An Improved Method for Generating Oxygen Maps with He-3 MRI

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Introduction: A noninvasive method of identifying focal regions of pulmonary ventilation/perfusion (V/Q) mismatch would be of great use in understanding the underlying pathology of different lung diseases. Current clinical methods for observing V/Q relationships are invasive and give only global information. Hyperpolarized noble gas imaging opens the possibility of generating maps of the spatial distribution and time evolution of intrapulmonary oxygen partial pressure, p_{O2}, since the T1 of hyperpolarized gas in the lung is believed to be directly proportional to p_{O2} [1]. In turn, the time rate of change of p_{O2} is related to the local perfusion. Thus a necessary first step in using hyperpolarized gas to measure V/Q relationships is to create T_1 maps at several time points during a breath hold. Early implementations of such a technique required multiple breath holds [2], while a more recent implementation requires only a single breath hold [3], but both techniques are burdened by the requirement to separate T1 decay from the decline of the longitudinal magnetization due to RF consumption. Moreover, these techniques yield plausible values of T_1 only over a relatively large region and are practical only for a single section per breath hold. Here we demonstrate a method for generating high-quality pixel-by-pixel p_{O2} maps in a single breath hold. The acquisition and analysis is greatly simplified by measuring T1 directly, thereby eliminating the need to determine the local flip angle (B1).

Methods: A T1 map can be calculated directly, without the need to calibrate the B1 field, by acquiring two consecutive images, each at a different time within the same breath hold, whose difference is due only to T1 decay. This can be accomplished using a standard gradient-echo sequence if the central *k*-space line of the earlier image is acquired last, the central *k*-space line of the later image is acquired first, and there are no RF excitations in between which affect the imaged section. As a specific example, we could use a reverse centric acquisition followed by a time delay for T1 relaxation and subsequently a (forward) centric acquisition.

To the extent that the voxel magnitudes in each image are dominated by information from the central *k*-space line, the difference between the two magnitude images is due only to T1 decay during the time between the end of the first image acquisition and the beginning of the second. Therefore, a T1 map can be obtained by taking the voxel-by-voxel ratio of the two magnitude images ρ_1 and ρ_2 and calculating T_1 from the relationship $T_1(x,y) = T_D / \ln [\rho_1(x,y) / \rho_2(x,y)]$. Since the T1 decay rate of hyperpolarized noble gas in the lung is dominated by the interaction with oxygen, the p_{O2} can be calculated directly from this relationship.

Seven healthy subjects underwent hyperpolarized He-3 lung MR imaging on a 1.5T whole-body MR scanner (Magnetom Sonata, Siemens Medical Solutions). Subjects were positioned supine in the MR scanner, and starting from maximum expiration, subjects inhaled, at room temperature and pressure, a gas mixture that contained approximately 300 ml of He-3 and 700 ml of nitrogen. Immediately following the gas inhalation, subjects were asked to hold their breath and projection coronal reverse centric / centric data sets were acquired. Typical parameters included: TR/TE, 10/2.5 ms; matrix, 96 x 128; FOV, 315 x 420 mm; flip angle, 3.5°; time delay between corresponding central *k*-space lines, 2 sec. The reverse centric / centric pairs were repeated four or five times during each breath hold of ~15 seconds to permit the time course of T1 decay to be measured. Signal-ratio and T1 maps corresponding to each reverse centric / centric pair were calculated.

Results: Figure 1 shows three signal-ratio maps calculated from three consecutive reverse centric/centric image pairs obtained during a single breath hold. The average values of these ratio maps correspond to average T1 (p_{O2}) values of 21.3 (123), 22.3 (117), and 23.6 sec. (111 mbar), respectively, which are in agreement with previously reported typical values. Figure 2 shows a T1 and p_{O2} map calculated from the first of the three ratio maps. The white pixels correspond to ratio values near 1, where there is no measurable T1 decay between the pair of underlying acquisitions. Such values would be expected to occur in regions of the lung that are ventilated but not well perfused, such as the major airways. Indeed, the pattern of white pixels seems to correspond to the expected location and pattern of the airways. One notable exception is the ventilation defect at the periphery of the upper right lung (arrow), which can be seen more clearly in the underlying images (not shown). The white pixels around the edge of the defect suggest that this area is not well perfused.

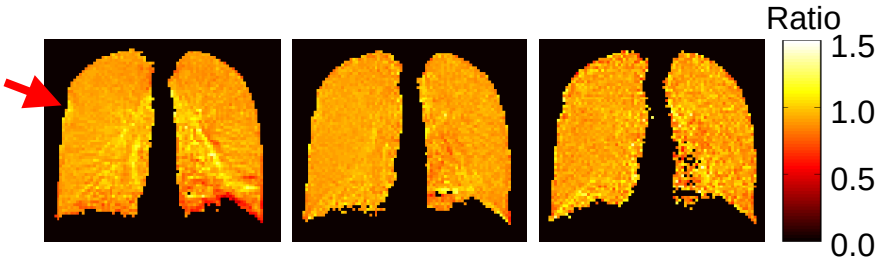

Figure 1. Signal-ratio maps from three consecutive reverse centric / centric acquisitions. The arrow denotes a ventilation defect that was seen in the underlying He-3 images.

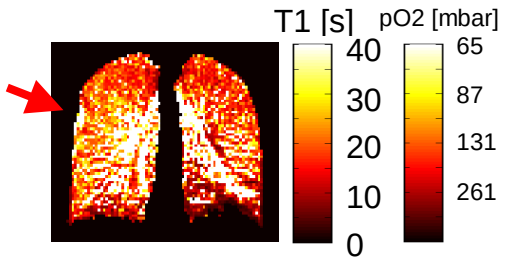

Figure 2. T1 and p_{O2} map corresponding to the first signal-ratio map in Fig. 1.

Conclusion: We have developed a technique that can acquire detailed T1, and thus p_{O2}, maps by obviating the need to accurately determine the B1 field. In initial experience, plausible values for p_{O2} were obtained. In principle, this method can be easily extended to acquire p_{O2} maps for several sections simultaneously, although in this case we need to ensure that diffusion across the section during the delay time does not significantly alter the signal measurements.

References

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Acknowledgements: This work was supported by the Commonwealth of Virginia Technology Research Fund (Grant No. IN2002-01), Siemens Medical Solutions and Amersham Health.