Selective Excitation of Dissolved ^{129}Xe

General Leung[1], Graham Norquay[1], Rolf F Schulte[2], and Jim M Wild[1]
[1]*Department of Cardiovascular Science, University of Sheffield, Sheffield, South Yorkshire, United Kingdom*, [2]*GE Global Research, Munich, Germany*

Target Audience Hyperpolarized MR spectrally selective pulse designers

Purpose Short RF pulses for frequency selective excitation of dissolved ^{129}Xe

Introduction Hyperpolarized ^{129}Xe is a promising contrast medium that is capable of probing physiological parameters owing to its solubility in tissues [1-2]. When dissolved, the ^{129}Xe resonance shifts approximately 200 ppm from the gas signal, with distinct separation of the signals from the dissolved (^{d}Xe) and gas (^{g}Xe) phase resonances. Previous studies have used long excitation pulses to selectively excite ^{d}Xe resonances, assuming a minor ~1-2◦ perturbation of the larger ^{g}Xe peak. However, owing to the low solubility of ^{129}Xe in blood coupled with the a small blood volume to air space ratio in the lung, the intensity of ^{d}Xe is approximately two orders of magnitude lower than the intensity of ^{g}Xe. This means that even a 1° flip angle on the ^{g}Xe peak will result in ^{d}Xe and ^{g}Xe signals of equal magnitude. Non-Cartesian trajectories are often needed to capture the short T_2* of the ^{d}Xe (< 2ms [3]), this sizeable off-resonance ^{g}Xe peak can create undesirable imaging artifacts. However, longer, more frequency selective RF pulses are suboptimal due to the T_2* dephasing during the pulse. Ideal excitation pulses for imaging dXe should have very low side band excitation coupled with short pulse length to minimize in-pulse T_2* relaxation [4]. Spectroscopists have used composite pulses extensively for water suppression which may be ideally suited for ^{d}Xe imaging. In this work, we compare standard RF excitation pulses with shaped and composite pulses based on their spectral selectively and performance in relation to T_2* relaxation.

Methods The Bloch equations were numerically simulated over a 4 kHz range using a T_2* of 1.6ms and 80ms for ^{d}Xe and ^{g}Xe respectively. Shaped pulses were designed using the Shinnar-Le Roux method [5] with a minimal time bandwidth product, minimum phase and minimum stop band ripple. Composite pulses were designed for notched attenuation at ^{g}Xe frequency (3.5kHz @1.5T). Spectra were acquired on a 1.5T GE HDx scanner using a custom built solenoid coil tuned to 17.66 MHz. Hyperpolarized ^{129}Xe was infused into whole blood and spectra were acquired using the excitation pulses described.

Results Simulated excitation pulses and profiles are plot in Fig 1. The shortest pulse in this study (500 µs hard pulse) is least affected by T_2* dephasing and produces transverse magnetization $M_{xy}=0.86M_o$ on resonance (red). However, despite having a nominal bandwidth of 2 kHz, the ^{g}Xe signal is only ½ an order of magnitude lower than ^{d}Xe. The1.8ms long Hamming-windowed sinc pulse provides only half the total M_o, and gives poor side band excitation as well. An 800 µs, 6 element optimized composite pulse delivers $M_{xy}=0.72M_0$, but has ^{g}Xe excitation over five orders of magnitude less than ^{d}Xe (black). Fig 2 shows spectra experimentally acquired with these two pulses, normalized to the highest dissolved spectral peak showing a dramatic excitation difference at ^{g}Xe. With hard pulse excitation the gas is nearly an order of magnitude higher than either dissolved peak. With composite pulse excitation, the gas peak is nearly undetectable. Inset in the figure is a 100x magnification of the y-axis to show the residual excited gas peak. Measured excitation is 2 orders of magnitude lower than the dissolved peak, corresponding to a 4-5 order of magnitude suppression.

Discussion Excitation with a composite pulse precludes slice selectivity, necessitating three dimensional encoding but this also eliminates the requirement for a slice refocusing pulse, which reduces effective echo time. If spectral selectivity is required, the minimum phase SLR pulse performs well in regards to side band suppression, however, the length of this pulse reduces signal in an already low SNR regime. The phase toggled implementation of the composite pulse generates no excitation at the tuned frequency, while generating a wide excitation band off resonance.

This allows for the precise tuning to the resonance of gas to enable minimum excitation at this frequency. Even in the presence of B0 inhomogeneity, this pulse has >4 orders of magnitude suppression over a 600Hz range.

Conclusions Standard excitation pulses perform poorly for the selective excitation of ^{d}Xe, especially at lower fields where their resonance separation is small. While minimum phase SLR pulses can provide up to 3.5 orders of magnitude suppression and deliver high tip angles, tuned composite pulses can be made very short, delivering a higher percentage of M_O to the transverse plane and provide sharp resonance notches that are ideal for suppressing narrow line shapes such as in the case of ^{g}Xe.

References [1] Cleveland PLoS ONE 5, no. 8(2010): e12192.[2]Wolber, *Magn Reson Med* 43,4 (2000):491–496[3]Xu Proc XeMat Dublin T9-21(2012) [4] Mugler P Natl Acad SciUSA107 no.50 (Dec14, 2010): 21707–21712. [5] Pauly J IEEE *IEEE T Med Imaging* 10, no. 1 (1991): 53–65.

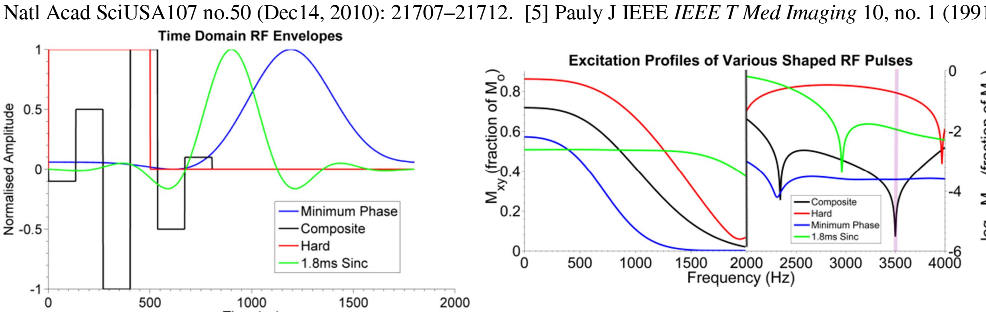

Figure 1: Time domain envelope of RF excitation pulses (left) and their resulting profile including T_2* in pulse relaxation (right). Far right (beyond dashed lines) is log magnitude to emphasize small differences. ^{d}Xe is at 0Hz and ^{g}Xe is 3.5kHz (purple line). The short dissolved ^{129}Xe T_2* puts difficult criteria on RF pulse length as seen by the M_{xy}(0Hz) as pulse length increases. Suppression of signal from is very strong for both shaped and composite pulses.

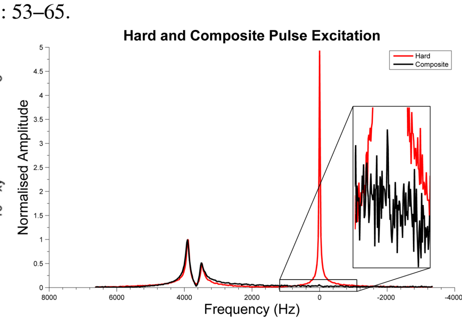

Figure 2: Spectra of ^{g}Xe (at 0Hz) and ^{d}Xe (at 3500-4200 Hz) using a hard pulse excitation (red) and a 6 element, 800us composite pulse (black), inset is 100x magnification in amplitude.