

Moderate protein content does not influence on DWI-thermometry: Temperature-controlled Artificial CSF phantom study

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INTRODUCTION

Among MR thermometry, the most clinically applicable method may be the post processing of diffusion-weighted images (DWI) ^{1,2}. Although only applicable to non-restricted water, e.g., cerebrospinal fluid (CSF), it is potentially useful in assessing the thermal pathophysiology of the brain in both patients ^{2,3} and healthy subjects ¹. However, this DWI-thermometry might be influenced by the composition of the CSF, which can strongly affect its viscosity and diffusivity ⁴. We have also experienced temperature decline with DWI thermometry in the case of head trauma ⁵. In normal adults, the CSF protein concentration is the range of 0.18 to 0.58 mg/ml ⁶. The purpose of this study was to investigate the influence of protein content on DWI thermometry by using artificial CSF (ACSF) with variable protein concentrations at near brain temperature.

METHODS

Artificial CSF phantom: Diffusion-weighted and MR spectroscopy images of ACSF phantoms (six different

albumin concentrations) were acquired to investigate the influence of protein content on DWI thermometry. The ACSF phantoms consisted of 60 ml ARTCEREB® irrigation and perfusion solution for cerebrospinal surgery (Na⁺: 145mEq/l, K⁺: 2.8mEq/l, Mg²⁺: 2.2mEq/l, Ca²⁺: 2.3mEq/l, Cl⁻: 129mEq/l, HCO₃⁻: 23.1mEq/l, P: 1.1mmol/l, glucose: 0.61 g/l, pH 7.3, Otsuka Pharmaceutical Factory, Inc., Naruto, Japan) and 0 – 480.5mg albumin from bovine serum (pH 7, Wako Pure Chemical Industries, Ltd., Tokyo, Japan). **Data acquisition:** Images were acquired five times using a 1.5T MR scanner (Sonata, Siemens, Erlangen, Germany) equipped with a receive-only CP head array coil. DWI were taken in the axial plane using a spin-echo echo planar imaging diffusion-weighted sequence (TR: 3500ms, TE: 79ms, flip angle: 90°, bandwidth: 1955Hz/pixel, slice thickness: 5.0mm, matrix size: 128 × 128, FOV: 230 × 230mm, NEX: 3, three slices, b value: 800s/mm², MPG: six directions, zero filling interpolation). Due to the maintaining the consistent temperature of samples in the MR magnet, we produced a water-jacket-style thermo maintaining equipment ⁷, and we acquired the images at several controlled temperatures (27.0-42.0°C). **Temperature calculation:** Temperature was calculated using the following equation: $T (^{\circ}\text{C}) = 2256.74 / \ln(4.39221 / D) - 273.15$ ⁸, where D [mm²/s] is the diffusion coefficient. The mean temperature was calculated by histogram curve-fitting method ⁹. The region of interest was manually segmented on the b0 image. An optical fiber thermometer (Anritsu Meter Co., Ltd. FL-2400, Tokyo, Japan) was used as a reference. **Viscosity measurement:** The viscosity of ACSF was measured at same temperatures with MR acquisition (27.0-42.0°C) using an Ubbelohde viscometer (#0, Sibata Scientific Technology Ltd., Saimata, Japan) and the method was based on the Japan Industrial Standard K2283-2000. The mean kinematic viscosity (five times measured) of ACSF was calculated as Ct , where C is the viscometer constant (0.003539mm²/s²) and t is the ACSF migration time in the viscometer. **Statistics:** Comparisons were performed using paired t tests (Matlab; The Mathworks, Natick, MA, USA). The correlation was evaluated as significant for P values <0.05.

RESULTS AND DISCUSSION

Albumin concentration vs. viscosity: Figure 1 shows the relation between albumin concentration and kinetic viscosity. The difference in kinetic viscosity between distilled water and ACSF was not significant ($p = 0.49$) at 37.0 °C. Kinetic viscosity slightly linearly increased with ACSF solution albumin concentration ($R^2 = 0.9457$). The difference between distilled water and ACSF without albumin was 1.70%. The maximum albumin content (8mg/ml, 40 times of normal) increased 3.31% from normal albumin content (0.5mg/ml) at 37.0 °C. **Albumin concentration vs. diffusion coefficient:** Figure 2 shows the relation between albumin concentration and the diffusion coefficient obtained from DWI. There was no significant both positive and negative relation between ACSF solution albumin concentration and diffusion coefficient, and the linearity between albumin concentration and diffusion coefficient was low ($R^2 = 0.2419$). **Albumin concentration vs. DWI thermometry:** Figure 3 shows the relation between albumin concentration and the results of DWI thermometry. There was no significant declining affect by the content of albumin. Figure 4 shows the Bland-Altman plot between the setting temperature and the results of DWI thermometry with variable albumin content (same as Figure 3). From the Bland-Altman analysis, there were no both fixed bias and proportional bias between the setting temperature and the results of DWI thermometry.

CONCLUSION

The approximately 40 times protein content of normal adult in ACSF slightly increased viscosity and did not decrease the diffusion coefficient at 37.0 °C. The results of DWI thermometry were not influenced by the protein content in the range of 0.0 to 8.01 mg/ml at near body temperature.

References [1] Sakai K et al., NMR Biomed, 2011; 24(9): 1063-1067, [2] Yamada K et al., NeuroReport, 2010; 21: 851-855, [3] Sai A et al., JMRI, 2013; in press, [4] Reiber H, Restorative Neurology and Neuroscience, 2003; 21: 79-96, [5] Tazoe J et al., ISMRM, 2012; 3708, [6] Seehusen DA et al., American Family Physician, 2003; 68(6): 1103-1108, [7] Sakai K et al., <http://dx.doi.org/10.11239/jsmbe.51.R-95>, [8] Kozak LR et al., Acta Paediatrica, 2010; 99: 237-243, [9] Sakai K et al., NMR Biomed, 2012; 25(2): 340-346.

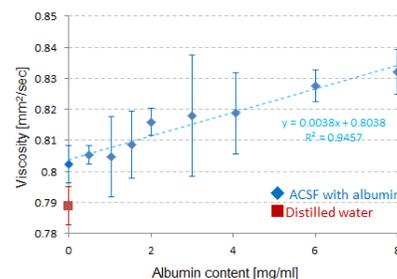


Figure 1. The relationship between albumin concentration and viscosity (37.0°C).

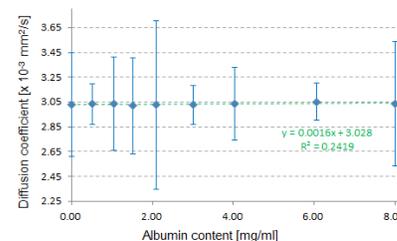


Figure 2. The relation between albumin concentration and diffusion coefficient (around 37.0°C).

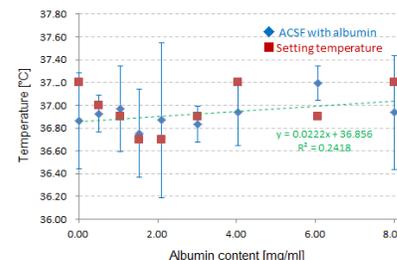


Figure 3. The relationship between the albumin concentration and the results of DWI thermometry (around 37.0°C).

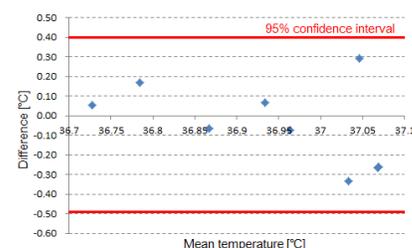


Figure 4. Bland-Altman plot between the setting temperature and the results of DWI thermometry.