Direct SAR measurements using MRI: a phantom study of proton decoupling at 7 tesla

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Introduction. In high field magnetic resonance many imaging sequences, particularly those using multiple refocusing pulses, cannot currently use optimal data acquisition parameters due to specific absorption rate (SAR) limitations. The case becomes even more limiting in heteronuclear MR spectroscopy experiments, in which high power proton decoupling is desirable for both increased sensitivity and also spectral simplification. Current SAR limits are set essentially using conservative estimates based upon simulated electric field distributions within the body, and/or very limited phantom measurements of temperature using fibre-optic probes. A far more desirable non-invasive method of estimating SAR would be to use MRI itself. Although it is well-known that MR can be used for temperature mapping, primarily using the proton reference frequency (PRF) method [1], there are very limited reports of using MR for SAR measurements [2]. In this phantom study, we measure SAR directly at 7 tesla using MR for a number of different proton decoupling powers, and sample conductivities.

Measuring SAR using MRI. The SAR at each pixel can be calculated from the time-dependent temperature field T(x,y) [3]:

$$C\frac{dT(x,y)}{dt} = \frac{k}{\rho}\nabla^2 T(x,y) + SAR(x,y)$$

where C is the specific heat, k the thermal diffusion coefficient, and ρ the density of the sample. In almost all cases:

$$\frac{k}{\rho}\nabla^2 T(x,y) << SAR(x,y), \quad \Rightarrow \quad C\frac{dT(x,y)}{dt} = SAR(x,y)$$

Therefore, measurement of in situ heating using the PRF method, followed by calculation of the initial slope of temperature vs. time (before perfusion increases significantly and/or convective heat losses occur) gives a non-invasive measurement of SAR.

Materials and Methods. Gelatin gels were formed with 0, 50, 75 and 100 mM NaCl. Four cylinders (diameter 1 cm) were spaced 1 cm apart, and oriented with their long axis parallel to that of the horizontal 7 tesla bore. A quadrature birdcage coil was used for transmission and reception. To simulate a spectroscopic sequence with proton decoupling (it is assumed that heating during a heteronuclear spectroscopic experiment such as DEPT [4] is dominated by decoupling), a WALTZ-4 sequence [5] was applied for 320 ms, with a 2 second "relaxation delay" between each application. After every 24 signal averages, a fast gradient echo is acquired to measure temperature (128 x 128 data matrix, 2 mm slice thickness, TR=100 ms, TE = 10 ms) and the process repeated 30 times, resulting in a total experimental time of ~30 minutes. Various values of B_1 were used for the WALTZ-4 sequence, with the 90° pulse widths adjusted accordingly. To obtain temperature maps the phase-sensitive images were phase-unwrapped, and corrected for drifts in the B_0 field. SAR values were calculated from the slope of the first 6 minutes using a value of C of 4180 $(^oC\ kg)^{-1}$

Results and Discussion. Figure 1(a) shows a temperature image of the four phantoms after 6 minutes of proton decoupling with a B_1 field of 40 μT. There is slight non-uniformity in the images which might occur due to proximity effects. Figure 1(b) shows a plot of temperature vs. time for the three saline phantoms. The SAR maps, shown in Figure 1(c) were calculated from the slope of the graph. Identical experiments run with B_1 values of 5-10 μT gave values of SAR lower than 1 W/kg (data not shown)

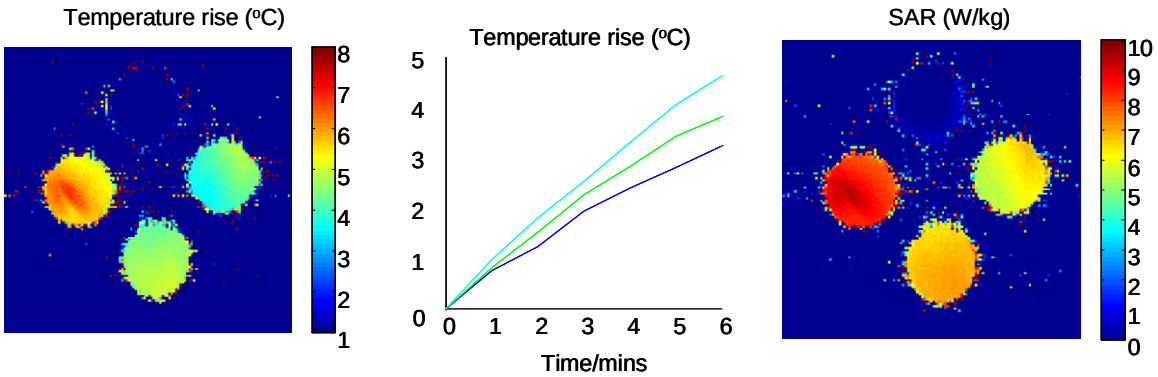

Figure 1. (a) Temperature map of four phantoms after 6 minutes of proton decoupling. From the top, rotating clockwise, the tubes are pure water, 50 mM, 75 mM and 100 mM saline containing 1% w/v gelatin. (b) Plot of temperature vs. time for the first 6 minutes from the central 16 voxels of each tube containing saline: (cyan 100 mM, green 75 mM, blue 50 mM). (c) Image of SAR calculated on a pixel-by-pixel basis.

Conclusion. Direct SAR measurements using MRI are potentially a valuable tool in complementing and verifying computational models of sample/patient heating via electric fields. The PRF method is independent of tissue type, and unlike fibre-optic measurements SAR by MRI does not require invasive probes and allows several hundreds or thousands of localized measurements in a very short data acquisition time. Work is undergoing in transferring the methodology to studies using a human 7 tesla scanner for in vivo measurements.

References: [1] K. Kuroda et al. , Biomed. Thermol., 13, 43, 1993, [2] B.Behnia and A.G.Webb, Magn.Reson.Eng. 23B, 1, 2004. [3] Y.Wang and D.B.Plewes, Magn Reson Med 42: 158, 1999. [4] D.M.Doddrell, D.T.Pegg and M.R.Bendall, J.Magn.Reson. 48, 323, 1982, [5] M.H.Levitt, R.Freeman and T.Frenkiel, J.Magn.Reson. 47, 328, 1982.