Time- and spatially-resolved *in vivo* human brain MR-spectroscopy using hyperpolarized ^{129}Xe

W. Kilian[1], F. Seifert[1], H. Rinneberg[1]
[1]Physikalisch-Technische Bundesanstalt, Berlin, Germany

Introduction

Due to the high solubility of xenon in blood and tissue, hyperpolarized ^{129}Xe (HpXe) holds promise for MR measurements of HpXe dissolved in various organs. Besides the diffusivity of lung parenchyma [1] and the perfusion of the heart and kidney [2], brain perfusion is one of the most interesting physiological parameters accessible with HpXe [3,4]. Due to the high amount of HpXe needed for human *in vivo* measurements, mainly animal studies have been reported up to now. Recently we reported on quantitative MR measurements of HpXe in human brain [5]. Using a commercial head coil (licensed for human applications) with improved B_1-field homogeneity we were able to resolve for the first time both ^{129}Xe resonance lines in 2D-CSI images and analyzed the time course of the signal amplitudes obtained from time dependent measurements by an improved perfusion model.

Methods

For polarizing ^{129}Xe (natural abundance) by spin-exchange optical pumping [6] a home-built flow system [7] was used. One liter of HpXe gas (normal conditions) was accumulated as ice in the LN trap and thawed to fill a detachable Tedlar^{TM} bag (GSTP001-0707, JENSEN INERT, Coral Springs, USA). ^{129}Xe polarizations of 8-15% were routinely achieved.

All MR measurements were performed on a 3 tesla scanner (MedSpec 30/100, BRUKER BIOSPIN MRI, Ettlingen, Germany) using a commercial double-resonant ^{1}H/^{129}Xe open birdcage head-coil (RAPID BIOMEDICAL, Würzburg, Germany).

By phantom measurements using a glass bulb (5 cm diam.) filled with HpXe the spatial distribution of the B_1-field was investigated. Loading the head coil with a hollow cylinder (14 cm inner diam.) serving as tissue equivalent phantom, 20 consecutive FIDs (RF pulse repetition time Δt=3 s) were measured with the glass bulb positioned at different sites in the x-z-plane within the loading phantom. To determine the average flip angle α the decaying amplitudes were fitted to $\cos^n\alpha$.

For time dependent *in vivo* measurements 40 consecutive FIDs (RF pulse repetition time Δt=3 s, 2.8 kHz ≈ 80 ppm RF pulse bandwidth centered 200 ppm with respect to the ^{129}Xe gas resonance, 20 kHz acquisition bandwidth with 2048 complex data points) were recorded with the head of the healthy volunteer lying in the head-coil. After the first FID measurement with the Tedlar^{TM} bag positioned on top of the head-coil (yielding a signal from HpXe gas) the volunteer inhaled the HpXe gas and held breath for about 40 seconds. For data analysis each FID was multiplied by a Gaussian prior to applying a fast Fourier tranform, resulting in a line broadening of about 34 Hz.

In 2D-CSI measurements 20 seconds prior to starting the MR sequence the volunteer inhaled the HpXe and held breath until the end of the scan lasting 15 seconds. The 2D-CSI sequence was modified to account for the needs of Hp-gas imaging. Due to the decay in polarization and hence loss in signal intensity by each RF excitation the *k*-space was sampled in a spiral way starting from the center (*k*=0). By omitting the outer corners of the 16x16 matrix a reduction of the acquisition time to 3/4 was achieved without appreciable loss of information.

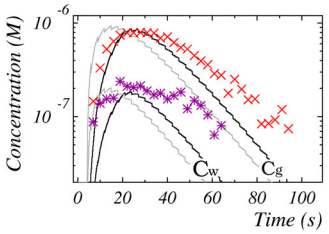

Figure 1: Dynamics of the 196 ppm (x) and 193 ppm (∗) lines. Grey lines: perfusion model (t_{inhale}=0 s); black lines (t_{inhale}=20 s).

Results

The flip angle measurements proved that the head-coil has a sufficiently homogeneous B_1-field distribution resulting in less than 10% variation of the adjusted flip angle within a concentric cylindrical volume of at least 10 cm in height and diameter.

The time dependent spectroscopic measurements gave comparable results as reported in [5] showing two resonance lines, one predominant line at 196 ppm and one weaker line at 193 ppm. To derive the time course of the line amplitudes each spectrum was fitted by a sum of two Gaussian lineshapes. By comparing the dynamics of the measured amplitudes with HpXe concentrations obtained from the perfusion model given in [5] (see Fig. 1 gray lines) we encountered considerable discrepancies. Due to the larger volumes (V_{Xe}=0.6-1 l) of HpXe used in the present experiment, the inhalation time t_{inhale} was no longer negligible as assumed in [5]. Therefore, we extended the perfusion model to account for finite inhalation times. In this way we achieved a better match between measured data and calculated HpXe concentrations without changing model-parameters. The remaining discrepancies (mainly seen as overestimated amplitudes of the 193 ppm line) might arise from noise increasing the Gaussian fit amplitudes. It is planed to circumvent this problem by using a fit procedure developed for analyzing data from ^{1}H brain spectroscopy [8].

In our very first 2D-CSI measurements [9] considerable smearing of the signals beyond the brain region was seen. With the new *k*-space sampling procedure this artifact has clearly been eliminated as seen in Fig. 2. In addition, due to the higher sensitivity of the new head-coil and the larger volumes of HpXe used, the weaker ^{129}Xe resonance line at 193 ppm is clearly resolved in the 2D-CSI image and a fit of the sum of two Gaussian lineshapes could be performed.

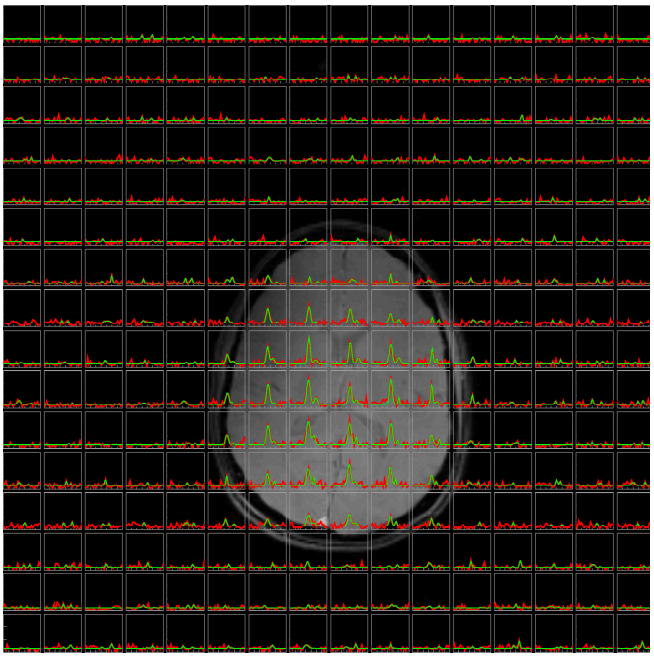

Figure 2: 2D-CSI image of HpXe dissolved in human brain (FOV 38.4 x 38.4 cm^2, 16 x 16 matrix, slice thickness 20cm): measured signal (arbitrary amplitudes, red lines) within a range of 202 ppm to 188 ppm. Green lines show fit of two Gaussian lineshapes for the dominant 196 ppm line and the weaker line at 193 ppm. Superimposed is a ^{1}H image of a 5 mm slice at the center of the brain.

Discussion

With the new head coil simultaneous ^{1}H/^{129}Xe measurements are possible at high SNR and a homogeneous B_1-filed distribution over the volume of the human brain is achieved, resulting in more accurate quantitative measurements and more reliable conclusions of the origin of the detected ^{129}Xe signals. After improving data analysis and achieving higher ^{129}Xe polarizations we plan to investigate changes in brain perfusion in patients.

References

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