Field inhomogeneity may substantially affect hyperpolarised 129Xe rat head spectra

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Introduction: Recent results have shown that hyperpolarized 129Xe rat head spectra may be affected by changes in the shimming procedure [1]. An example is shown in Fig 1, where the shimming was concentrated on 8 mm thick slices in the cerebellum and brain. The shape of the second peak is clearly affected by the change shimming; however this pattern is not consistent from animal to animal, suggesting that the differences do not simply arise from the choice of different slices to shim on.

In preparation for the acquisition of 129Xe rat head spectra, our group has up to this point shimmed the field by monitoring the width and symmetry of the proton resonance whilst altering the shim-coil currents. Unfortunately this method of shimming can be tedious and is liable to produce nonideal shim states because of the number of parameters involved in the optimization process. Moreover, the field homogeneity may be distorted by the boundaries between tissue and void spaces. To investigate the homogeneity of the field in rat head and as a first step towards studying the possible effects inhomogeneity may have on the 129Xe dissolved phase spectrum, we have implemented a field-mapping algorithm. The results indicate that even with a supposedly well-shimmed state, there is a substantial variation in the field that may cause or contribute to anomalies in rat head spectra.

Methods: The field in a sample may be qualitatively mapped by acquiring two gradient-echo images at different echo times and then calculating the difference in phase [2,3]. This procedure is complicated by the existence of jumps or wrapping in the phase map when the phase exceeds $+/-\pi$. Several algorithms that can correctly unwrap the phase maps now exist (eg [4,5]), and these were implemented in a 2D phase-unwrapping program.

A male Sprague-Dawley rat was set in the bore of a Varian 4.7T Inova MR spectrometer and a 3 cm proton and 129Xe dual-tuned surface coil was placed over its head. The field was shimmed in the usual way until the operator was satisfied that a "good shim state" had been achieved. Proton images were acquired with a standard gradient-echo sequence at echo-times of 7 and 11 ms. The images were acquired in the transaxial (6 slices), coronal (3 slices) and sagittal (1 slice) orientations. After acquisition, the phase unwrapping program was applied to the phase maps calculated for each slice in each orientation. Since the unwrapped phase is only unique up to an unknown additive constant, the phase in each slice was aligned to the neighbouring slice by equating the parts of the images where the three orientations overlap.

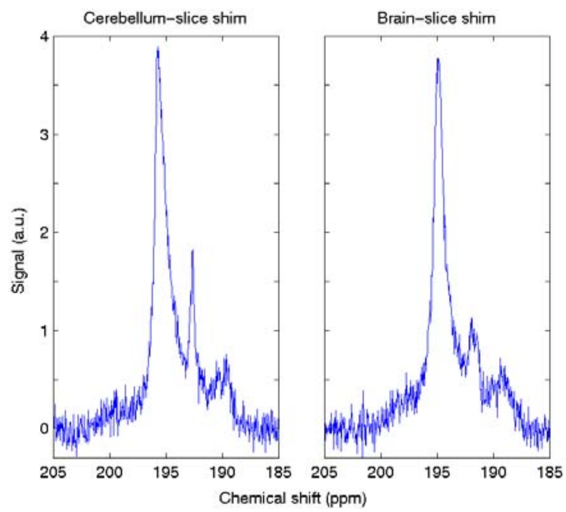

Figure 1: Rat head spectra acquired for two different shim states. All other conditions were identical.

Results & Discussion: Figure 2 shows the final field homogeneity map in all three orientations. Even though the field is reasonably homogeneous over most of the brain, there is some deviation at the posterior ventral portion where the cerebellum is located. Outside of the brain it is clear that there is some substantial variation in the field ranging across ~600 Hz within the FOV of the surface coil. Assuming that the median phase value corresponds to the centre frequency of the receiver, this frequency range equates to a field deviation of around 3 ppm in the field at the proton resonance. At the resonance frequency of 129Xe the effect is even more pronounced, with the variation equating to around an 11-ppm change in field. As the total width of the dissolved part of the 129Xe spectrum is ~10-15 ppm, it is probable that this inhomogeneity is affecting the quality of 129Xe rat head spectra. In particular, the spread in frequencies across the rat head is probably responsible for the overlap in the bases of the principal peaks and probably contributes to the obfuscation of the smaller amplitude peaks on some occasions. Moreover, it is impossible to rule out the possibility that one of the principal peaks is a result of the distortion of the field.

The above-described field mapping procedure will form the basis for an automatic shimming algorithm that reliably obtains the best global shim of the rat head. A systematic study of the effects of shimming on rat head spectra will then be possible.

References: [1] Kershaw et al, submitted to MRM (2005); [2] Schneider et al, MRM 335-347 (1991); [3] Webb et al, MRM 20,113-122 (1991); [4] Kramer et al, Int J Electron Comm 12-116 (1996); [5] Chavez et al, IEEE Trans Med Imag 966-977 (2002).

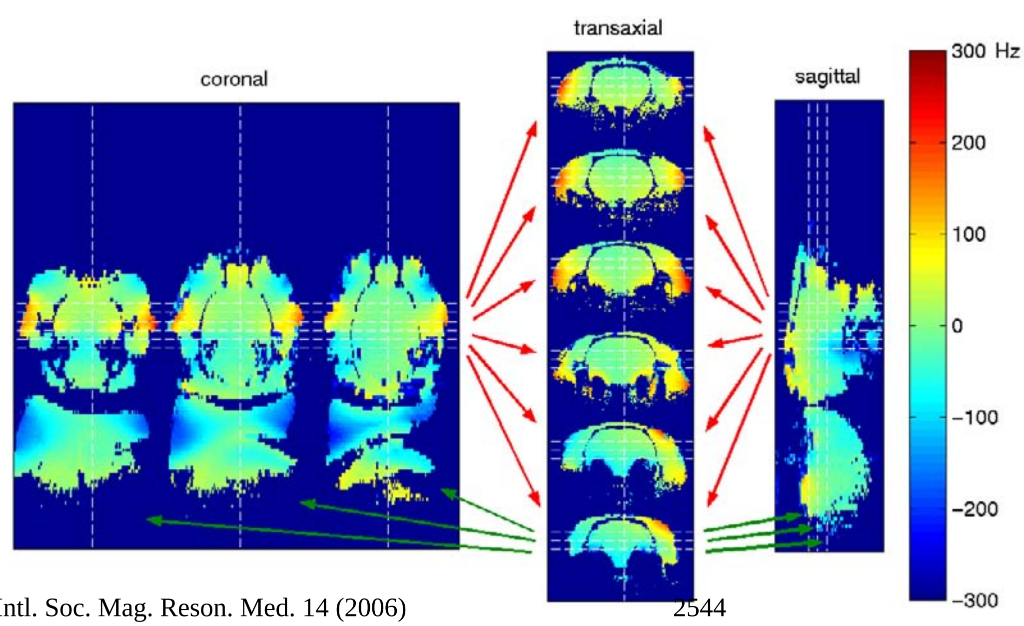

Figure 2: Field homogeneity map for the rat head. The dotted white lines indicate the position of the slices in the other orientations. The red arrows indicate how horizontal the lines in the coronal and sagittal images correspond to the transaxial slices. The green arrows do the same for the coronal slices.