

SPECTROSCOPY OF DISSOLVED ^{129}Xe IN HUMAN BRAIN AT 1.5T

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Target audience: Brain MRI, hyperpolarized ^{129}Xe spectroscopy and RF coils engineering.

Purpose: Hyperpolarized (HP) ^{129}Xe , when inhaled into the lungs, dissolves in the blood via the alveolar-capillary pathway and can be used to study perfusion in other organs. HP ^{129}Xe has a large range of chemical shift and can be used to study uptake in the human brain when dissolved ^{129}Xe is transferred across the blood-brain barrier to white matter, grey matter and cerebral lipids. The dynamics of ^{129}Xe uptake in the human brain has been previously measured at 3.0T¹; this study reported detection of NMR peaks from ^{129}Xe dissolved in white and grey matter, with no evidence of peaks from blood or lipids, despite what has been observed previously in the rat brain³. An earlier study at 1.5T in the human brain exhibited only a single dominant peak from brain tissue². The motivation of our work is to demonstrate dynamic spectroscopy of ^{129}Xe in the human brain at 1.5T using optimized RF brain coil designs at 17.6 MHz. Given the large RF wavelength, this work evaluates results from a spiral topology as compared to conventional loop topology.

Method: Two RF quadrature transmit-receive coils (QTR) were constructed, one with conventional loop topology as shown in Fig 1(a) and the second with a spiral topology as shown in Fig 1(b). Both the loop and spiral coils were of dual-Helmholtz design and equal dimensions. In-vivo spectroscopy of the human brain with HP ^{129}Xe was performed on a GE 1.5T (Signa HDx) system. HP ^{129}Xe gas (86% ^{129}Xe , 12% polarization) was inhaled in doses of 1L and 500mL for the Loop and the Spiral QRT respectively⁴. The subject tolerated the breath-hold well and vital signs were monitored throughout the scan. Whole-brain ^{129}Xe spectra were acquired using a pulse-acquire sequence, with an inter-pulse delay (TR) of 2s. FA was 90°, with an RF pulse-width of 500µs (50mW average power) and bandwidth of 1.2 kHz, centre frequency was set to 197ppm downfield from the ^{129}Xe gas peak. The FID was multiplied by Gaussian line-broadening of 3.5 Hz before transforming into the frequency domain.

Result: The $Q_{\text{unloaded}}/Q_{\text{loaded}}$ ratio was 12 and 10 for Spiral and Loop QRT respectively, the Spiral QTR was 12% more RF power efficient on the scanner. The ^{129}Xe brain spectrum from the Loop QTR showed peaks attributable to ^{129}Xe in lipids, white matter, grey matter and blood, whereas, the spectrum from the Spiral QTR showed lipid, white matter and grey matter peaks only, as shown in Fig 2. Also, the time series spectra from the Spiral QTR displayed a gradual uptake and decay, whereas, the signal from the Loop QTR exhibited continuous decay from the initial value.

Discussion: As the sensitivity profile of the Spiral QTR is focused along the axis of polarization; which is the centre of the brain as shown in Fig1 (see red dashed lines), the signal detected by the spiral QTR is localized to the brain. Within the region of interest the Spiral QTR is efficient; in-contrast, the sensitivity profile of the Loop QTR is broader and extends beyond the brain, thus detecting signal from outside the region of interest. This may explain the presence of a red blood cell peak, a larger lipid peak (presumably subcutaneous lipids) and a broader spectral width of the grey matter peak which are not observed with the

Spiral QTR as shown in Fig 2. The time-evolution of signal amplitude from the spiral QTR for ^{129}Xe white matter and grey matter peaks is shown in Fig 3. A gradual uptake was observed followed by a steady decay in signal. The uptake is characterised by the finite time elapsed during inhalation ($H=6\text{s}$) and the transit time ($\tau=8\text{s}$) required for blood to flow from the lung to the brain. The decay in signal is dominated by the T_1 of the reservoir of HP ^{129}Xe gas in the lung ($T_{1g}=23\text{s}$) and the T_1 of HP ^{129}Xe dissolved in the blood ($T_{1b}=10\text{s}$). We hence arrive at the model shown in expression (1) to explain the time-evolution of white matter and grey matter peaks as shown in Fig 3. This work is preliminary and additional samples are required to further validate this model.

Conclusion: In this work we have demonstrated multiple dissolved ^{129}Xe peaks in the human brain in-vivo for the first time at 1.5T. In addition to separate peaks attributed to grey and white matter, we have detected peaks from ^{129}Xe in red blood cells and lipids in the head. We have also optimized the topology of QTR dual Helmholtz RF coils for ^{129}Xe brain spectroscopy and have developed a preliminary model to describe dissolved ^{129}Xe uptake from the lungs to the brain as a first step towards quantitative trans-blood-brain barrier brain perfusion measurement.

References:

1 W. Kilian, *et al.*, *Magnetic Resonance in Medicine*, 51 (2004), 843-47. 2 J. P. Mugler iii, *et al.*, *Magnetic Resonance in Medicine*, 37 (1997), 809-15. 3 K. Nakamura, *et al.*, *Magnetic Resonance in Medicine*, 53 (2005), 528-34. 4 G. Norquay, *et al.*, *Journal of Applied Physics*, 113 (2013).

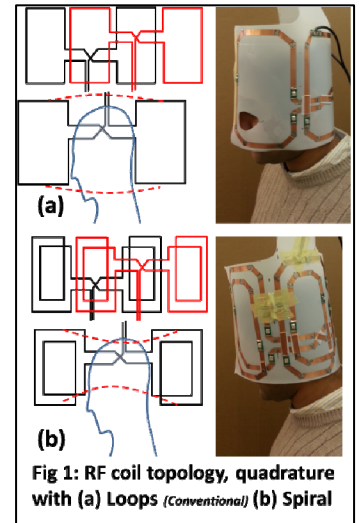


Fig 1: RF coil topology, quadrature with (a) Loops (Conventional) (b) Spiral

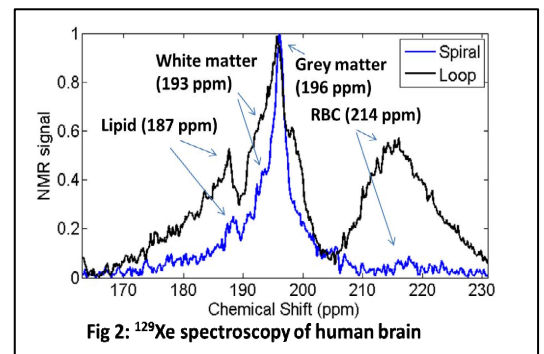


Fig 2: ^{129}Xe spectroscopy of human brain

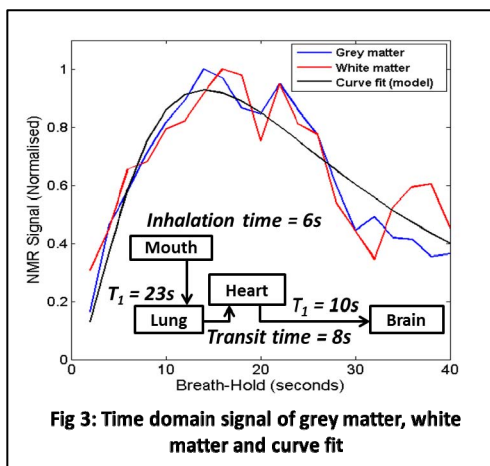


Fig 3: Time domain signal of grey matter, white matter and curve fit

$$\left(1 - e^{-\frac{t}{H}}\right) \left(1 - e^{-\frac{t}{\tau}}\right) e^{-\frac{t}{T_{1g}}} e^{-\frac{t}{T_{1b}}} \quad (1)$$

H = Inhalation time constant
 τ = transit time constant
 T_{1g} = T_1 of ^{129}Xe In lung air-space
 T_{1b} = T_1 of ^{129}Xe dissolved in blood