Imaging the human brain with dissolved xenon MRI at 1.5T

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Target Audience: Brain imaging and function; hyperpolarized noble gases community.

Purpose: When inhaled into the lungs, xenon dissolves into blood, and is carried to the brain where it crosses the blood-brain barrier and dissolves into brain tissues. The T_1 of ^{129}Xe dissolved in blood is 8s, long enough for the hyperpolarized (HP) ^{129}Xe signal to be detected in the brain and distal tissues from the lungs[1]. ^{129}Xe has a large NMR chemical shift range, providing spectroscopic distinction of the different compartments of the brain, namely: the cerebral blood (red blood cells RBCs and plasma), grey-matter, white-matter and lipids[2-5]. The aim of this work was to demonstrate high-resolution spectroscopy and 2D gradient echo imaging of HP ^{129}Xe dissolved in the human brain at 1.5 T for the first time. In this study, we demonstrate HP ^{129}Xe as a safe, non-invasive contrast agent for imaging of xenon (blood) delivery to different compartments of the human brain in vivo.

Method: An 8-leg birdcage coil (300 mm diameter and 300 mm length), tuned to the ^{129}Xe Larmor frequency (17.7 MHz at 1.5T) was constructed. In-vivo spectroscopy and imaging of HP ^{129}Xe dissolved in the human brain was performed on a GE 1.5 T Signa HDx MR scanner. ^{129}Xe nuclei were hyperpolarized by spin-exchange optical pumping to a nuclear polarization of 40-50%[6]. Isotopically-enriched xenon gas (87% ^{129}Xe) was delivered in doses of between 600 mL and ~ 1 L for inhalation by the study subjects (healthy). Typical MR pulse sequence parameters for both spectroscopic and imaging experiments were as follows: *Spectroscopy*: pulse-acquire sequence, inter-pulse delay time (TR) = 2 s, flip angle = 55°, bandwidth = 1.2 kHz, center frequency = 197 ppm downfield from the ^{129}Xe gas peak. *1D FID chemical shift imaging (CSI):* left-right phase encoding, TR = 0.7 s, bandwidth = 1.2 kHz, slice thickness = 200 mm, matrix = 1 x 24, flip angle = 40°. *2D (spoiled) gradient echo (SPGR) imaging:* axial slice, echo time = 1.7 ms, TR = 34 ms, bandwidth = ±2 kHz, field of view = 22 cm, slice thickness = 50 mm, matrix = 32 x 32, flip angle = 12.5°. For a single 2D SPGR scan procedure, three separate images were acquired and averaged; the first one 8s after inhalation, the second after 16 s and the third after 24s. All the subjects tolerated the breath-hold well and vital signs were monitored throughout the scan.

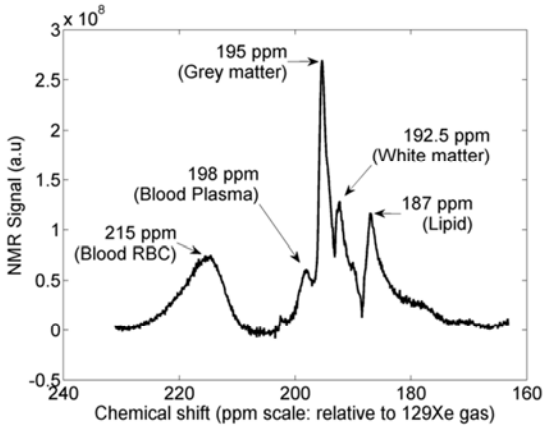

Figure 1: Spectroscopy of hyperpolarized ^{129}Xe dissolved in human brain at 1.5T (1.2kHz bandwidth, 1024 no of points)

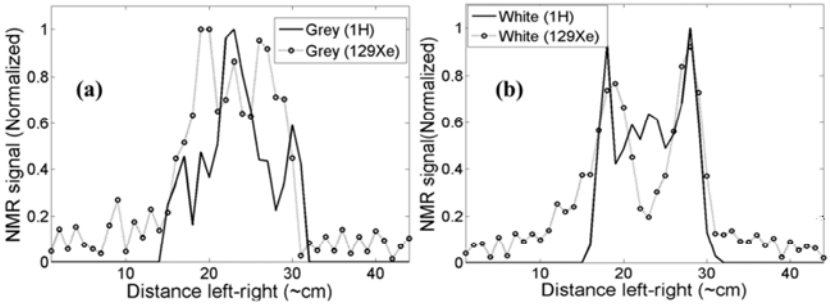

Figure 2: 1D chemical shift projection of hyperpolarized ^{129}Xe dissolved in human brain from left-to-right direction for (a) grey-matter and (b) white-matter. ^{1}H projection for reference.

Results: The ratio of $Q_{unloaded}/Q_{loaded}$ for the custom-built ^{129}Xe brain RF coil was 3. High-resolution spectroscopy of HP ^{129}Xe in the human brain showed several peaks, which we have attributed to ^{129}Xe dissolved in cerebral blood (RBCs and plasma), grey-matter, white-matter and lipids, as shown in Figure 1. 1D chemical shift imaging in the left-right direction indicates that the distribution of grey-matter and white-matter shows some correlation with that measured by ^{1}H images segmented for grey-matter and white-matter, as shown in Figure 2. 2D axial (Figure 3(b)) SPGR imaging of HP ^{129}Xe dissolved in the human brain (Figure 3(a)) correlated well with the structural information from the ^{1}H grey-matter images (Figure 3(c)). Figure 3(a) shows the average ^{129}Xe brain image from the three separate acquisitions (same breath-hold).

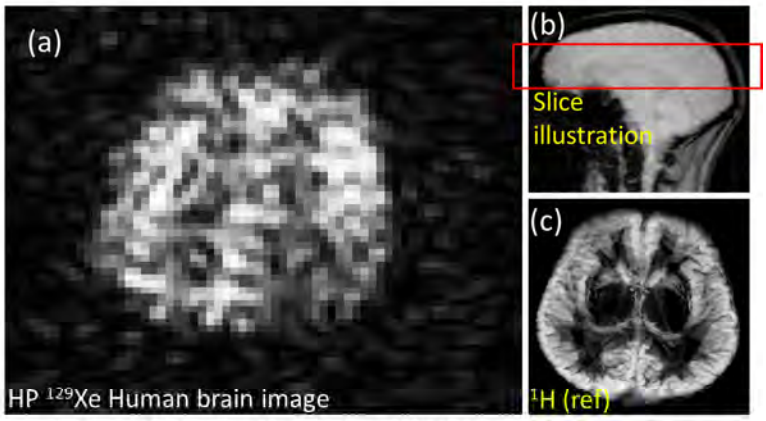

Figure 3: (a) Image of hyperpolarized ^{129}Xe dissolved in human brain (predominantly grey matter) (b) illustration of slice selection and (c) ^{1}H image of the brain segmented for grey matter

Discussion and Conclusions: Although the 1D CSI and 2D axial SPGR imaging of HP ^{129}Xe dissolved in the human brain correlates well with the ^{1}H MR imaging, the signal-to-noise ratio is not yet comparable to that of ^{1}H. It is worth noting that the signal in the ^{129}Xe SPGR image predominantly from the grey-matter peak, which demonstrates effective transport of xenon across the blood brain barrier. In conclusion, we have demonstrated anatomically meaningful imaging of HP ^{129}Xe dissolved in the human brain for the first time, and we believe this non-invasive inhaled contrast agent may find application in studies of brain function in the future.

References: **1**. G.Norquay, et al, MRM. doi:10.1002/mrm.25417. **2**. W. Kilian, et al, MRM, 51 (2004), 843-47. **3**.W. Kilian, et al, Proc. Int. Soc. Magn. Reson. Med. 13 (2005); ISSN 1545-4436 **4**. K. Nakamura, et al, MRM, 53 (2005), 528-34. **5**. J. P. Mugler Iii, et al, MRM, 37 (1997), 809-15. **6**. G. Norquay, et al., JAP, 113 (2013).