Hyperpolarized ^{83}Kr Imaging on a Clinical 3 T System

Daniel James Lee[1], Joseph Six[2], Matthew Clemence[3], Paul M Glover[1], Thomas Meersmann[2], and Karl Stupic[2,4]

[1]SPMMRC, University of Nottingham, Nottingham, Nottinghamshire, United Kingdom, [2]Medical School, University of Nottingham, Nottingham, Nottinghamshire, United Kingdom, [3]Philips Healthcare, Guildford, Surrey, United Kingdom, [4]National Institute of Standards and Technology, Boulder, Colorado, United States

Target Audience Researchers working with hyperpolarized gasses and lungs/respiratory disease.

Purpose Respiratory diseases have become one of the leading causes of hospitalizations, a rising cause of death, carry high economic impacts and one person in seven is currently affected by lung disease in the UK. The need to obtain sensitive, non-invasive information for diagnosis is therefore vital for improved healthcare, for reducing costs and for evaluating treatment efficacy. For this, MRI is an ideal modality, as it is non-invasive, there are no exposure limits and no long-term side effects.

The limitations of ^{1}H MRI in the respiratory system are in the need for high tissue or fluid density to obtain high-resolution imaging. Therefore imaging the respiratory system with MRI requires a novel approach. The technological advances made at the physics – biomedical sciences interface with hyperpolarized (hp) noble gases promise to become the most significant advance in pulmonary diagnostics in decades.

Current research in the field of lung MRI has focused on two isotopes, ^{3}He and ^{129}Xe. These isotopes have produced high-resolution images, oxygen distribution mapping, and gas perfusion information. Here a different class of isotope, a quadrupolar isotope (spin $I > 1/2$), has been used which has shown sensitivity to changes in the environment being probed and therefore provides a different contrast mechanism[1]. The isotope ^{83}Kr has the potential to become a new contrast agent for respiratory MRI where changes such as inflammation, lung surfactant concentration, and alveolar shape could be monitored as important pathologies for lung disease.

A platform for *ex-vivo* animal lung imaging with hp noble gas isotope ^{83}Kr is being developed. An ^{83}Kr coil suitable for phantom imaging on a 3T MRI system has been built and assessed using a phantom to evaluate the feasibility of lung imaging using hp ^{83}Kr.

Methods The coil, shown in Figure 1, was constructed on a cylindrical former (diameter = 22 cm, length = 40 cm). The coil design was a transmit/receive saddle-coil[2], a well-established volume coil design for use at 4.8 MHz (the resonant frequency of ^{83}Kr at 3T). The coil was resonant at 4.877 MHz, had an impedance of $Z = 40 - i2\ \Omega$ and a quality factor of $Q \approx 2400$. The phantom consisted of an acrylic cylinder (diameter = 20 cm, length = 5 cm) with two access ports. One port provided the inlet for the hp ^{83}Kr. The second port provided vacuum prior to the introduction of the hp ^{83}Kr (this port was closed when the hp ^{83}Kr was introduced to the phantom). Scanning was performed on a Philips multi-nuclear 3T Achieva system (Philips Healthcare, Best, The Netherlands). Experiments included spectroscopy sequences to confirm the detection of ^{83}Kr, FFE imaging and multiple-dynamic FFE imaging for T_1 measurement. Hp ^{83}Kr was produced via stopped flow spin-exchange optical pumping (SEOP) with a 100 W diode array laser (QPC Lasers) line-narrowed to 0.5 nm at the Rb D1 transition of 794.7 nm. The SEOP cell contained 1 g of Rb and the krypton mixture of 25 % krypton, 10 % nitrogen, 65% helium. A diagram of SEOP system is provided in Figure 2.

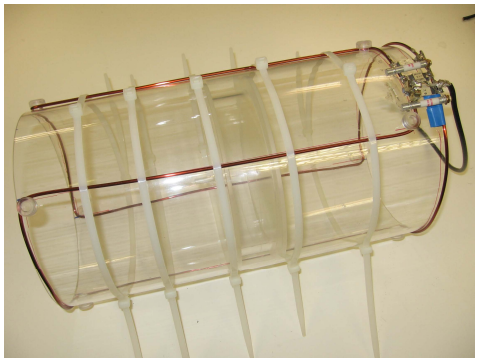

Figure 1 – The coil with phantom in place.

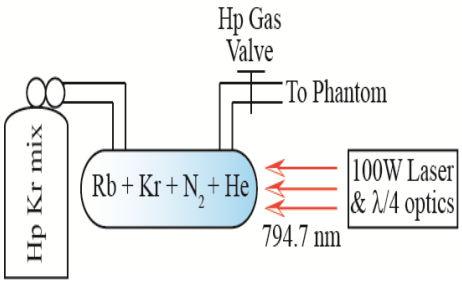

Figure 2 – SEOP system.

Results A spectrum obtained from the ^{83}Kr is presented in Figure 3, and an axial image of the phantom is presented in Figure 4. Both clearly demonstrate the feasibility of detecting ^{83}Kr on the 3 T system. The plot of signal intensity versus time (Figure 5) yields a T_1 of 48 s when fitted using equation 1 from Stupic et al.[1] which accounts for polarization destruction from the RF pulse.

Discussion Detection of hp ^{83}Kr has been demonstrated using a clinically available MRI system both through spectroscopy and imaging. The T_1 time of 48 s allows for short term hp ^{83}Kr storage at this field strength. The T_1 in lungs will be significantly shortened.

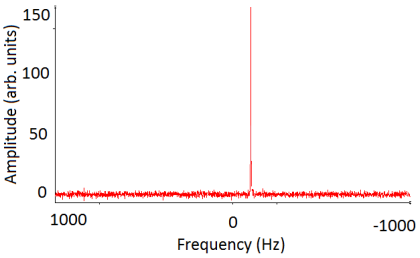

Figure 3 - ^{83}Kr spectrum obtained with a polarization of approximately 1%, a pressure of 1 atmosphere, and a 25% dilution. The phantom had a volume of 1570 cm^3, approximately 10% of the total coil volume.

Figure 4 – Pulse acquire ^{83}Kr image. 6 mm x 6 mm resolution. 500 mm x 500 mm FOV. Flip angle 24°.

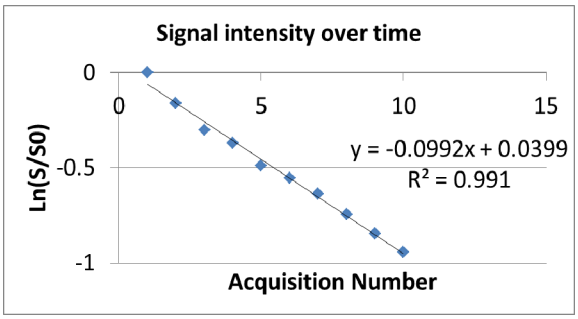

Figure 5 – A plot of signal intensity (normalised to the first signal reading) versus acquisition number used to fit T_1. The repetition time between experiments was 4 s.

Stupic et al.[1] measured T_1 = 1 - 2s in rat lungs at 9.4 T. The T_1 in human lungs is still unknown, but may be significantly longer than in rodent lungs due to the approximately 3 - 4 times larger alveolar diameter compared to those found in rat lungs.

Conclusion Initial experiments with hp ^{83}Kr show much potential for future imaging applications. The described setup allows for future measurements with porcine lungs that will provide a more realistic estimate of the ^{83}Kr relaxation behaviour in humans.

Acknowledgments Philips Healthcare Clinical science for technical support. Funded by the University of Nottingham's Bridging the Gaps scheme.

References 1. Stupic et al., *Phys. Med. Biol*. 2011. 2. D.M. Ginsberg and M.J. Melchner. *The Review of Scientific Instruments*, 41(1) 1970. 3. Brinkmann D and Kuhn D 1980 *Phys. Rev. A* 21 163–7.