Imaging cadavers - 'cold brain' MRI effects and noninvasive diffusion thermometry of the CSF

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Aims: 1. To understand the 'cold brain' effects seen in cadaveric imaging, and to modify sequences to overcome these.
2. By exploiting these changes to develop new non-invasive MRI-based thermometry of the brain core.

Introduction MR Imaging of post mortem (PM) brain, both removed and *in-situ*, is being used to investigate pathological correlates of MR changes in various diseases such as prion disease and multiple sclerosis. MRI can also be used to guide the dissection process of the pathologist.

The MRI appearance of brain tissue after death is however altered by a number of factors, including tissue degradation and – when imaging is performed *in-situ* - the tissue being cold (having been refrigerated at about 2-5°C). T_1 is reduced; the effect on CSF signal is particularly marked. The Apparent Diffusion Coefficient (ADC) is also lower. Thus imaging sequences which have been optimised for in-vivo work give different tissue contrast in cadavers. In particular, FLAIR imaging is designed to virtually eliminate the CSF signal. In long-TR Spin Echo sequences the TR value is often reduced (down to about 2s) so that the CSF signal becomes T_1-weighted and is reduced down to that of surrounding white matter.

Imaging: A human cadaver refrigerated for 48 hours was imaged at 1.5T. Fast spin echo (FSE) imaging used TR=2.6s; TE1=12ms; TE2=96ms. FLAIR imaging used TR=9.9s; TE=166ms; TI=2.473s. DWI used TR=10s; TE=90ms; matrix 128x128; FOV 240x240mm; 18 axial slices each 7mm thick with 2mm gap; b=0, 1000 s mm^{-2}.

MRI modelling: To understand the MRI behaviour of brain tissues (CSF and white matter WM) as their temperature is lowered, estimates of tissue parameters (PD, T1 and T2) are required. White matter values were estimated from PM studies made within our group. CSF values of T_1 and ADC were estimated using published values for CSF and water.

The diffusion coefficient (DC) of water has been reliably measured by Mills[1]. ADC values of CSF in-vivo [2 3] are close to that of water at 37°C ($3.04\ 10^{-9}\ m^2\ s^{-1}$ i.e. $3040\ 10^{-6}\ mm^2\ s^{-1}$), and therefore water values have been used to represent CSF over the whole temperature range (fig 1). The T_1 of water as a function of temperature has been well documented [4 5]. Published values for CSF are close to those of water, (possibly slightly lower because of the effects of dissolved paramagnetic oxygen and of cellular debris), and again water values were used to simulate the signal of CSF. FLAIR and spin echo image intensity ratios (CSF:white matter) were estimated as a function of temperature.

Results The observed bright CSF signal was well modelled by simulations; reducing FLAIR TI predicted that CSF could be nulled (fig 2). Reducing FSE TR was unable to bring CSF signal down to that of WM (as is done in-vivo). Measured ADC of CSF was $1.15\ 10^{-9}\ m^2\ s^{-1}$; from this, the CSF was estimated to be 1.0 °C (95% confidence limits 0.2-1.8 °C).

Conclusions
1. ADC and T_1 values for CSF are close to those of pure water. Reliable water values are available in the literature.
2. ADC thermometry is probably reliable to within 1°C, and has potential for non-invasive measurement of brain temperature.
3. CSF suppression at low temperatures is possible in FLAIR with reduced TI.
4. Modelling signal behaviour is imprecise without detailed knowledge of PD T1 and T2 values in PM brain parenchymal tissue.
5. ADC measurements on samples of cold extracted CSF, and comparison with water, will validate the non-invasive thermometry method.

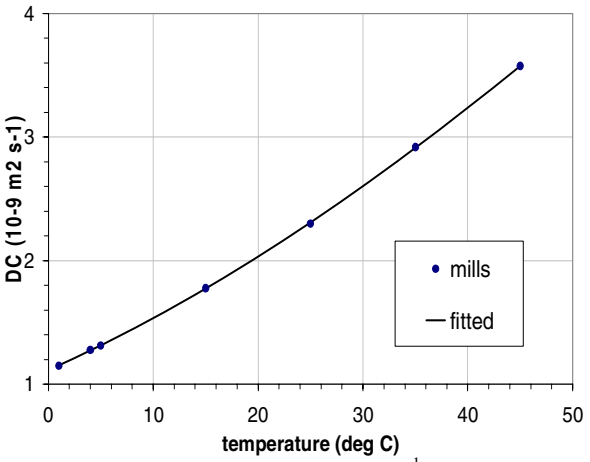

figure 1: DC of water (interpolated from Mills[1])

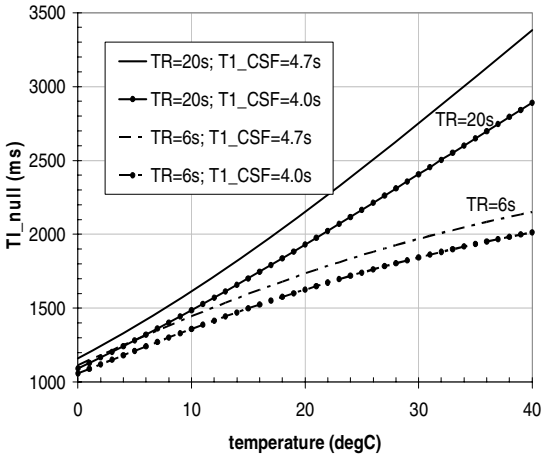

Fig 2: Predicted FLAIR TI values to null CSF

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4. Krynicki Physica 1966; 32:167
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