Hyperpolarised ^{3}He Production and Low Field Imaging (0.15T)

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Abstract
In recent years, much interest has been devoted to the new technique of lung imaging using hyperpolarised (HP) noble gases. We demonstrate an in-house production technique using metastable optical pumping. A non-magnetic peristaltic compressor is used to transfer HP gas from the optical pumping cell to a storage vessel. We are able to accumulate around 40 ml of gas polarised to around 15 % in half an hour. Sufficient NMR signal is provided by the small dose, to allow acquisition of slice-selected images of the entire lung volume using single shot RARE at 0.15T

Introduction
Hyperpolarised (HP) ^{3}He imaging of the lungs is a rapidly developing diagnostic technique. The NMR signal can be enhanced by approximately five orders of magnitude by optical pumping, thus compensating for the low density of the gas, and providing unsurpassed images of the air-ways. There are two laser-based methods for producing HP gas: direct optical pumping on metastable ^{3}He[1] and spin exchange with an alkali vapour. In this work, we are use direct optical pumping, which has the advantage of the efficient use of photons but the disadvantage that the gas is produced at a low pressure. Various expensive and complex schemes have been devised for compressing the HP ^{3}He gas that is needed for neutron targets. These require large and highly polarised samples of HP gas, whereas for medical imaging the requirements are more modest. We demonstrate here the ability to accumulate sufficient HP gas in about half an hour to allow multi-slice imaging at low field (0.15T). The HP gas is polarised using a system constructed entirely in-house which incorporates a non-magnetic peristaltic compressor.

Gas Production Method
In our system, the optical pumping cell, a 320 ml pyrex tube, is filled with ^{3}He gas to a pressure of 1 to 5 mbar and subjected to a uniform field of 2 mT. The ^{3}He gas is optically pumped by a 2W fibre laser[2] tuned to 1083 nm. A peristaltic compressor is used to transfer gas from the optical pumping cell to a storage vessel at a much higher ultimate pressure[3]. The compressor, shown in Fig. 1, is ideal for use with HP gases because the only material that is in direct contact with the gas is the 5 mm internal diameter Tygon® plastic tubing which is non-magnetic. All other components are also non-magnetic, apart from the drive shaft which is made from 316L stainless steel for mechanical reasons. The compression ratio of the device is potentially limitless. However, general wear and tear of the tubing usually yields compression ratios of a few thousand with the outlet at a pressure of one bar. The tubing itself is contained in an evacuated jacket, which aids the restitution of the tubing after occlusion. The diameter of the compressor is 10 cm and the fastest rotation speed of the roller head is 300rpm.

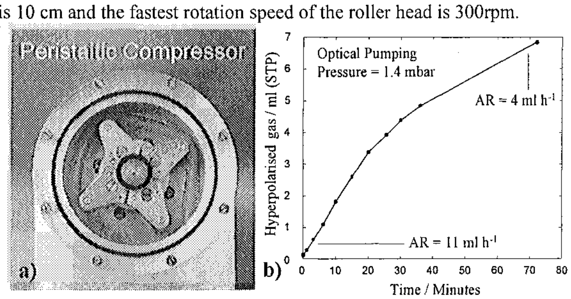

Figure 1: a) The peristaltic compressor b) The production shown is for typical operating conditions. The compressor was pumping at a volume rate of 15 ml per second. The Accumulation rate (AR) is in units of ml of 100% polarised spins.

Figure 1b shows the accumulation of hyperpolarised gas during a typical production run. The gas pressure in the optical pumping cell was 1.4 mbar yielding a polarisation of 20 % under flowing conditions. During accumulation the polarisation slowly decreased to around 12 – 15 % due to T_1 relaxation in the storage vessel (< 50 mins). The initial production rate for this run was equivalent to 11 ml (STP) of 100% polarised ^{3}He gas per hour.

Imaging
It is possible to obtain reasonable images of the lung using less than 1 ml of HP gas[4]. However, such a small quantity provides sufficient signal for acquisition of only one thick slice. Using the peristaltic pump to accumulate larger quantities of gas yields more signal for imaging allowing acquisition of thin slice selected images and multi-slice imaging across the entire lung. In figure 2, the entire lung has been captured using a multi-slice single shot RARE sequence, with only one excitation per slice. RARE imaging of hyperpolarised gas can only be achieved over many slices if B_1 homogeneity is uniform across the whole lung volume since small deviation in flip angle of the 180^0 refocusing pulses would lead to rapid bulk depolarisation of the gas. We use a large, whole-body transmit coil to achieve a uniform B_1 profile.

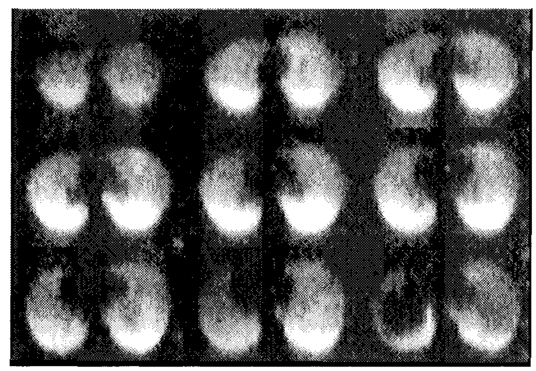

Figure 2. A multi-slice RARE image of the lungs of a healthy volunteer (64 x 64, FOV 400 mm, slice thickness 15 mm.)

Discussion
We have demonstrated that small quantities of HP gas can be used for human MR imaging of the lungs using RARE at low field. The peristaltic pump provides a means of compressing or transferring HP gases. With the current system we can easily produce 6-8 doses of HP gas a day but we expect to improve the HP gas storage which will allow us to accumulate larger quantities. Mechanical improvements of the peristaltic pump are required since at present there are some losses of polarisation: the effective T_1 due to relaxation at the outlet port of the compressor is less than 50 minutes limiting the gas production rate, as shown by the decreasing slope in Fig. 1. We aim to replace the steel shaft by a non magnetic alternative.

Acknowledgements
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References
1. F D Colegrove, LD Shearer and GK Walters *Phys. Rev.* **132**, 2651 (1963).
2. Keopsys inc., FRANCE
3. PJ Nacher, G Tastevin, X Maitre, X Dollat, B Lemaire, J Olejnik. Proceeding of Les Houches workshop on hyperpolarised gases in MR, p18 (1999)
4. CJ McGloin, S Fichele, A. Benattayallah, S. Monfraix, J. R. Owers-Bradley, R.W. Bowtell, A. Moody, P.S. Morgan, *Proc. Intl. Soc. Mag. Reson. Med,* **9**, 947 (2001), ISMRM, Glasgow, 2001.