Ultrafast Blood T1 Mapping with Steady-State Free Precession (SSFP) Imaging

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Introduction

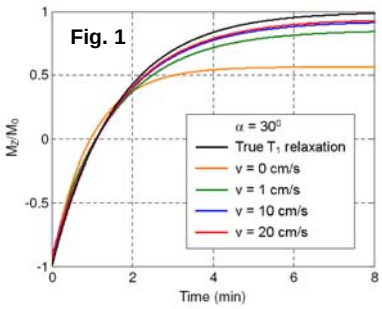
Blood T_1 is a critical parameter for black blood imaging (1) and perfusion quantification with arterial spin labeling imaging (2). Conventional T_1 measurement is time-consuming as the longitudinal relaxation curve is sampled with varied inversion times (TI) in separate scans. Characterized by high imaging speed while preserving a high signal-to-noise ratio, TrueFISP (3) has been proposed for in-vivo T_1 mapping of static tissue with inversion recovery (IR) preparation (4). The apparent T_1 of static tissue estimated with IR-TrueFISP, however, exhibits a complicated dependence on the flip angle and the relaxation time constants (T_1/T_2) of the tissue (5). An interesting observation from our experiment is that IR-TrueFISP may provide an efficient yet accurate approach for in-vivo blood T_1 mapping, due to the replenishment of blood spins with longitudinal magnetization unperturbed by the TrueFISP pulse train. Therefore, blood pool signals in IR-TrueFISP acquisitions generally follow the conventional T_1 recovery model. In this study, we conduct experiments and computer simulations to investigate the feasibility and reliability of using IR-TrueFISP for blood T_1 measurement.

Materials and Methods

All MR imaging was in accordance with the Institutional Review Board guidelines, and performed on a 3.0 T whole body scanner (Siemens Trio, Erlangen, Germany) with a standard setup of body coil transmission and phased-array head coil reception. Six healthy volunteers (age = 16-25 years, F/M = 2/4) were imaged after written informed consent was obtained from each of them. For IR-TrueFISP scans, the $\alpha/2$-($\pm\alpha$) scheme was adopted for efficient signal stabilization, and phase encoding advanced in a centric order (TR = 5 ms, TE = TR/2, $\alpha = \{10^0, 30^0, 50^0\}$, in-plane matrix = 128x128, FOV = 220 mm). Following a spatially nonselective hyperbolic-secant inversion pulse and 20 dummy scans, 50 phases of TrueFISP readout were carried out with 19 lines of k-space data obtained during each phase. The TI values corresponding to the 50 phases thus ranged from 100 ms to 4850 ms with a step of 95 ms. At the end, the magnetization was restored to the +z axis using a $-\alpha/2$ pulse. The procedure was then repeated for the next 19 k-space lines and so on with a total scan time of 48 sec. Images were obtained from a 5-mm axial slice where the sagittal sinus was perpendicular to the slice. Signals were extracted from regions-of-interest at gray matter and mid-sagittal sinus, and fitted to a three-parameter model: $k_1*(1-k_2*\exp(-t/k_3))$. The effects of α and flow velocity (v) were estimated with numerical simulations of Bloch equations. Phase-contrast (PC) MRI was acquired at the same imaging slice to estimate the mean venous blood flow velocity in sagittal sinus (FOV = 220 mm, matrix = 128x128, flip angel = 15°, TR = 25 ms, TE = 3 ms, VENC = 60 cm/s along z axis, scan time = 3 s). For comparison, single-phase IR-TrueFISP acquisitions were performed at 16 different TI's (100-5000 ms).

Results and Conclusion

Figs. 1 and 2 show the simulated signal evolution of blood signal with respect to v and α, in which multi-phase IR-TruFISP signals deviate from the theoretic value when the tissue is static and α increases. Listed in Table 1 are the predicted accuracy and variation of measurement based on 50 sets of computer-generated IR-TrueFISP data (SNR = 10 and Gaussian noise). Experimental data show good compatibility with the numerical results in that when α increases from 10^0 to 30^0, and 50^0, the T_1 of venous blood (v ~ 18 cm/s by PC-MRI) remains stable (1648±96 ms, 1725±110 ms, and 1652±103 ms, respectively), whereas the measurement in gray matter (static tissue) remarkably varies (1112±42 ms, 655±41 ms, and 428±35 ms, respectively). Repeatability was tested on 4 subjects and coefficient of variation was ~2%. The measured blood T_1 shows a linear relationship with age in the studied span of age (Fig. 3). As shown in Fig. 4, T_1 seems to increases with v when males and females are considered separately. Females tend to have slower venous flow although no T_1 difference has been observed between genders. It is noted that single-phase scheme consistently measures T_1 longer than multi-phase scheme (Fig. 5). The discrepancy could be because the interval between single-phase scans was not long enough and thus longitudinal signals were slightly saturated after the scan of the first TI. In conclusion, we have demonstrated the feasibility of using multi-phase IR-TrueFISP for fast (< 1 min) and reliable (2% repeatability) in-vivo blood T_1 mapping.



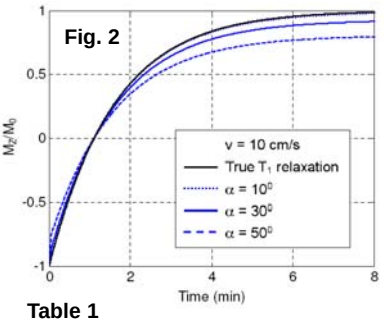


Table 1

Assigned T_1 = 1600 ms	v = 0 cm/s	v = 10 cm/s	v = 20 cm/s
$\alpha = 10^0$	1498±16	1599±9	1599±7
$\alpha = 30^0$	1012±65	1592±10	1598±11
$\alpha = 50^0$	587±8	1588±11	1595±11

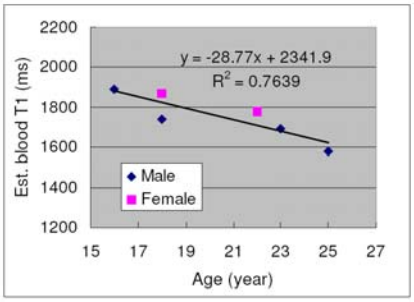


Fig. 3

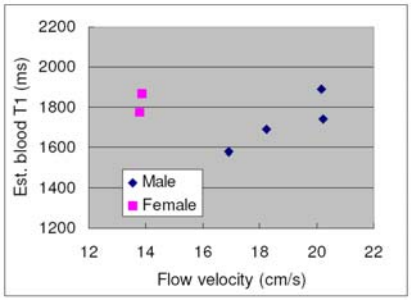


Fig. 4

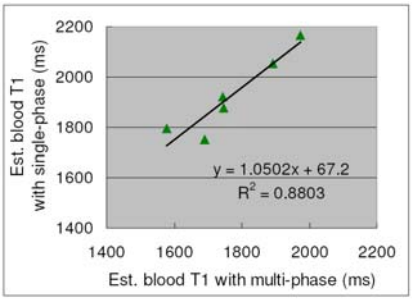


Fig. 5

References

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