In Vivo Arterial Blood T_2 Measurement with Arterial Spin Labeling at 9.4 Tesla

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Introduction

Cortical arterial oxygen saturation level is lower than the systemic level (1) and can increase during stimulation (1–2). In previous oxygen tension measurements of pial arterial vessels, an arterial oxygen saturation level of ~85% was observed, which is much less than systemic levels (near 100%). T_2 is sensitive to the blood oxygen saturation and it can be used to determine the baseline arterial oxygen saturation level (3), which can be an important physiological parameter. However, accurate measurements of arterial blood are not simple. In this work, continuous arterial spin labeling (ASL) was used to isolate arterial blood signals and measure the arterial blood T_2 value of isoflurane-anesthetized rats at 9.4 T.

Materials and Methods

Four male Sprague-Dawley rats weighing 350–450 g were studied. Animals were initially induced under 5% isoflurane in a mixture of medical air and O_2 gases, and intubated for ventilation. The femoral artery was then catheterized. For the remainder of the experiment, the isoflurane level was maintained at 1.2±0.1% in an air:O_2 mixture in a ratio to attain a fraction of inspired oxygen of 30%. Blood gas was sampled intermittently and maintained at normal physiological levels. The body temperature was kept at 37.5°C by a warm circulating-water pad.

MRI experiments were performed on a Varian 9.4 T, 31-cm-diameter system and two actively-decoupled coils for ASL. Images were acquired with a custom-designed single-shot spiral read-out. After signal excitation, first-order gradient moment nulling was applied to compensate the dephasing effect of flowing blood. A short labeling time of 300 ms and post-labeling time 300 ms were adopted to ensure the labeling blood water in the arterial side imaged slice but not in the tissue/capillary (4). Other imaging parameters were: flip angle = 90°, slice thickness = 4 mm, spin-echo time *TE* = 10, 20, 30, 40, 50, 60, 70, 80 ms, TR = 1.5 s, matrix size 64×64, and field of view 2.56 cm×2.56 cm, and number of average = 100. The difference of the control and labeled image (i.e., ΔM) was calculated at different *TEs* (Fig. 1) and T_2 values were then fitted. To validate that ΔM originated mostly from the arterial blood signal, the control and labeled images were also acquired with diffusion gradients in three directions using b = 50 mm/s^2. Tissue T_2 values were also measured from the ASL control images without diffusion gradients.

Results and Discussion

With small diffusion gradients (b =50 mm/s^2), ΔM decreased by 70% compared to that without diffusion gradients at *TE* = 10 ms (Fig. 2), indicating that most of the signal originated from the flowing arterial blood. Thus, the estimation of T_2 from ASL data without diffusion gradients also stems from arterial blood. The measured arterial blood T_2 of the imaged cortex was 30.6 ± 4.0 ms and 30.0 ± 2.6 ms for the whole brain, while the measured tissue T_2 of the cortex was 37.7 ± 0.7 ms and 38.3 ± 1.2 ms for the whole brain. Our arterial blood T_2 is slightly lower than the value measured *in vitro*, while tissue T_2 values agree well with previous measurements (3). A slightly lower arterial T_2 value can be explained by methodological and physiological differences. Compared to *in vitro* experiments (3), T_2 was measured from regional micro-arterial cerebral blood water in this work. According to the relationship between the oxygen saturation level and *in vitro* blood T_2 measured at 9.4 T, our arterial blood T_2 can occur when an arterial oxygen saturation level was 0.88 ± 0.01 (calculated using a P50 of 38 mmHg for rat hemoglobin) which was lower than the measured systemic arterial oxygen saturation level of 0.95 ± 0.03 at the femoral artery. This is highly feasible, since our arterial signals mostly occur from the cortex, not from large pial arteries, due to the use of post-labeling time of 300 ms (4). This work demonstrated the feasibility for measuring regional cerebral arterial blood oxygen saturation by arterial blood T_2 measurement. The results were in agreement with the finding that the intra-cortical arterial oxygen saturation in rats is less than the assumed 100% (1–2), suggesting that oxygen saturation level of arterial blood should be considered in BOLD signal models in fMRI.

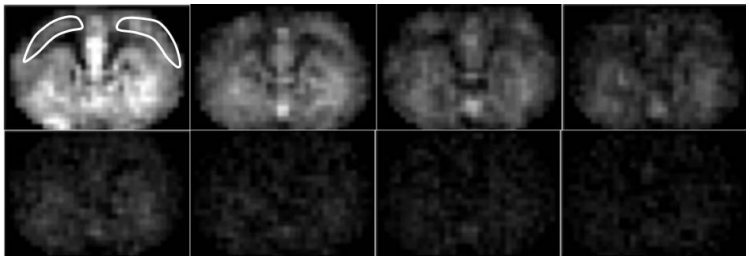

Figure 1. (a) ΔM with respect to *TE*, measured without diffusion gradients. From top to bottom and left to right, *TE* increases from 10 ms to 80 ms. The signal intensity decreases with *TE* increase. The region in the left top image indicates the cortical area.

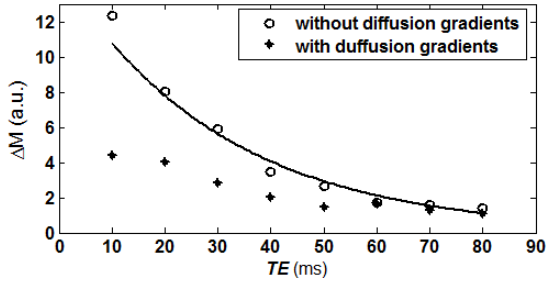

Figure 2. A plot of ΔM from cortical area of a representative rat. Without diffusion gradients, the best fit is plotted and the fitted T_2 was 30.7 ms.

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