Measurement of multi-slice cerebral blood flow with T1-normalized arterial spin labeling MRI using a volume RF labeling coil

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Introduction Arterial spin labeling (ASL) MRI tags arterial spins as endogenous tracer and the signal change is sensitive to CBF[1-3]. However, the RF tagging pulse may also attenuate tissue signal through magnetization transfer (MT), direct RF saturation and off-resonance spin locking effects, particularly when a volume RF coil is used. Importantly, ASL MRI contrast scales with T_{1app}, the apparent T_1 under the RF tagging pulse, which varies with its amplitude and offset [4-5]. Nevertheless, a single T_{1app} value is often used for CBF calculation. As T_{1app} map is heterogeneous, such a global T_{1app} approach may be oversimplified for mapping regional CBF.

Materials and Methods Animal experiments were carried out in accordance with institutional guidelines. MRI was obtained at 4.7 Tesla. We obtained single slice T_{1app} (slice thickness = 3mm) and T_1 MRI with an inversion recovery sequence using identical recovery time in 10 adult male Wistar rats. We had B_1=4.7 μT, a labeling distance of 15 mm (Δω=10,000 Hz), modulation frequency of 250 Hz, and post-labeling duration of 300 ms. In addition, CBF was obtained with amplitude modulated (AM)-ASL (TR/TE=6,500ms/28ms, NA=32) in two Wistar rats[6-7]. CBF was calculated as $CBF=\lambda\cdot(I_{ref}-I_{tag})/(2\alpha\cdot I_0)\cdot C$, where I_{ref} and I_{tag} are image intensities when RF labeling and reference pulses are applied, respectively, and I_0 is control image without RF irradiation. In addition, λ is the brain/blood partition coefficient, α is the inversion efficiency. In addition, $C\approx e^{\delta/T1a}\cdot T_{1app}$, and λ=0.9 ml/g and α=0.65.

Results and Discussion Fig. 1 shows single-slice T_1, T_{1app} and T_{1app}/T_1 maps of a representative normal animal. T_1 and T_{1app} maps were heterogeneous, being 1.56 ± 0.15 s and 0.83 ± 0.09 s (B_1=4.7 μT and Δω=10 kHz), respectively. Despite their spatial heterogeneity, the parametric T_{1app}/T_1 map was reasonably homogeneous, being 0.53 ±0.02. Ventricle appeared hyperintense, likely caused by cerebral spinal fluid (CSF) partial volume effect. We found T_1, T_{1app} and T_{1app}/T_1 to be 1.55 ± 0.03 s, 0.84 ± 0.01 s and 0.54 ± 0.01, respectively (n=10).

Fig. 2 compares the single-slice CBF map calculated from T_{1app} map, single T_{1app} value (T_{1app}=0.84 s) and the scaled T_1 map ($T_{1app}=\eta\cdot T_1$ with η=0.54), respectively. In addition, CBF' calculated from a single T_{1app} value and T_1 map were found to be 0.98 ± 0.31 and 1.02 ± 0.31 ml/g.min, respectively. Whereas the CBF values were reasonably close to one another, subtle difference in the CBF map can be detected. This is because by using the mean T_{1app}, CBF calculated from the single T_{1app} value can approximate the mean CBF measurement from the T_{1app} map and scaled T_1 map, it may not fully account for T_{1app} heterogeneity-induced regional CBF difference. This can be better appreciated in Fig. 3, which is an overlaid scatter plot of CBF and CBF', per voxel. The proposed T_1-map-normalized CBF' closely correlated with the T_{1app}-map-normalized CBF (black square), where CBF'=0.92 CBF + 0.04 ml/g.min and the coefficient of determination R^2 is 0.93. In comparison, the correlation between CBF' calculated using the single T_{1app} value and CBF (red circle) was CBF'=0.81 CBF + 0.12 ml/g.min, R^2=0.71.

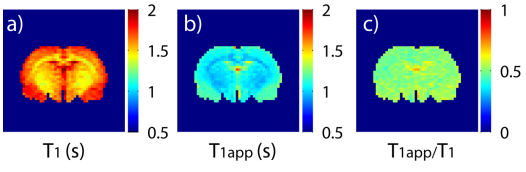

Fig. 1, Comparison of T_1, T_{1app} and T_{1app}/T_1 maps. Whereas T_1 and T_{1app} (4.7 μT, Δω=10 kHz) maps show noticeable heterogeneity, T_{1app}/T_1 map is reasonably homogeneous.

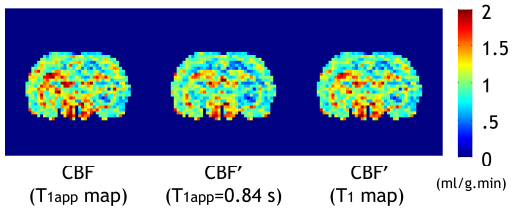

Fig. 2, CBF map obtained with scaled T_1-map better characterizes regional CBF than that with a global T_{1app} value.

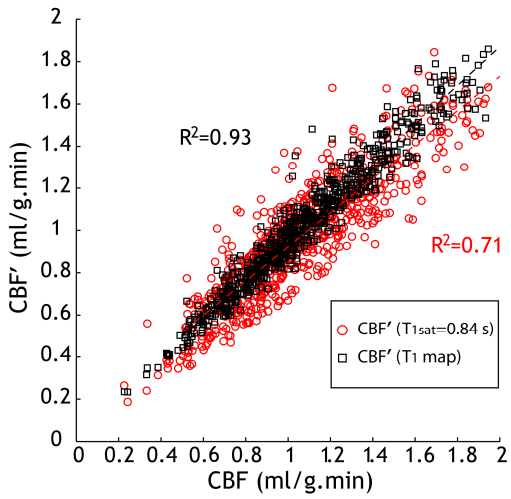

Fig. 3, CBF calculation using scaled T_1 map (R^2=0.93, black square) better correlates with the approach of a single T_{1app} value (R^2=0.71, red circle).

The proposed approach can be extended to study multi-slice CBF. Due to concomitant RF irradiation effects, T_{1app}/T_1 depends on RF offset and power. We serially varied RF offset and power and showed that T_{1app}/T_1 as a function of RF irradiation offset can be described by linear regression relationship. This allows us to scale multi-slice T_1 map with pre-determined coefficient to derive T_{1app} map for multi-slice CBF calculation using AM-ASL MRI (Fig. 4). Such an approach is applicable for studying heterogeneous neurological disorders such as acute stroke.

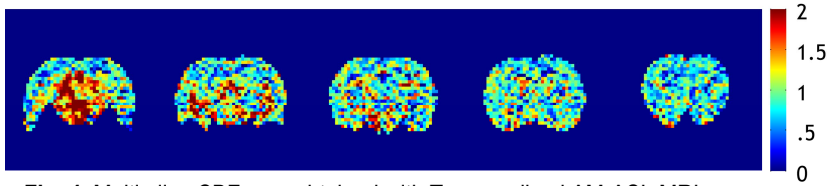

Fig. 4, Multi-slice CBF map obtained with T_1-normalized AM-ASL MRI.

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