Rapid Diffusion-Weighted Thermometry (DWT) using 3D singleshot Stimulated EPI

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INTRODUCTION

Temperature sensitive properties that can be measured using MRI techniques include the proton resonant frequency (PRF) shift [1], T_1 relaxation time [2], and the diffusion coefficient of water molecules [3]. Molecular diffusivity in MRI has been measured most accurately by using conventional 2D singleshot diffusion weighted-EPI (2D ss-DWEPI), because of its immunity to motion artifacts. However, 2D ss-DWEPI is limited to intracranial applications far from the sinus, due to the severe geometric distortion caused by strong non-linear local magnetic fields at or near tissue/air or tissue/bone interfaces. Although susceptibility induced distortions can be reduced by using multishot DW acquisition techniques, these multishot techniques, in general, suffer from artifacts caused by phase errors induced by small local or global motions coupled with the large diffusion gradients. These artifacts (motion and susceptibility artifacts) cause inaccuracy in diffusion measurement. In this report, temperature measurement using 3D singleshot DW stimulated echo planar imaging (3D ss-DWSTEPI) is presented [4]. 3D ss-DWSTEPI is a rapid 3D singleshot imaging technique that is almost free from both artifacts, therefore temperature distributions can be measured rapidly and accurately. This technique may be useful for feedback applications to control temperature, such as ablation using HIFU, RF, or microwave.

METHODS

Preliminary experiments were performed on a clinical 3T MRI system (Trio, Siemens Medical Solution, Erlangen, Germany) using a head RF coil. Imaging parameters were matrix 128x33x24, spatial resolution (2.0 mm)^3 isotropic, TR 2.0 s, TE 75 ms, and diffusion weighting with b=0 and 400 s/mm^2 along 3 perpendicular directions. The pulse sequence is shown schematically in Fig. 1, and described in detail in a separate report. [4] Once the images are acquired, the diffusion coefficient can be calculated according to Eq. (1) and related to temperature according to Eq. (2). [3]

$$D = \ln(S_0/S_1)/(b_1 - b_0) \qquad (1)$$

$$T - T_0 = \left(kT_0^2/E_a\right)\left[(D - D_0)/D_0\right] \qquad (2)$$

where S_1/S_0 is the signal amplitude ratio from two different images, b_1 and b_0 are the diffusion weightings of the respective images, k is Boltzmann's constant, E_a is the activation energy, D_0 is a reference diffusion coefficient and T_0 is and a reference temperature. The reference data used was $D_0 = 2.03X10^{-3}\,mm^2/s$ and $T_0 = 20^\circ C$. [5] A rectangular phantom filled with gelatin was used and temperature measurements were taken after each scan with an alcohol thermometer inserted into the phantom for an independent measurement of temperature. The phantom was chilled and then heated to 5 different temperatures: 11°, 13°, 18°, 19°, and 40°C. Two scans were made at 13°, 19°, and 40°; one scan was made at 11° and 18°. The signal amplitudes were calculated from a region of interest of a central slice.

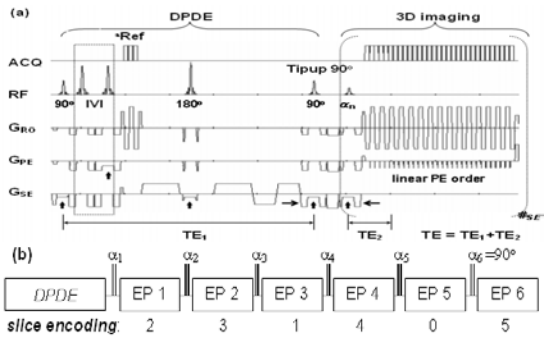

Fig. 1 *Schmatic pulse diagram of 3D ss-DWSTEPI, consisting of DPDE and 3D data acquisition. A complete set of k_y views are acquired after each α RF pulse. Inner-volume imaging was used to define the reduced phase FOV. The imaging echotrain is repeated for all actual slice-encodings as shown in (b).*

RESULTS and DISCUSSIONS

The results are displayed in Fig. 1. Mean values are plotted with error bars. Also plotted in circles is the data acquired by Tofts et al using an NMR spectrometer. [5] The linear fit to the data is reasonably good and our data matches the data obtained by Tofts et al quite well. The data presented is only a quick preliminary investigation of diffusion weighted thermography (DWT). There was a relatively large standard deviation in the measured temperature and our values of D have been slightly overestimated, causing the fitted curve to consistently give temperature values that are higher than those presented by Tofts et al. A Substantial amount of water was present inside the phantom, especially when heated to 40°C. The diffusion gradients are strong enough to shake the patient table during imaging, causing fluid motion in the phantom. This motion is the reason for the large standard deviation and slightly overestimated values of D. Acquisition time to measure the temperature of an isotropic medium was a few seconds, and about 10 seconds for anisotropic tissue, which requires at least 3 diffusion encodings to measure average diffusivity. To reduce imaging time to measure the temperature of an anisotropic tissue, a DWI technique designed to measure the average diffusivity can be used. [6]

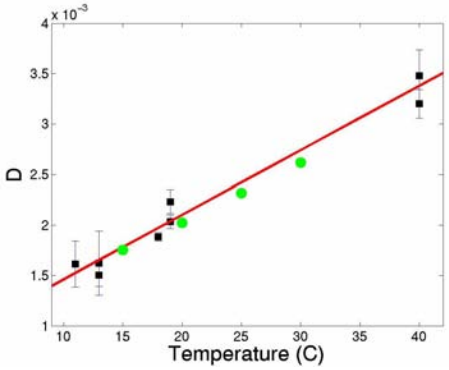

Fig. 2 *Plot of Diffusion Coefficient versus temperature. Our data is represented by black squares and error bars. Green circles represent data acquired by Tofts et al[5] using an NMR spectrometer.*

CONCLUSIONS

Temperature of a phantom was measured accurately by using the novel pulse sequence 3D singleshot DWSTEPI. This sequence promises to improve DWT as it does not suffer from the distortion problems that plague conventional 2D ss-DWEPI outside of the brain and yet it is still fast enough to provide adequate temporal resolution for all applications.

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