

# 2D Chemical Shift Imaging of hyperpolarized isotopically enriched $^{129}\text{Xe}$ within human brain

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## Introduction

Due to the high solubility of xenon in blood and tissue, hyperpolarized  $^{129}\text{Xe}$  (HpXe) MR measurements in various organs are becoming more and more interesting. 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 [3-5]. The high sensitivity of the  $^{129}\text{Xe}$  resonance frequency to the molecule/tissue HpXe has bound to gives hope for a specific probe [6].

## Methods

For polarizing  $^{129}\text{Xe}$  (natural abundance, or isotopically enriched) by spin-exchange optical pumping [7] a home-built flow system [8] was used. About half a liter of HpXe gas (normal conditions) was accumulated as ice in the LN trap and thawed to fill a detachable Tedlar™ bag (GSTP001-0707, JENSEN INERT, Coral Springs, USA).  $^{129}\text{Xe}$  polarizations of 12-18% 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  $^1\text{H}/^{129}\text{Xe}$  open birdcage head-coil (RAPID BIOMEDICAL, Würzburg, Germany).

By phantom measurements using a glass bulb (2 cm diam.) filled with HpXe (natural abundance) 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  $\Delta t=3$  s) were measured with the glass bulb positioned at 25 different sites in the x-z-plane within the loading phantom. To determine the average flip angle  $\alpha$  the decaying amplitudes were fitted to  $\cos^n \alpha$ .

In 2D-CSI measurements 15 seconds prior to starting the MR sequence the volunteer inhaled the HpXe (isotopically enriched to 82%  $^{129}\text{Xe}$ ) 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  $16 \times 16$  matrix a reduction of the acquisition time to 3/4 was achieved without appreciable loss of information.

The raw data were rearranged in a  $16 \times 16 \times 1024$  matrix and a 2D FFT was performed to get the spatial distribution of the FIDs. These FIDs were analyzed by a time-domain frequency-domain (TDFD) method fitting frequency, amplitude, linewidth and phase independently for each line within user adjustable constraints [9]. For each of the 256 spectra of a 2D CSI acquisition the measured spectra, the fitted spectra and the values for the fitted parameters are obtained. Using the amplitudes color encoded images of the intensities of the different lines are obtained and overlaid onto a proton image obtained in the corresponding orientation.

## 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 12 cm in length and diameter (Fig. 1).

With the usage of hyperpolarized isotopically enriched  $^{129}\text{Xe}$  the signal to noise ratio (SNR) of the resulting spectra from the 2D-CSI measurements (performed in sagittal, axial and coronal orientations) was substantially increased (Fig.2 black line shows real part) yielding SNRs  $\gg 10$  for the dominant line at 196 ppm. Now the second line at 192 ppm is clearly resolved. The third line at  $\sim 187$  ppm is weakly seen in some of the spectra.

Besides the fitted spectrum (Fig. 2. red line) the TDFD method gives the amplitudes of the four lines at 0 ppm (corresponding to the signal from the gas phase), 186 ppm, 192 ppm and 196 ppm. In Fig. 3 these amplitudes of the four lines are imaged color encoded. Clearly the gas bag lying over the head of the volunteer was resolved. The image of the dominant line shows a uniform spreading over the brain in all orientations whereas the 186 ppm and 192 ppm lines are showing a more inhomogeneous distribution.

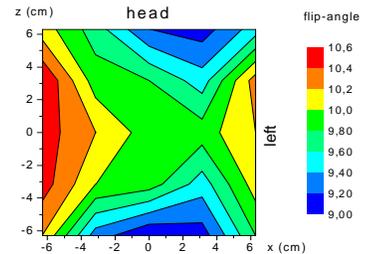


Figure 1: Distribution of flip angle for the  $^{129}\text{Xe}$  channel within the head-coil.

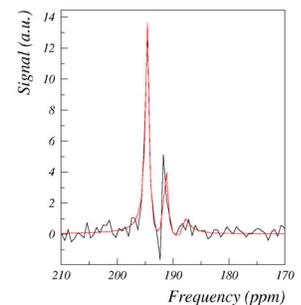


Figure 2: Single spectrum from a sagittal 2D-CSI measurement (black) with a fit of three lines (red).

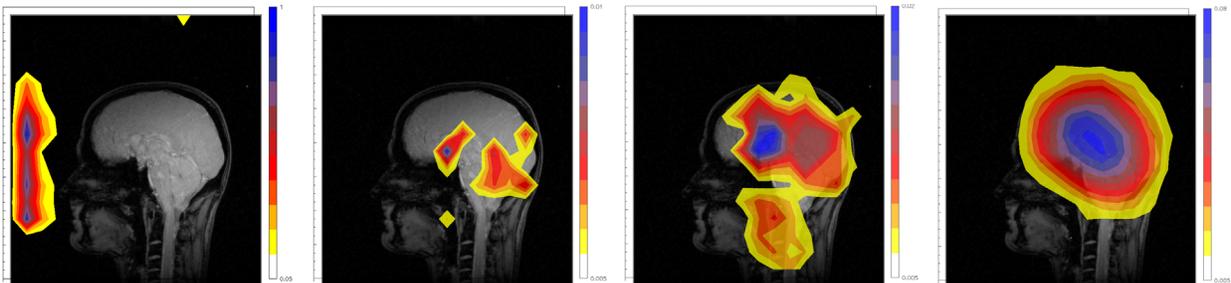


Figure 3: 2D-CSI image of HpXe (FOV  $32 \times 32 \text{ cm}^2$ ,  $16 \times 16$  matrix, no slice selection): measured signal strength of the four resolvable lines at 0 ppm, 186 ppm, 192 ppm and 196 ppm (from left to right) are color encoded pictured with an underlying proton image of the corresponding orientation..

## Discussion

With the usage of highly polarized isotopically enriched  $^{129}\text{Xe}$ , a dedicated head coil for simultaneous  $^1\text{H}/^{129}\text{Xe}$  measurements and a quantitative analyses of the obtained spectra we are now able to image the distribution of the different resonance lines in a routinely measurement protocol. Up to now we did not try to look for the blood peak at 215 ppm. Also the knowledge of the phase accumulation for the different lines were not implemented in the fit algorithm. After improving data analysis and achieving higher  $^{129}\text{Xe}$  polarizations we plan to investigate changes in brain perfusion in patients.

## References

1. Ruppert K. et al., *Mag. Reson. Med.*, **51**, 676 (2004)
2. Swanson S.D. et al., *Mag. Reson. Med.*, **42**, 1137 (1999)
3. Choquet P. et al., *Mag. Reson. Me.*, **49**, 1014 (2003)
4. Kilian W. et al., *Mag. Reson. Med.*, **51**, 843 (2004)
5. Proc. Intl. Soc. *Mag. Reson. Med.*, **11**, 767, 768, 770 (2004)
6. Lowery TJ et al., *Magn. Reson. Imag.*, **21**, 1235 (2003)
7. Walker T.G and Happer W., *Rev. Mod. Phys.*, **69**, 629, (1997)
8. Kilian W., PhD thesis, Freie Universität Berlin, (2001): [www.diss.fu-berlin.de/2001/105](http://www.diss.fu-berlin.de/2001/105)
9. Schubert F. et al., *Magn. Reson. Mat. Phys. Biol. Med.*, **14**, 213 (2002)

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## INTRODUCTION

- ◆ Xenon is highly soluble in blood and tissue.
- ◆  $\Rightarrow$  Hyperpolarized  $^{129}\text{Xe}$  (HpXe) MR measurements aim to brain function.
- ◆ Several distinguishable signals have been seen in the head up to now [1, 2].
- ◆ Nevertheless, the assignment to tissue compartment is unclear.
- ◆  $\Rightarrow$  Localized spectroscopic imaging brings further insight.

## METHODS

### $^{129}\text{Xe}$ Hyperpolarization

- Spin-exchange method with optically pumped Rb vapor [3] was used in a flow systems to produce HpXe [4]. Polarization of HpXe between 12-18% in 0.75 liter isotopically enriched  $^{129}\text{Xe}$  ( $^{129}\text{Xe} > 82\%$ ) gas was routinely achieved.
- For in vivo measurements HpXe was filled in Tedlar<sup>TM</sup> bags from which the volunteer inhaled the gas. For phantom measurements the hyperpolarized gas was filled in glass bulbs ( $\sim 5$  or  $2$  cm inner diam.).

### MR Methods

- All MR measurements were performed on a 3 tesla scanner (MEDSPEC 30/100, BRUKER Biospin MRI) with a transmit-receive double-resonant  $^1\text{H}/^{129}\text{Xe}$  open bird-cage head-coil (RAPID BIOMEDICAL).
- Flip angle calibration: trains of 20 FIDs were acquired; amplitudes fitted to  $\cos^2\alpha$ .
- 2D CSI measurements: excitation pulses (1ms duration, 6.21kHz bandwidth,  $\alpha \sim 22^\circ$ ) tuned to 200ppm with respect to  $^{129}\text{Xe}$  gas resonance frequency (34.67 MHz). For coronal and sagittal planes no slice selection was applied. For the axial plane a slice selection of 10cm was chosen (matrix  $16 \times 16$  points, FOV  $32\text{cm} \times 32\text{cm}$ ).

### In Vivo 2D CSI Sequence

- For CSI at each  $k$ -space point one FID has to be acquired:
  - $\Rightarrow$  resulting in 256 RF excitation pulses for a  $16 \times 16$  matrix
  - $\Rightarrow$  strong signal loss due to polarization decay when using HpXe
- To achieve uniform weighting of the  $k$ -space sampling of the  $k$ -space points was performed in a spiral way with  $|k| \leq k_{\text{max}}$ :
  - $\Rightarrow$  only 192  $k$ -space points needed to be sampled for a  $16 \times 16$  matrix
  - $\Rightarrow$  homogeneous point spread function in the image

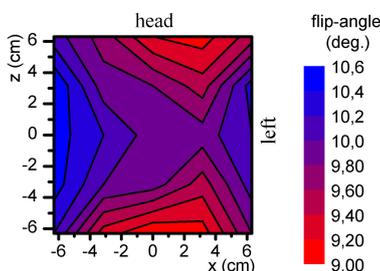
### Data Processing

After rearranging the acquired data to within a  $16 \times 16 \times 1024$  complex-valued matrix a 2D FFT was performed to get the spatial distribution of the FIDs. A Gaussian line broadening was applied ranging from 0 to 1.5 ppm. To analyze these FIDs a time domain frequency domain (TDFD) method was used to fit frequency, amplitude, linewidth and phase independently for each assumed line within user adjustable constraints [5].

## RESULTS

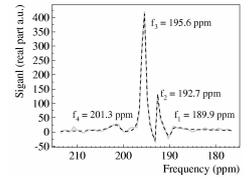
### Flip Angle Measurements

The head coil has a homogeneous  $B_1$ -field distribution resulting in less than 10% variation of the adjusted flip angle within a concentric cylindrical volume of at least 12 cm in length and diameter.

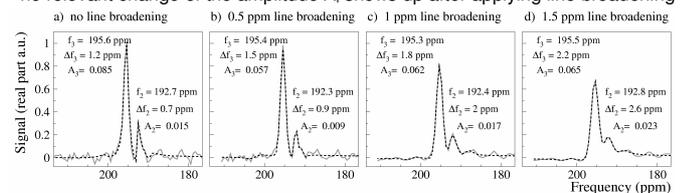


### In Vivo Measurements

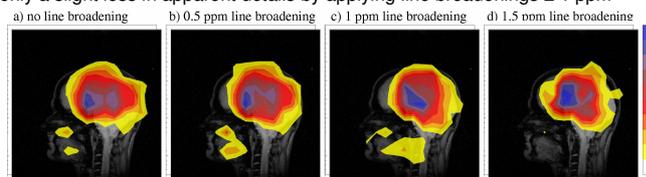
- The average over 180 spectra laying in the head region of the sagittal 2D CSI measurement shows that four lines can be resolved (no line broadening applied; gray line: averaged spectra; dashed line: fit of four Lorentzian lines).



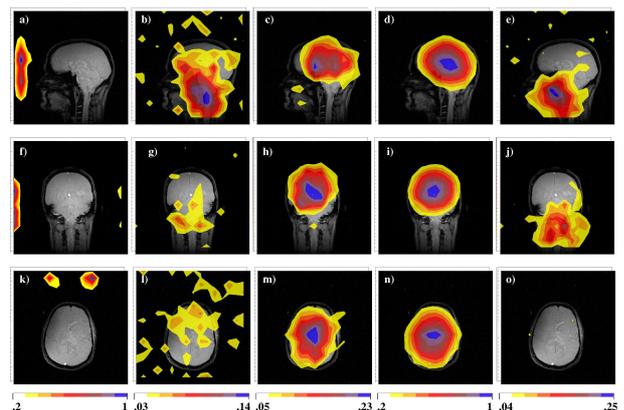
- Line broadening is shown by means of a spectrum from a voxel inside the brain:
  - mainly two lines are seen in the brain region
  - no relevant change of the amplitude  $A_i$  shows up after applying line broadening



- Colour encoded histograms of the 193 ppm line amplitude from fitting all 256 spectra from the sagittal 2D CSI with different applied line broadening:
  - no general change in signal spreading is seen
  - only a slight loss in apparent details by applying line broadenings  $\geq 1$  ppm



- Colour encoded histograms of the HpXe gas signal amplitude a), f), k) within the Tedlar bag and the four line amplitudes from HpXe within the human head derived by the TDFD-fitting procedure from the measurements without line broadening: a) to e) sagittal, f) to j) coronal and k) to o) axial views (consider the separate scaling for gas- and dissolved-phase signals; windowing of colour encoding is performed with respect to the sagittal view):
  - the Tedlar bag with remaining HpXe gas is clearly seen a), f), k)
  - the two dominant lines (196 ppm, 193 ppm) are confined to the brain region
  - the two minor lines (190 ppm, 201 ppm) arise from HpXe in non-brain tissue laying below the brain  $\Rightarrow$  no signal in l) and o) due to 10 cm slice selection



## CONCLUSION

- ◆ The developed 2D CSI acquisition together with a single breath inhalation of highly polarized enriched  $^{129}\text{Xe}$  gas is a robust technique to get spatially resolved dispersions of four dissolved-phase lines from human head.
- ◆ The two dominant peaks in human head studies at about 196 ppm and 193 ppm are clearly confined to the brain region and probable arise from HpXe dissolved in gray and white matter, respectively. Whereas the two minor peaks at about 190 ppm and 201 ppm arise from nonbrain tissue.

### References

- [1] Kilian W. et al., *Mag. Reson Med.* **51**, 676 (2004)
- [2] Nakamura K. et al., *Mag. Reson Med.* **53**, 528 (2005)
- [3] Walker T.G. and Happer W., *Rev. Mod. Phys.*, **69**, 629, 1997
- [4] Kilian W., PhD thesis, Freie Universität Berlin, 2001.  
[www.diss.fu-berlin.de/2001/105/](http://www.diss.fu-berlin.de/2001/105/)
- [5] Elster C. et al., *Mag. Reson Med.* **53**, 200 (2005)