Improving the Quantification of Continuous ASL: Simulations of the Adiabatic Inversion Efficiency using Phase Contrast Velocity Measurements

R. L. O'Gorman[1], D. J. Lythgoe[2], P. E. Summers[3], D. C. Alsop[4], S. C. Williams[2], F. E. Zelaya[2]

[1]Neuroimaging, King's College Hospital, London, United Kingdom, [2]Neuroimaging Research Group, Institute of Psychiatry, London, United Kingdom, [3]Institute for Neuroradiologie, University Hospital of Zurich, Zurich, Switzerland, [4]Center for Advanced Imaging, Beth Israel Deaconess Medical Center, Boston, MA, United States

Introduction

Accurate quantification of perfusion with arterial spin labelling (ASL) requires consideration of a number of factors, including the efficiency of the inversion pulse used for spin labelling. For continuous ASL (CASL) since the degree of spin inversion is velocity-dependent, the assumption of a constant value for the inversion efficiency may introduce errors into the perfusion calculations. By acquiring a series of cardiac-gated phase contrast angiography images at the level of the tagging plane it is possible to measure the velocity profile of spins throughout the cardiac cycle and estimate the inversion efficiency on an individual basis. The CASL perfusion values can then be derived using this calculated inversion efficiency. The purpose of this study was twofold: to estimate the adiabatic inversion efficiency using phase contrast MRA velocity measurements and simulations of the Bloch equations, and to assess the effect of this corrected inversion efficiency on the CASL perfusion measurements.

Methods

Perfusion images were acquired for 8 subjects (1 male, 7 female, age 23-40) using a multislice continuous ASL technique.[1,2] Imaging was performed with a 1.5 T GE Signa Horizon Echospeed scanner (GE Medical Systems, Milwaukee, WI, USA). Axial phase contrast angiography images were acquired at the level of the tagging plane using a velocity encoding strength of 100 cm/s and cardiac gating to record 20 frames per cardiac cycle (TR/TE = 23/9.3 ms, flip angle = 15°, slice thickness = 7mm, FOV = 24x18 cm^2, matrix = 256x224). Velocity measurements were performed by locally available software with manually-drawn regions of interest for the carotid and basilar arteries. The Bloch equations were then solved numerically using a Runge-Kutta method with an adaptive step size[4], taking into account the spin velocity distribution (assuming laminar flow and integrating over the cross-sectional area of the vessel), the labelling gradient strength (0.25 G/cm), and the RF amplitude (32 mG). The accuracy and reproducibility of the phase contrast velocity measurements were assessed using the AMPMFM flow trial phantom[3] with a calibrated computer-controlled pump (Shelley Medical Imaging Technologies, Canada).

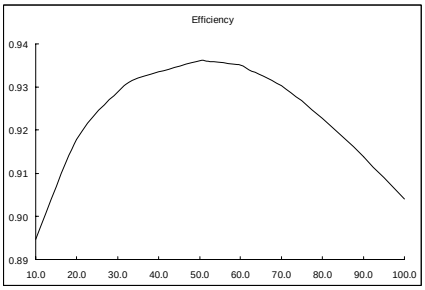
Results

The inversion efficiency is shown as a function of velocity in figure 1. For the velocities measured in this study the calculated inversion efficiencies associated with the labelling pulse ranged from 92%-94%, consistent with published data[5]. Taking into account the relative inversion efficiency associated with the amplitude modulated control[2] reduced these values to 69%-70%, slightly lower than the value of 71% assumed previously[6]. Including these reduced values for the inversion efficiency in the CASL perfusion calculations increased the whole-brain perfusion measurements by an average of 4% ($p<0.03$, paired t-test). The average measurement precision of the in-vitro flow measurements was 3% and the accuracy ranged from 1%-6% over a range of flow rates (100-1500 ml/s).

Discussion

We have demonstrated a strategy to quantify the velocity-dependent inversion efficiency of continuous ASL. Although the range of inversion efficiencies measured in this study was limited, it is likely that these effects may be larger in the presence of carotid artery stenoses or other vascular pathology, where increased flow rates may lead to an underestimate of the perfusion.

Figure 1: Inversion efficiency vs. flow velocity



References

1. Alsop et al. *J Cereb Blood Flow Metab* (1996) 16:1236-1249
2. Alsop et al. *Radiology* (1998) 208:410-416
3. Summers et al. *Proc ISMRM* (2001) p370
4. Press et al. Numerical Recipes. Cambridge University Press, 1987
5. Macotta et al. *NMR Biomed* (1997) 10:215-221
6. Chalela et al. Stroke (2000) 31:680-687