Rapid motion mapping of hyperpolarised gas flow using k-t subsampling methods

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Introduction

Hyperpolarised helium-3 imaging allows visualising the airways during inhalation of the gas. Time-of-flight approaches have been developed to enable the high temporal resolution required to track the gas motion through the human upper and proximal airways with true 10 ms temporal resolution [1]. This information can be used to determine flow asymmetries which occur within the first bronchial generations [2], and to reveal *pendelluft* phenomena between lung regions [3]. The previously published method demonstrates that gas arrival times could be readily measured from a set of 16 dynamic images acquired during a 10 s steady inhalation. Velocity and flow patterns could then be deduced. The method is valid as long as the flow velocity remains constant over the total acquisition time. Typically under physiological respiratory conditions the input or output flows can only be assumed constant over a few seconds, which limited the method if the number of dynamic images is to be maintained, To overcome this limitation a more rapid acquisition method was required which does not compromise SNR significantly and which can be implemented with a single receiver channel (which was all that was available on the current system). The approach taken in this work was to explore the use of k-t undersampling strategies with a modified training-data free reconstruction to achieve the required acceleration whilst removing the requirement for an initial, wasteful, helium-3 gas experiment to acquire training data. The lack of background signal in hyperpolarised helium-3 imaging means that images are often very sparse, depicting only the airways, this makes them particularly suited to undersampled acquisitions. In this work a 4-fold k-t undersampling of the dynamic images was performed and data reconstructed using k-t BLAST [4]. Total acquisition times as low as 2.8 s were obtained in a mouth-trachea cast phantom with little loss in signal to noise ratio.

Material and methods

The approach was validated using a mouth-trachea cast phantom into which gas was injected at physiological velocities. The rapid gas propagation in the phantom was imaged according to a time-of-flight approach described in [1]. Nitrogen gas with 3% of 5%-polarized helium-3 [5] was injected at a monitored (320±15) $mL \cdot s^{-1}$ constant flow rate [6] in a joint mouth print and trachea phantom. Two sets of 24 interlaced projection images were acquired with the same input flows and identical sequence parameters but with differing numbers of phase encoding steps: FOV=184×96 mm^2, BW=246 Hz/pixel, TR/TE=9.8/3.2 ms, with 10% echo asymmetry, a variable flip angle $\alpha = \arctan(24-n)^{-1/2}$ - where n is the image number from 1 to 24 - and a matrix of 56×48 or 56×12 for fully sampled and 4-fold undersampled data sets respectively. This led to a total acquisition time of 11.2 and 2.8 s respectively. The chosen undersampling pattern followed a regular sheared grid decimation scheme in k-t space defined by the 24 interlaced images. Both sequences were implemented on a 0.1 T MR-unit (Sopha-Imaging, France) retuned to the helium-3 frequency at 3.29 MHz and equipped with 14 $mT \cdot m^{-1}$ gradients and a third-party digital NMR console (Tecmag, Houston, Texas). An 84 mm diameter Helmholtz coil, set around the phantom trachea, with a quality factor of 640, was used for signal reception, and a larger 40 cm saddle coil, for transmission. Training data for the k-t BLAST reconstruction was obtained directly from the undersampled data using a method which averages temporally correlated signals within the undersampled data [7]. In this approach temporal correlations within the undersampled data are identified and knowledge of the undersampling pattern is used to determine which of these will be corrupted by aliasing. By averaging together uncorrupted correlated signals it is possible to obtain a high resolution estimate of temporal information with no aliasing.

Results

Maximal SNR ranged over the 24 images between 12 and 57 for the full acquisition, between 7 and 44 on unfolded data for the 4-fold accelerated acquisition. Fully sampled and undersampled images are presented for the two acquisitions on Figure a. and b. Reconstruction with k-t BLAST led from Figure b. to images on Figure c.

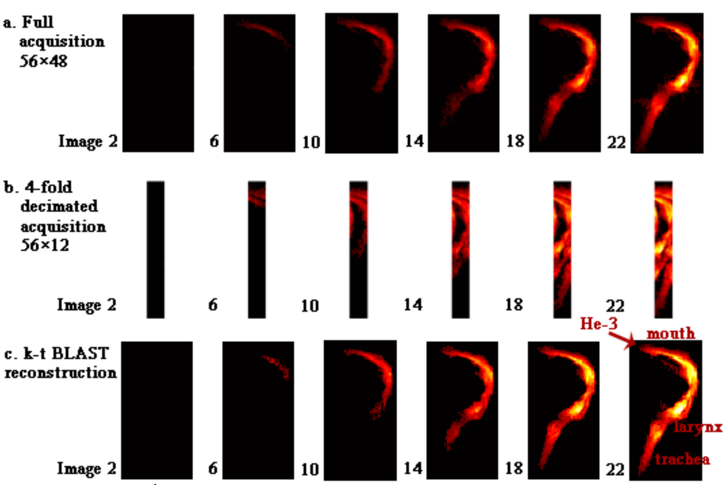

Figure: Every 4th image of the 24 acquired cine-images in a mouth-trachea phantom following **a.** full data acquisition **b.** 4-fold decimated data acquisition and **c.** k-t BLAST reconstruction

Discussion and conclusion

The large degree of sparseness and high degree of temporal correlation in these data meant that it was ideally suited to this type of acceleration. Even with the imposed tight FOV, judicious choice of k-space sampling strategy can take maximal advantage of this sparseness. Despite an initial small SNR, the image quality and the dynamic information were preserved. The variable angle cine-method highly benefits from the k-t undersampling approach. The addition of a multiple channel receive coil will increase maximum achievable accelerations. The resulting shorter acquisition times will free the stationary constraint on the imaged flow. They could also be traded in for the acquisition of additional images in order to follow the gas propagation further down and/or for 3D acquisitions which could then be considered *in vivo*.

References

1. Maître *et al.* Proc. Intl. Soc. Mag Reson Med 2007;**15**:460. **2**. Otis *et al.* J Appl Physiol 1956, 8(4):427-443. **3.** Venegas *et al.* J Appl Physiol 1988, 64(5):2108-2118. **4.** Tsao *et al.* Magn Reson Med 2003;**50**(5):1031-42. **5.** Choukeife *et al.* Proc. Intl. Soc. Mag Reson Med 2003;**11**:1391. **6.** de Rochefort *et al.* Magn Reson Med 2006;**55**(6):1318-1325. **7**. Malik *et al.* submitted

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