MEASURING THE CEREBRO-SPINAL FLUID TEMPERATURE USING DIFFUSION MRI

Z. Nagy[1], L. R. Kozak[2], M. Bango[3], M. Szabo[3], R. Gabor[2], and Z. Vidnyanszki[2]

[1]Wellcome Trust Centre for Neuroimaging, University College London, London, United Kingdom, [2]Szentagothai J. Knowledge Centre, MR Research Centre, Semmelweis University, Budapest, Hungary, [3]First Department of Pediatrics, Semmelweis University, Budapest, Hungary

Introduction: Hypothermia is often induced in patients after stroke, cardiac arrest or traumatic brain injury in order to minimize the damage to the neuronal tissue. During the hypothermic period the body temperature is usually measured external to the brain, giving only indirect evidence of the actual temperature of the brain. The diffusion constant of water is temperature dependent with a well known one-to-one relationship. The aim of this use diffusion-weighted MRI to measure the diffusion constant within the lateral ventricles of the brain and investigate how reliably this value yielded a temperature estimate.

Methods: *Data acquisition* All experiments were performed on a 3.0T Philips Achieva scanner (Philips Medical Systems, Best, The Netherlands) with the following imaging parameters: 128x128 matrix, FOV=190mm, TE = 90ms, TR = 8000ms, slice thickness = 1.5 mm with 1.5 mm gap. A single reference image was acquired along with 32 diffusion-weighted images with non-collinear diffusion encoding directions and b value of 800 s/mm^2. For the phantom experiments, one phantom was filled with artificial cerebro-spinal fluid (ACSF) (1) and two others with the same water that was used for preparing the ACSF. All three bottles were warmed to 41.5 °C before being placed into the head coil. The phantom with ACSF and one of the water phantoms were positioned side by side, close to the isocentre with the field of view centred on them. The other water bottle was put in contact with the first two but was not important for imaging. Instead the temperature was measured with a mercury thermometer in this phantom so that the liquid in the other two phantoms did not have to be disturbed. The three phantoms were bundled in thermo-blankets. While the contents of the phantoms were slowly cooling between about 41-32 °C the above mentioned sequence was run repeatedly and after each acquisition the temperature was measured in the 2nd water phantom. For the in-vivo experiments, adult volunteers were imaged. One of the volunteers was imaged 3 times consecutively in order to investigate the reproducibility of the method. *Image analysis:* For each dataset we calculated the diffusion constant for each of the 32 diffusion weighted directions according to (2)

$$D = \frac{\ln(S_0 / S)}{b}$$

where D is the diffusion constant in units of mm^2/s, b is the applied diffusion-weighting in units of s/mm^2 and S_o and S are the voxel signal intensities of the reference and diffusion-weighted images respectively. This value was then converted to the corresponding temperature according to (3)

$$T = \frac{2256.74K}{\ln\left[\frac{4392.21\times10^{-3}\,\frac{mm^2}{s}}{D\,\frac{mm^2}{s}}\right]} - 273.15^{o}K$$

where T is in units of Kelvin but after subtracting 273.15K the value corresponds to the usual units of Celsius. Finally, the 32 temperature estimates were averaged. For the phantoms the temperature estimates were averaged within a 6x6 region of interest in the centre slice or a volume of interest within 12x12 regions in the 12 center slices. For the human volunteers the temperature estimates were only considered within the lateral ventricles.

The above procedure resulted in artificially high mean temperature estimates within the lateral ventricles of the brain. We hypothesize that this was due to the slow flow and pulsatile movement of the CSF and excluded all temperature estimates which were higher than 44 °C. Due to partial volume effects some temperature estimates were also artificially low. For this reason a lower threshold of 30 °C was also set. This is not the first use of outlier rejection methods in diffusion tensor MRI (4) however in our case a physiological threshold was set because the temperature of the cerebrospinal fluid of an adult should be close to ~38 °C.

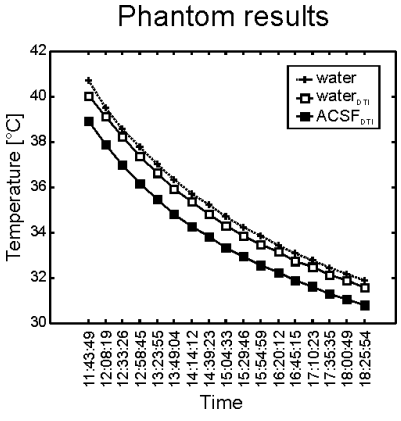

Figure 1

Results: Figure 1 displays results of the measurements on the cooling phantoms. As expected the estimated temperature within the ACSF phantom was lower than the true temperature. This offset was ~1.4 °C when considering both the smaller and the larger ROIs. This offset is due to the fact that the ACSF is not pure water but contains chemicals which hinder the diffusion of water. The estimated temperature in the water phantom was also slightly lower (0.4 °C) which may be due to a miscalibration of the mercury thermometer, impurities in the water used, slightly weaker gradients than requested or combination of these factors. The results from one of the human volunteers are displayed in Figure 2. The mean temperature within the lateral ventricles was 37.8 °C which is in good agreement with previously reported estimates using MR spectroscopy or invasive methods. Furthermore, there was no statistically significant differences among the histograms of voxelwise temperature estimates for the volunteer who was imaged 3 times consecutively (Kolmigorov-Smirnov test)

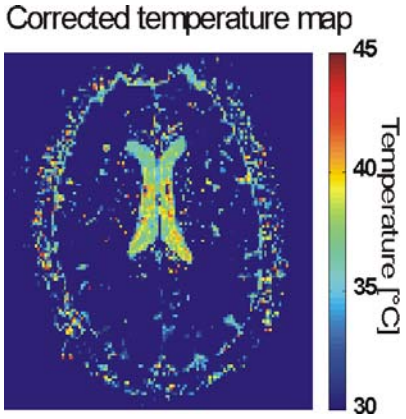

Figure 2

Discussion: We have demonstrated the feasibility of diffusion-weighted MR imaging for temperature mapping within the lateral ventricles of the brain. This method is not useful within the brain tissue, due to the restricted diffusion of water there (note the artificially low temperature in Figure 2). Also, due to the movement of CSF within the lateral ventricles care must be taken in order to avoid artificially high estimates of temperature. However, diffusion (tensor) imaging is often already included in the MRI protocols for patients in whom hypothermia is induced as a protective mechanism. Therefore, with no extra scanning required, the temperature estimate can be obtained as a simple post processing step. Knowledge of the brain temperature may improve the current protocols of induced hypothermia in patients.

References

1. Davson HWK, Segal MB. The physiology and pathophysiology of the cerebrospinal fluid. Edinburgh, Churchill Livingston, UK, 1987.
2. Stejskal EO, Tanner JE. Spin Diffusion Measurements-Spin Echoes in Presence of A Time-Dependent Field Gradient. J. of Chemical Physics 1965; 42:288-292.
3. Mills R. Self-Diffusion in Normal and Heavy-Water in Range 1-45 Degrees. Journal of Physical Chemistry 1973; 77:685-688.
4. Chang LC, Jones DK, Pierpaoli C. RESTORE: robust estimation of tensors by outlier rejection. Magn Reson Med 2005; 53:1088-1095.