NOVEL DOUBLE INVERSION OF BOTH TAGGED AND REFERENCE IMAGES FOR PULSED ARTERIAL SPIN LABELING

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INTRODUCTION

Pulsed arterial spin labeling (PASL) MRI measurements of brain perfusion are often limited by noise, deriving in part from incomplete cancellation of spin effects - such as magnetization transfer (MT)[1] - in tag and control (T&C) scans.

The overall goal of this study was to improve the design for PASL. The specific aims were:

1. To reduce MT noise while maintaining the slice profile from double inversion in T&C images (a problem of EPISTAR[2]);
2. To balance transient eddy-current effects from pulsed field gradients (a problem of PICORE[3]);
3. To compare quantitatively the new technique to EPISTAR and PICORE using first and second order image texture analysis[4];

METHODS

Sequence Design: A diagram of the proposed PASL method (Double inversion with proximal labeling of both T&C images, DIPLOMA) is sketched in **Figure 1**. Because the flip angle (α) is the same for all pulses, slice profiles and MT effects are similar in both T&C scans. In addition, slab-selective gradients are being used in both T&C scans to balance eddy-current effects. The remaining pulse sequence structure for perfusion MRI is similar to QUIPPS II[5]. The PASL methods of PICORE and EPISTAR are also shown for comparison.

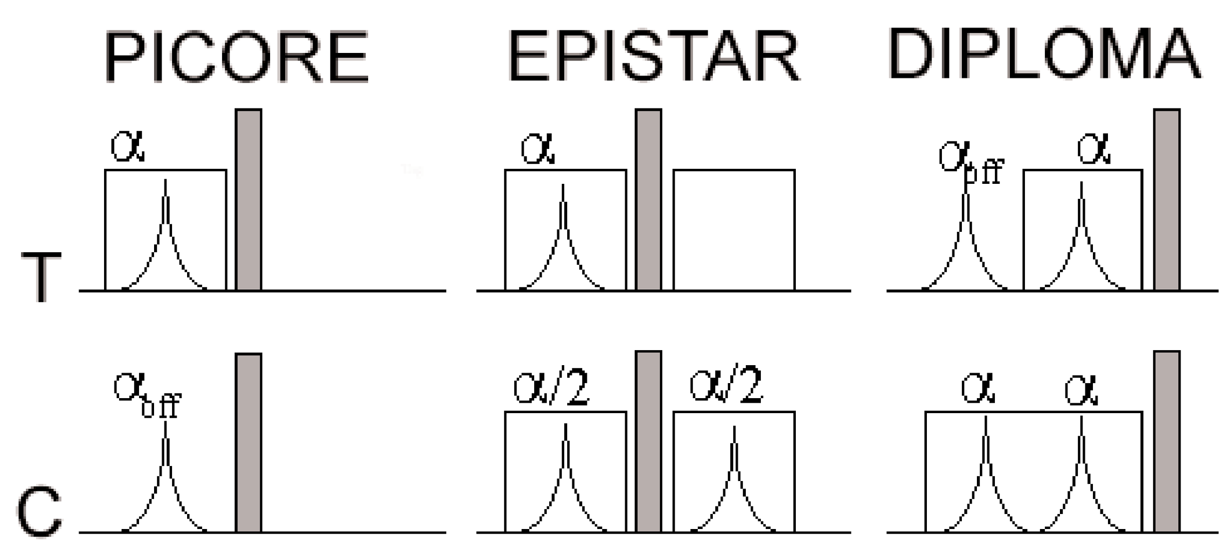

Figure 1. Methods of PICORE, EPISTAR, and DIPLOMA PASL

Comparison to EPISTAR and PICORE: Improved MT compensation with DIPLOMA was tested on a 3% agarose phantom. Thirteen healthy volunteers (mean age 45±14 years, 4 men and 9 women) were studied using DIPLOMA, PICORE, and EPISTAR in the same session. To determine whether DIPLOMA was significantly better than others in measuring perfusion, perfusion images were analyzed quantitatively using image texture analysis of first order (Mean Signal Intensity (MSI) and Coefficient of Variation of Signal Intensity (COVSI)) and second order (Contrast, Correlation, Entropy, and Angular Second Moment (ASM)).

RESULTS

Table 1 lists MT compensations, indicating that DIPLOMA achieved the best result.

Table 1. Results from MT measurements of agarose phantom expressed as *Z* scores for each PASL schemes.

PASL schemes	MT Mode [a]	Compensated Mode [b]
DIPLOMA	28.4	**1.1**
EPISTAR	15.7	6.1
PICORE	16.4	3.8

[a] MT mode (S_1): MT measurements with tagging pulse *on* but control pulse *off*
[b] Compensated mode (S_2): MT measurements *on* both tagging and control pulses
Z-score=($S_{1 \text{ or } 2}$-S_{ref})/STD_{ref}, where STD_{ref} is the standard deviation of the image intensity in reference mode (S_{ref}), which was performed without tagging and control pulses.

Figure 2 shows representative PWI of a volunteer obtained with the different PASL methods. This demonstrates that image contrast and signal uniformity across slices improved with DIPLOMA (also see **Table 2**)

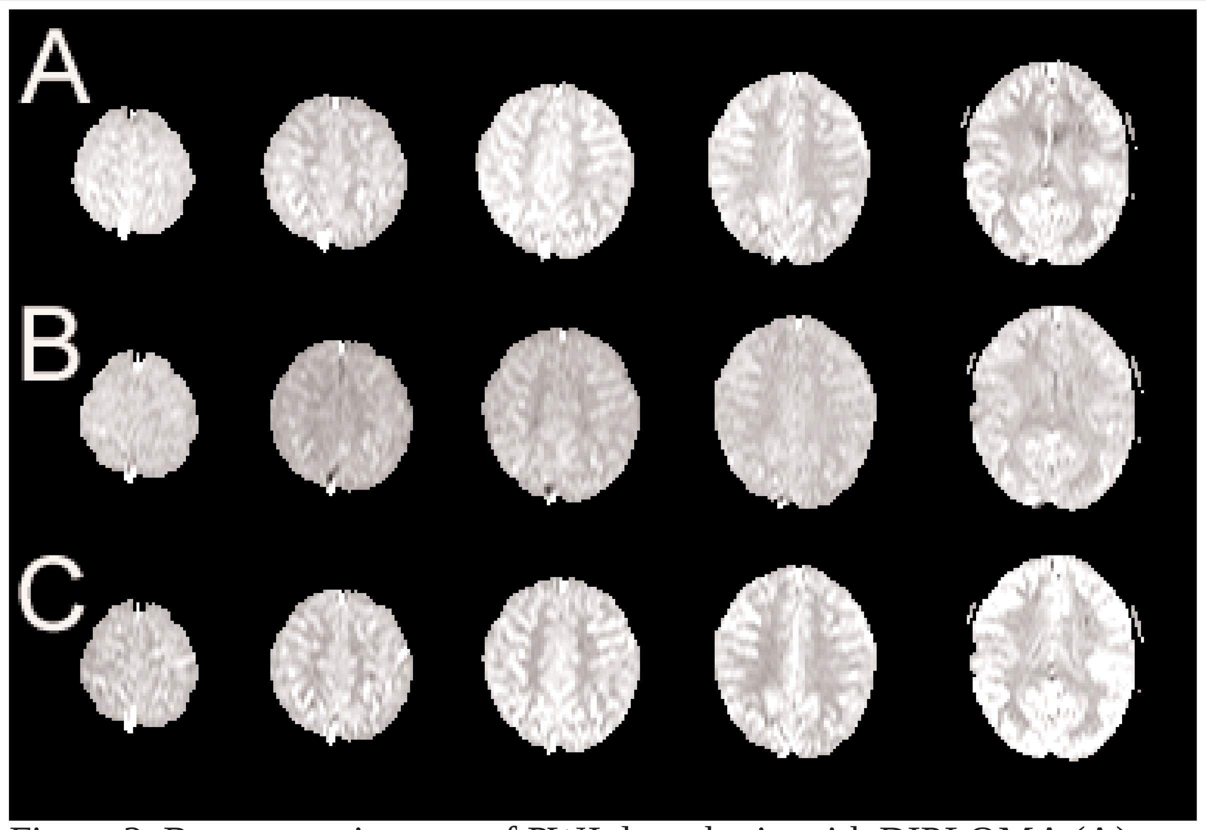

Figure 2. Representative sets of PWI data obtain with DIPLOMA (A), EPISTAR (B) and PICORE (C) on a volunteer. Images were scaled to the same brightness for better comparison.

Table 2 lists perfusion signal intensity across image slices of 13 volunteers, showing signal uniformity improved with DIPLOMA.

Table 2. Slice uniformity of PWI data of each PASL method averaged on 13 subjects

PASL Methods	Slices 1	2	3	4	5	Variation (%)
DIPLOMA	**1.00** ± 0.06	**0.98** ± 0.06	1.00 ± 0.06	0.99 ± 0.05	0.99 ± 0.04	2.0
EPISTAR	0.93 ± 0.04	**0.88** ± 0.06	0.91 ± 0.05	0.93 ± 0.04	**0.98** ± 0.06	11.3
PICORE	1.00 ± 0.08*	**0.97** ± 0.08	0.99 ± 0.08	1.01 ± 0.08	**1.13** ± 0.09	16.5

Perfusion signal intensities were normalized by that of the 1st slice in DIPLOMA on five slices.
Data show mean ± standard deviation of 13 subjects.
Variation (%)=100*(maximum – minimum)/maximum, indicated in bold face.

Table 3 lists results from a texture analysis of PWI of 13 volunteers. The most significant improvements of DIPLOMA were increased MSI and higher contrast compared to EPISTAR and larger entropy and less ASM distortion compared to PICORE.

Table 3. Differences in PWI textures between the different PASL methods by using first and second orders of texture analysis of perfusion images from 13 volunteers.

FEATURE	DIPLOMA	EPISTAR	PICORE	DE (%)	DP (%)
MSI [a]	1.00 ± 0.05‡	0.92 ± 0.06	1.01 ± 0.08	**8**	1
COVSI	0.14 ± 0.03†‡	0.11 ± 0.03	0.18 ± 0.05	**21.4**	**-28.6**
Contrast	187 ± 126‡	144 ± 81	186 ± 129	**23**	0.5
Entropy	2.88 ± 0.15†	2.86 ± 0.13	2.83 ± 0.15	0.7	**1.7**
Correlation	0.63 ± 0.06	0.65 ± 0.07	0.64 ± 0.07	-3.2	-1.6
ASM	1.81 ± 0.87†	1.86 ± 0.72	2.08 ± 0.95	-2.8	**-14.9**

[a] MSI of EPISTAR and PICORE normalized by that of DIPLOMA. Data show mean ± standard deviation of 13 subjects. Data in the forth and fifth columns are percent difference between DIPLOMA to EPISTAR (DE) and DIPLOMA to PICORE (DP), respectively.
† $p \leq 0.008$ Diploma vs. PICORE ‡ $p \leq 0.008$ Diploma vs. EPISTAR

CONCLUSIONS

- DIPLOMA improved perfusion measurements with the best MT compensation;
- Increased perfusion signal intensity (MSI) with DIPLOMA should benefit measurement sensitivity;
- Higher image contrast should help in differentiating better between gray matter and white matter perfusion;
- Increased image complexity (larger entropy) and improved image uniformity (less ASM)should benefit measurement precision;

Together, these improvements should benefit studies of cerebral perfusion, especially of conditions with low cerebral blood flow and increased blood brain barrier permeability, such as Alzheimer's disease.

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