Hyperpolarised gas filled MRI catheter with MR pressure measurement sensitivity

J. M. Wild[1], S. Ajraoui[1], X. Xu[1], M. H. Deppe[1], A. J. Swift[1], S. Rajaram[1], D. J. Kiely[2], and J. Parra-Robles[1]
[1]University of Sheffield, Sheffield, Yorkshire, United Kingdom, [2]Sheffield Pulmonary Vascular Disease Clinic, United Kingdom

Introduction: The development of MR visible catheters for interventional MRI has included catheters with active RF coils [1] and those filled with a contrast agent [2]. An exogenous nucleus such as ^{19}F [3] has advantages for the latter in that the background signal is nil. The remaining technical challenge is sufficient sensitivity to the catheter signal and the capability to rapidly switch between the ^{1}H anatomical scout scan and the catheter image from the exogenous nucleus. In this work the feasibility of using a hyperpolarised gas filled catheter for catheter tracking was explored with pulse sequences for synchronous dynamic ^{3}He/^{1}H MRI [4]. The pressure dependence of the ^{3}He apparent diffusion coefficient (ADC) [5] in the catheter balloon was also demonstrated in phantom experiments with the ultimate aim of MR based pressure measurement without the use of a transducer.

Methods: Two latex balloon catheters were investigated, the first (Bard, UK) had a maximum inflated tip volume of 10 ml. The second was a cardiac catheter with a 1.5 ml volume balloon tip (BD, Singapore). Imaging was performed on a 3T whole body system (Philips Achieva) using two ^{3}He RF coils; a homebuilt birdcage diameter 7 cm and a Helmholtz linear T-R coil with loop diameter 19 cm (Pulseteq, UK). The catheters were filled with gas from 25 ml and 2 ml syringes respectively containing a mixture of 15% ^{3}He with 85% N_2 gas. The ^{3}He was polarised with SEOP equipment (GE Healthcare) to ~ 25%. Initial catheter visibility experiments were performed with the small birdcage coil by dynamic imaging of a 2D projection with a spoiled gradient echo pulse sequence (parameters: FOV (15cm)^2, 64^2 matrix, TE/TR 1.1/8 ms, flip angle 10°). Twelve time points were acquired continuously whilst the catheter balloon was inflated. The feasibility of dynamic ^{3}He catheter tracking in ^{1}H MRI was then investigated using the ^{3}He coil and the ^{1}H body coil with a synchronous dual resonance sequence [4] that interleaves between ^{3}He and ^{1}H acquisition per phase encode step. Sequence parameters were FOV 180 mm^2, 64^2 matrix, TE/TR 1.1/8 ms, flip angle 10°, 200 mm slice, 10 time frames. The catheter was inflated during imaging inside an upright cylindrical phantom containing 2 l of $CuSO_4$ solution.

The **pressure dependence** of the ^{3}He ADC [5], inside the larger catheter balloon was investigated with multi b-value pulsed gradient spectroscopy using 16 b-values with bipolar d.w. gradients stepped evenly between +/- 6.624mT/m (ramp time: 5e-4 s, plateau time: 8e-4 s, peak b-value: 0.36 s/cm^2). The pressure in the catheter balloon was varied by inserting it inside a 50 ml syringe and gluing the catheter feed in place such that the syringe was airtight (Fig 1). Pressure was then varied by compressing the piston in decreasing volume gradations with the balloon feed clipped off. The ADC was fitted to a mono-exponential; a valid model in this relatively free diffusion regime with the weak b-values and short diffusion time used [6].

Results:

Fig 1 (left) Pressure testing rig, catheter balloon inflated.

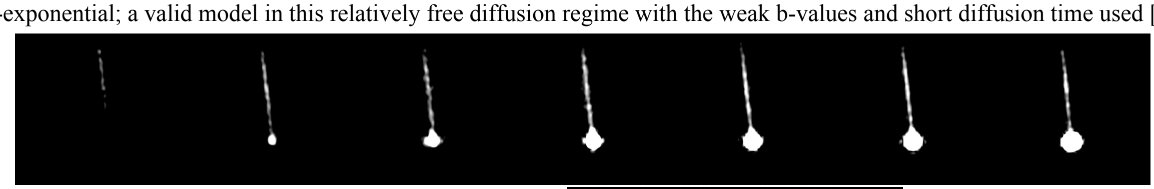

Fig 2 (above) Dynamic ^{3}He MRI time series of the inflation of the catheter tip. The signal from the catheter feed channel is also well visualized.

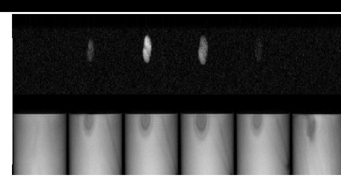

Fig 3 (left) Synchronised dynamic ^{3}He (top) and ^{1}H MRI (bottom) time series of the inflation of the catheter tip balloon inside the cylindrical water phantom.

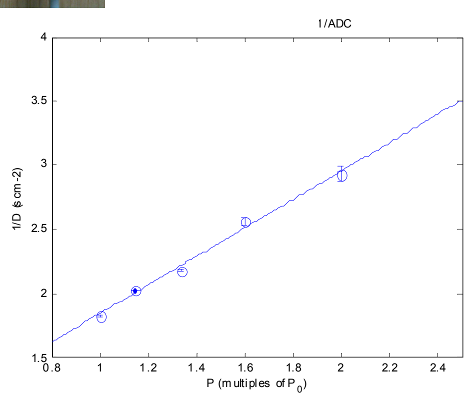

Fig 4 Relation between the ^{3}He ADC (1/D) as measured with a mono-exponential fit to the 16 b-value data and the pressure in the syringe. Error bars represent the standard deviation from 2 repeat sets of diffusion measurements. The pressure measurement is expressed as a multiple of P_0 the starting pressure, which is greater than atmospheric due to compression of the gas mixture in the insertion syringe, the compliance of the catheter wall and the resistance of the syringe plunger. Assuming ideal gas laws and that the linear relation observed can be extrapolated down to atmospheric pressure, then P_0 can be inferred as 1.6 atm from knowledge of the free diffusion coefficient of the ^{3}He /N_2 mixture at atmospheric pressure; D_0=0.88 cm^{2}s^{-1}

Discussion: The results demonstrate that hyperpolarised ^{3}He can be used as an effective catheter tracking agent, the commonality of the spoiled gradient echo sequence used in the synchronised ^{1}H-^{3}He acquisition ensures decent ^{1}H scout images can be obtained at the same time as good ^{3}He catheter images. Whilst hyperpolarised gas catheters are probably too involved for routine interventional use, the inverse linear relation between ^{3}He diffusion coefficient and the pressure outside the catheter opens up a powerful direct means of pressure measurement with ^{3}He NMR. These ideas will be explored in-vivo and with encapsulated ^{3}He inside micro-bubbles [5] for non-invasive pressure measurement.

References: [1] Ladd M.E. et al J Magn Reson Imaging. 1998;8(1):220-5. [2] Omary RA et al, J Vasc Interv Radiol. 2000 Sep;11(8):1079-85. [3] Kozerke S et al, Magn Reson Med. 2004;52(3):693-7. [4] Wild JM et al NMR Biomed. 2010 Sep 6. [Epub ahead of print] [5] Wild JM et al Proc. Intl. Soc. Mag. Reson. Med. 16 (2008), 1743 [6] Parra-Robles J et al, J Magn Reson. 2010;204(2):228-38.

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