thermometry. Moreover, Sakai et al. [2] have already proposed an automated determination method for lower and higher thresholds to obtain the proper mean temperature in the LV. We can therefore combine these two methods to obtain mean temperature from DWI acquisition without any human biases such as manual LV segmentation. Furthermore, the combination of the proposed method and the threshold determination method [2] might be key steps to feasibly automate mean deep brain temperature calculation on the MRI console soon after finishing DWI acquisition.

D. Limitations

To obtain a relatively stable diffusion coefficient in the CSF, we chose the body of LV area. Nevertheless, the size and the spatial distribution of the LV area in the brain have much variety. Therefore, we cannot simply divide the spatial existence of LV by the age, the gender, and the size of the brain. Even if there is such difficulty in healthy group, for patients who have large atrophy on their LV, the proposed method may not have its usefulness. Further investigation may reveal the solutions of this problem.

IV. Conclusuion

LV temperatures in healthy subjects were measured by DWI thermometry using a new calculation method with automated LV body area definition. The proposed method seems to yield appropriate temperatures comparable to manual LV area definition, using tympanic temperature as a reference.

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