QUIPSS II with window-sliding saturation sequence (Q2WISSE)

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Introduction:

Perfusion disorders impact the function of human organs (i.e., brain, heart, and kidneys]. Presumably early diagnosis of impaired organ perfusion may guide timely therapeutical interventions and improve the clinical outcome of patients. Arterial Spin Labeling (ASL) is a non-invasive imaging technique for quantitative assessment of tissue perfusion rates, with which arterial blood is magnetically labeled as a tracer that diffuses freely between vascular and tissue compartments[1]. However, the accuracy of estimation could be affected in application by the fact that labeled blood spins experience variable transit times[2]. To minimize this systematic error, QUIPSS II (Quantitative imaging of perfusion using a single subtraction II) was introduced: it incorporates 15-lobe sinc saturation pulses at time TI1 after the inversion pulse and before the image acquisition in order to achieve a defined bolus length [2]. Q2TIPS [(QUIPSS II) with thin-slice TI1 periodic saturation] [3] is a further improvement that replaces the sinc thick-slice saturation pulses by a periodic train of thin-slice saturation pulses and thus prevents the error caused by the mismatch between saturation and inversion slice profiles because of the imperfect slice profile of thick sinc pulse. About 30 RF pulses with a flip angle of 90º are typically required for one side (proximal side of the imaging slice). In Q2TIPS FAIR (flow-sensitive alternating inversion recovery)[4], trains of saturation pulses are required on both sides of the imaging slice, resulting in a total of about 60 RF pulses. SAR (specific absorption rate) is of notable concern given the large number of applied RF pulses, especially when this saturation module is combined with True FISP (fast imaging with steady state precession), TSE (Turbo Spin Echo), or other SAR intensive sequences. The aim of this work is therefore to develop a strategy to reduce the high SAR using a window-sliding saturation scheme while still maintaining the sharpness of the saturation slice profile.

Method:

Thin and thick slice saturation pulses are combined in a window-sliding manner to replace the Q2TIPS thin slice saturation pulses, which is refereed as Q2WISSE (QUIPSS II with window-sliding saturation sequence). A schematic representation of Q2WISSE for one side saturation is shown in Fig. 1A. The first thin saturation pulse with a thickness of d1 (20mm in this study) was applied at time TI_1 close to the imaging slice by a gap of g (8mm in this study), and the second thin saturation pulse was applied immediately following the first rf pulse by sliding away from the first rf pulse slice position by a distance of b (5mm in this study). After these two thin saturation pulses, all the blood in the band with a thickness of d1 + b was saturated on one side of imaging slice. Following the thin saturation pulses, a thick slice saturation pulse with a thickness of d2 (70mm in this study) was applied at a position away from the second slice by a distance of b using 90º optimal amplitude

Fig.1A: scheme of Q2WISSE.

Fig.1B: Sequence diagram for Q2WISSE FAIR TrueFISP

modulated sinc pulse with 9 lobes. Optionally, second thick saturation pulses could be applied immediately after the first thick slice saturation pulse to achieve more complete saturation, and another thick saturation pulse was applied just before the image acquisition to suppress possible blood flow. In this manner, the good slice profile was ensured by the thin slice saturation pulse while the saturation thickness of d1+2b+d2 was achieved by the combination of thin and thick slice saturation pulses. For two side saturation which is required in FAIR-like labeling scheme, the pulses can be alternatively applied to each side of the imaged slice.
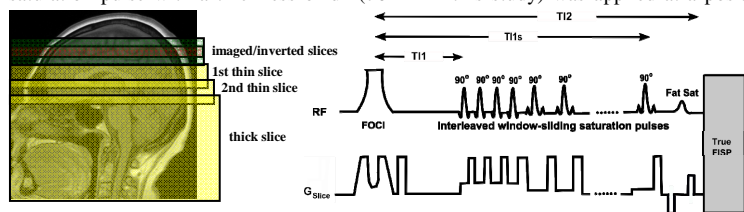
The scheme was implemented with FAIR True FISP, as shown in Fig1B, on a clinical 3T whole body MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany). An adiabatic RF FOCI (frequency offset corrected inversion) pulse was utilized to obtain a better slice profile of the slice selective inversion[5]. The perfusion rates of brains and kidneys were measured with the proposed technique and Q2TIPS for comparison in seven healthy volunteers after informed consents were obtained. The measurement parameters were as follows: TE = 1.88ms, acquisition bandwidth = 606Hz/Pixel, flip angle = 70˚, matrix=128 x 96, FOV = 320 – 350mm for the kidney studies and FOV = 210 – 240mm for the brain study, imaging slice thickness /tagging slice thickness = 8/22mm, TR = 5sec, and measurements = 40 (20 pairs) for the kidney scan and 60 (30 pairs) for the brain scans. A centric-reordered k-space acquisition scheme was applied. To minimize artifacts from the transient signal oscillations in TrueFISP, a variable flip angle preparation of 14 rf pulses was implemented [6]. The excitation frequency was carefully chosen to avoid the banding artifacts within the kidney by a few pre-scans before the perfusion measurement. TI_2 = 1.3sec for the kidney scans and 1.5sec for the brain scan, TI_1 = 0.7sec and TI_{1S} = TI_2 – 0.1sec for Q2TIPS. The slice thickness of the periodic saturation pulses for Q2TIPS was 20mm. Quantitative perfusion maps were computed on a pixel-by-pixel basis from the magnetization ΔM using a tissue/blood partition coefficient λ of 0.8 for the kidneys and 0.9 for the kidneys, T_1 of 1.15s for the kidney cortex and 1.49sec for the brain grey matter. An inversion efficiency of 0.95 was assumed.

Results:

Fig.2 shows brain cerebral blood flow (CBF) rate maps obtained with Q2WISSE (A) and Q2TIPS (B) for a healthy volunteer. The two techniques were also compared in measuring renal blood (RBF) flow rates, and the RBF maps achieved with Q2WISSE (Fig.2A) and Q2TIPS (Fig.2B) are also shown. The minor artifacts
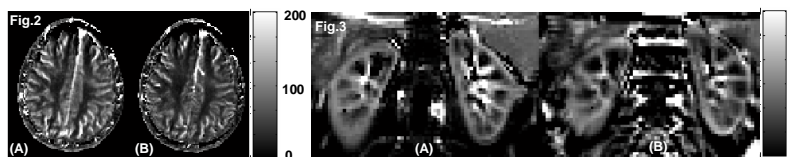

Fig.2: Brain CBF rate (mL/100mL/min) maps obtained with Q2WISSE (A) and Q2TIPS(B).

Fig.3: Renal perfusion rate (mL/100mL/min) maps for a healthy volunteer. Q2WISSE (A) vs. Q2TIPS (B).

seen in the renal perfusion maps are more likely motion or susceptibility artifacts. The maps acquired with Q2WISSE are generally in a good agreement those with Q2TIPS as seen in Fig. 2 and 3. For more specific comparison, the perfusion rates in the brains and kidneys obtained with these two techniques are summarized in Table 1 for all seven volunteers. For the brain, the values acquired with the two methods are in excellent agreement. For the kidneys, due to the motion and susceptibility artifacts the agreement between the two methods is not as good as that for the brains. A paired t-test was performed on eight kidney cortex data sets to confirm the agreement. The mean difference (ΔRBF=11.5, SD= 25.4) was not significantly different. t=1.10 (t_c = 2.36) and two-tail p = 0.30, providing evidence that there is no significant difference between the two methods.

Discussion: SAR can be significantly reduced with the proposed method while the good saturation slice profile is still preserved. In this study, 60 saturation rf pulse in Q2TIPS were replaced with seven rf pulses. Although the rf energy of the 9 lobe sinc pulse for the thick slice pulses is larger than that of the thin slice rf pulses, the reduction in rf energy (hence SAR) was reduced by *six times* for the saturation module in this study. In the application of ASL, high magnetic field is usually preferred for long T_1 and high SNR. Given the fact that SAR is proportional to the square of the field strength, the proposed method may prove significantly beneficial to achieve high resolution perfusion rate maps in the high field.

Volunteer		Q2WISSE		Q2TIPS	
		GM	WM	GM	WM
V1	Brain	57	20	63	27
V2	Brain	96	20	94	23
V3	Brain	69	31	68	30
		Cortex	Medulla	Cortex	Medulla
V4	LK	269	173	250	114
	RK	297	106	244	130
V5	LK	292	155	234	137
	RK	263	131	263	153
V6	LK	232	65	245	77
	RK	223	71	235	85
V7	LK	275	143	272	83
	RK	257	158	273	82

Table 1. Summary for perfusion rates (mL/100mL/min) measured by Q2TIPS and Q2TIPS for gray matter (GM) and white matter (WM) of the brains, as well as cortex and medulla of the left kidneys (LK) and right kidneys (RK) for seven healthy volunteers.

References: 1. Detre JA et al. MRM 1992;23[1]:37-45. 2. Wong EC et al. MRM. 1998;39[5]:702-708. 3. Luh et al. MRM 1999;41(6):1246-1254. 4. Song R. et al ISMRM 1999;41(6):1246-1254. 5. Payne GS. et al. MRM 1997;38(5):828-833. 6. Vibhas S. MRM 2003;49(1):151-157.