Improved ASL Contrast in Multiphase STAR Labeling

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INTRODUCTION

Arterial spin labeling (ASL) techniques have proven to be an excellent tool to obtain quantitative maps of perfusion non-invasively [1, 2]. In most of the ASL implementations, a single delay time TI between labeling and control image acquisition is used to estimate CBF values. In such cases, the effects caused by the regional differences in arterial transit time are difficult to estimate and can potentially introduce errors in calculation of perfusion values [3]. This is particularly true for patients with blood flow-related diseases such as stroke and carotid arteries stenosis. A possible approach to overcome this transit time problem is based on performing multiple ASL experiments at various TIs between labeling and MR acquisition [4]. However, with these conventional multiple phases ASL techniques, the ASL contrast at later phases is impaired due to repeated application of excitation pulses and longitudinal relaxation making it difficult to evaluate the tissue perfusion in regions where the transit time is longer. In the present study we present an optimization of the acquisition scheme by exploring a modulation on the flip angle of the MR acquisition to keep the ASL contrast constant over multiple phases.

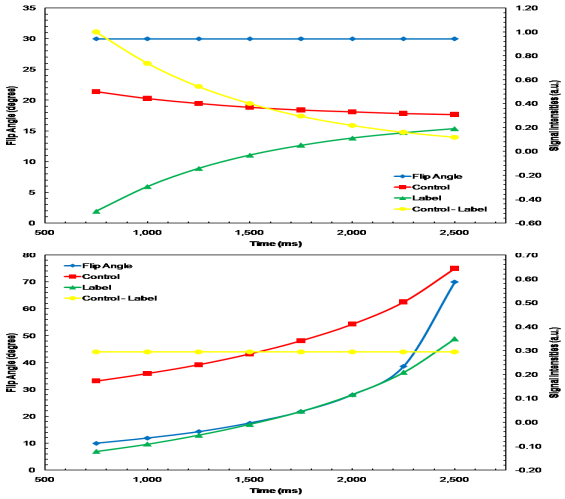

Figure 1: The results of simulations using a constant flip angle for a multiple phase ASL experiment (top row) and using a flip angle modulation according to Eq. 1 (bottom row).

MATERIALS AND METHODS

We performed a simulation based on the longitudinal and transversal magnetization during the ASL train for both control and labeling conditions. Applying the constraint condition of maintaining the signal difference between control and label images constant for all ASL phases we derived the flip angles for each phase. The flip angle for the *i-th* phase is given by:

$$FA_i = \arctan\left(\frac{\sin(FA_{\max})*\exp\left(\frac{-(m-i)\tau}{T_1}\right)}{\sqrt{1+\sum_{k=1}^{m-i-1}\sin^2(FA_{\max})*\exp\left(\frac{-2k\tau}{T_1}\right)}}\right) \quad \text{Eq. 1}$$

where FA_{max} is the maximum flip angle to be used, which needs to be specified based on the repetition time since the steady state has not been taken into account for simulations purpose, m is the total number of phases, τ is the delay between phases and T_1 is the relaxation time of the blood. Healthy adult volunteers were scanned in a 3T Achieva system (Philips Medical Systems, The Netherlands) equipped with gradients capable of 80mT/m amplitude and 200mT/m/ms slew rate and an 8-channel head coil. All subjects were free of neurological disorders. Images were acquired using a GE-EPI sequence with the following parameters: TR/TE=5000/14ms, FOV=240x240mm^2, matrix=64x64, slice thickness=5mm and 6 phases acquired with TIs ranging from 750ms to 2000ms (τ = 250ms). A set of 25 ASL acquisitions was made for signal averaging.

RESULTS

Fig. 1 shows on the top row the typical evolution of the transverse magnetization during the control (red line) and the labeling (green line) condition during a multiphase ASL experiment. As the flip angle (blue line) is kept constant for all phases, the signal of the difference between both conditions evolves to zero making it impossible to evaluate accurately regions where the transit time is longer than 1.3s for instance. On the bottom, Fig, 1 reveals how the signal difference between label and control images can be constant if the flip angle used for MR acquisition is modulated. Fig. 2a shows perfusion-weighted images obtained from a representative volunteer using the standard multiphase ASL with a constant flip angle of 30 degrees. It can be clearly noticed the compromised ASL contrast in the later phases, which is in agreement with the expected from the simulation. Fig. 2b shows the data obtained from the same subject using the flip angle modulation. Even when the later phases are acquired, a reasonable perfusion contrast can be seen.

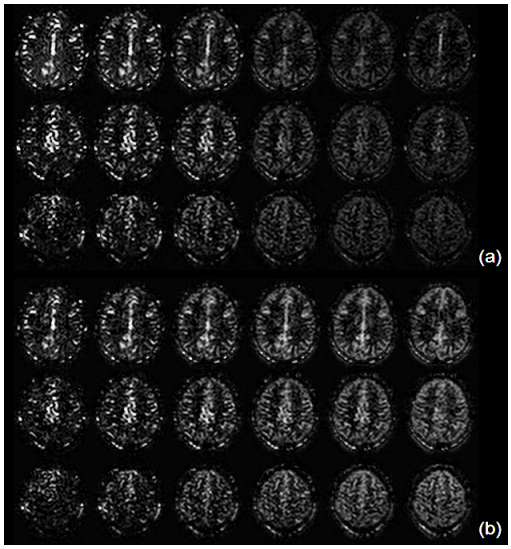

Figure 2: (a) Perfusion-weighted images obtained from a representative volunteer using a conventional multiphase ASL acquisition scheme (with constant flip angle for all phases) and (b) using a flip angle sequencing calculated based on Eq. 1.

DISCUSSION AND CONCLUSIONS

In this study, the combination of flip angle sequencing and multiphase ASL revealed the advantages of the implementation to evaluate tissue perfusion even in regions where the long transit times usually compromise the analysis. Even though according to the simulations the signal intensity of the perfusion weighted image in a multiple phase acquisition can achieve higher values for some phases when using the conventional approach, it usually occurs for time points when the spins from the blood from the larger vessels still have high signal compromising the accuracy of the CBF estimation. On the other hand, one can appreciate in Fig 2b the improve perfusion contrast in the later phases in the white matter, for instance, which is known to have a longer transit time when compared to the gray matter areas. In summary, flip angle sequencing can be a useful improvement for multiphase ASL. Further optimization of the model will likely allow quantitative analysis of the CBF as well as of the transit time.

REFERENCES

[1] Detre JA et al, *NMR Biomed* 1994; 7:75-82. [2] Golay X et al, *Top Magn Reson Imaging* 2004;15:10-27. [1] Calamante F et al, *NMR Biomed.* 1996;9:79–83. [4] Buxton RB et al, *Magn Reson Med.* 1998;40:383–396.