Assessment of cerebral perfusion MRI using arterial spin labeling and dynamic susceptibility contrast in individuals with carotid artery disease

B. J. MacIntosh[1], E. Sideso[2], M. J. Donahue[1], A. Bjørnerud[3], M. Günther[4], A. Handa[5], J. Kennedy[2], and P. Jezzard[1]

[1]Clinical Neurology, FMRIB Centre, Oxford, Oxfordshire, United Kingdom, [2]Acute Stroke Programme, Nuffield Department of Clinical Medicine, John Radcliffe, Oxford, Oxfordshire, United Kingdom, [3]Medical Physics, Rikshospitalet University Hospital, Oslo, Norway, [4]Neurology, University hospital Mannheim, University of Heidelberg, Heidelberg, Germany, [5]Nuffield Department of Surgery, John Radcliffe, Oxford, Oxfordshire, United Kingdom

INTRODUCTION Dynamic susceptibility contrast (DSC) is the industry-standard perfusion MRI technique and involves imaging the brain during first passage of a gadolinium-based contrast agent [1]. Arterial spin labeling (ASL) is an emerging, non-invasive technique capable of measuring cerebral perfusion by magnetically labeling water in arteries. The physical principles of ASL are closer to the gold standard $H_2^{15}O$ PET technique because the magnetically labelled water spins are able to exchange at the level of the capillaries while the DSC is an intravascular contrast agent. As ASL techniques improve and give rise to improved CBF quantification [2, 3], whole-brain capabilities [4, 5] and shorter scan durations [6], a case could be made to use ASL in a clinical setting and obviate the need for a contrast agent. The purpose of this study is to compare a 3D whole-brain ASL with DSC in a group of patients with known carotid artery disease, which is an established risk factor for stroke [7].

METHODS A perfusion MRI study was conducted in 10 patients using a 3 T Siemens MRI system and with approval from the local research ethics committee. Patients' duplex ultrasound scan revealed a spectrum of disease burden (Table 1). 3 of the 10 patients underwent a carotid endarterectomy (CEA). The imaging protocol included: gradient-echo DSC (2:10), 3D GRASE pulsed ASL at 10 inversion times (TI; scan time 8:00), dynamic Look-Locker ASL angiography (2:45) [8], time-of-flight angiography (2:30), T_1-weighted anatomical (1:45). DSC acquisition parameters were chosen to adhere to the latest stroke imaging guidelines [9]: TR/TE=1481/30 ms, 22 slices, matrix 128 x 128, 1.7 x 1.7 x 5 mm^3, GRAPPA acceleration=2. DSC and ASL data were collected with the same orientation and through-plane resolution. ASL parameters were: TR/TE = 3166/23 ms, segmented acquisition along k_z, matrix 64x64x22, 3.2x3.2x5 mm^3, 5/8th k-space coverage, TI starts at 400, increments by 220, ends at 2380 ms, background suppression of static tissue, Q2TIPS=1600 ms. Time-to-peak (TTP; seconds) and peak amplitude were calculated by fitting a gamma-variate function to the dynamic angiography data. ASL data were analysed using a two-parameter fit of the multiple inflow curve at each voxel, producing CBF and arterial transit time (ATT) maps. DSC data were analysed using a circular singular value decomposition routine (http://www.cfin.au.dk). The arterial input function (AIF) was selected automatically from within a hand drawn ROI in proximal DSC slices at the level of the circle of Willis. DSC and ASL CBF maps were compared using: 1) the ratio of white (WM) to gray matter (GM) CBF levels, a metric that has been used in the literature to compare perfusion techniques [10], 2) a ratio of ipsilateral to contralateral hemisphere CBF (e.g. $ASL_{i/c}$) for the different brain lobes. GM masks included a thresholding step, i.e. μ_{CBF}/σ_{CBF} > 1.96, to avoid including problematic voxels in the analysis.

Patient	Age	M/F	ICA Stenoses Right	ICA Stenoses Left	WM/GM Ratios DSC	WM/GM Ratios ASL	DSC vs ASL Correlation
1	74	M	35%	35%	0.682	0.748	0.185
2	82	F	60%	60%	0.865	0.829	0.364
3	67	M	20%	40%	0.793	0.503	0.245
4	76	M	30%	85%	0.775	0.708	0.313
5	70	M	0%	40%	0.744	0.835	0.352
6	61	M	100%	65%	0.753	0.767	0.289
7	61	M	30%	50%	0.782	0.759	0.263
8	76	M	0%	80%	0.667	0.747	0.340
9	74	M	40%	0%	0.657	0.813	0.331
10	83	F	100%	15%	0.829	0.707	0.053
					0.755	**0.741**	**0.273**

Table 1 shows patient demographics, whole brain WM/GM CBF ratios for ASL and DSC and the GM voxel-wise correlation coefficient between DSC and ASL.

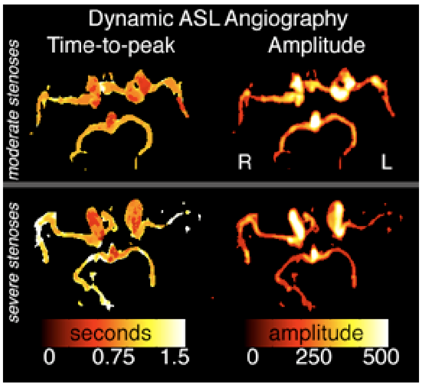

Fig.1. Results from the dynamic angiography data showing the time-to-peak (TTP; seconds) and peak amplitude signal for two patients. The patient (patient2; top) with moderate bilateral disease (60%, 60%) shows symmetric flow patterns at the level of the circle of Willis. The severe stenotic patient (patient4; bottom) shows signal void on the left side (ICA stenoses of 85%).

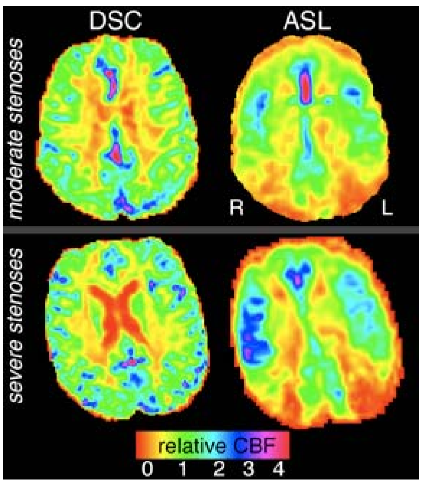

Fig. 2. DSC (left) and ASL (right) CBF maps from the same patients as in Fig. 1. CBF levels are shown in relative units. Top: Although ASL was collected with lower in-plane resolution compared to DSC, the CBF maps for a patient with moderate stenoses are in good agreement. Bottom: Some CBF DSC to ASL discrepancies are apparent in the MCA territories for the patient with severe stenoses. ASL reveals a pattern of asymmetry while the DSC is symmetric between hemispheres. This result was consistent for all 3 patients with severe stenotic disease.

RESULTS

Table 1 shows patient demographics and a summary of the DSC and ASL imaging results. DSC and ASL produced WM/GM ratios that were not statistically different from one another (unpaired t-test P > 0.9). A voxel-wise comparison of CBF in WM showed a reasonable ASL and DSC correlation that was significant (R = 0.27 ± 0.094, P < 0.01). Although ASL showed a trend towards a reduced CBF ipsilateral to the side of stenoses (e.g. $ASL_{i/c}$ = 0.96±0.16) the $ASL_{i/c}$ and $DSC_{i/c}$ were not statistically different from one another in each of the brain lobes (P>0.06). Figs 1 and 2 show representative dynamic angiography and CBF maps for two patients.

DISCUSSION

In the present study we extend comparisons of ASL and DSC that have been reported in the literature [10-13] by comparing these techniques in patients with carotid artery disease. From this preliminary patient dataset, whole-brain ASL performed at 3 T appears to have comparable image quality when compared to the DSC. We found CBF WM/GM ratios to be higher than what has been reported [10] but also found a stronger agreement between ASL and DSC. Interestingly, ASL showed CBF hemispheric asymmetry in all three patients with severe stenotic disease that went on to CEA. Future work will include 1) recruitment of additional patients, 2) DSC analysis that incorporates dynamic angiography TTP maps and local AIF selection to assess whether discrepancies between DSC and ASL can be reconciled by improved analysis strategies.

REFERENCES

1. Ostergaard, L., et al. MRM, 1996. 36(5): p. 715-25.
2. Yang, Y., et al. MRM, 2000. 44(5): p. 680-5.
3. Petersen, E.T., et al. MRM, 2006. 55(2): p. 219-32.
4. Gunther, M., et al. MRM, 2005. 54(2): p. 491-8.
5. Talagala, S.L., et al. MRM, 2004. 52(1): p. 131-40.
6. Fernandez-Seara, M.A., et al. MRM,2008.59(6):p.1467.
7. Lovett, J.K., et al. Neurology, 2004. 62(4): p. 569-73.
8. Gunther, et al. MRM, 2001. 46(5): p. 974-84.
9. Wintermark, M, et al. Stroke, 2008. 39(5): p. 1621-8.
10. Weber, M.A., et al. Invest Radiol,2003. 38(11):p.712-8.
11. Siewert, et al. Neurology, 1997. 48(3): p. 673-9.
12. Wolf, R.L., et al. J Neuroimaging, 2003. 13(1): p.17-27.
13. Ludemann, L., et al. Eur J Radiol, 2008 [e-pub].