Measurement of Perfusion During Transient Carotid Occlusion

Matthew Ethan MacDonald[1,2], Parviz Dolati[2,3], Linda Andersen[2,3], Cheryl R McCreary[2,3], John Wong[2,3], and Richard Frayne[2,3]
[1]*Biomedical Engineering, University of Calgary, Calgary, AB, Canada,* [2]*Seaman Family MR Research Centre, Foothills Medical Centre, Alberta Health Services, Calgary, AB, Canada,* [3]*Radiology and Clinical Neurosciences, University of Calgary, Calgary, AB, Canada*

Introduction: Ischemic stroke occurs when blood vessels feeding the brain become occluded and tissues do not receive adequate nutrition. Function is initially impaired, and with time, if flow is not restored the tissue will eventually become infarcted. Validation of restored flow is confirmed clinically by evaluating the macroscopic blood vessels with x-ray imaging using digital subtraction angiography (DSA) or with computed tomography (CT) angiography [1]. There can be a disconnection between restored flow observed with DSA and patient outcomes, as DSA does not provide information about the microscopic blood flow (*i.e.*, it does not provide information about the capillary bed and tissue perfusion). Measures of tissue perfusion can be obtained by kinetic modeling of contrast agent passage imaged rapidly with CT [2] or magnetic resonance (MR) imaging [3,4], and with arterial spin labeling (ASL) MR imaging [5]; of these three methods, ASL allows for the fastest repeatable measurements. It is our hypothesis that perfusion can be measured transiently with ASL during neurovascular interventions leading to an improved understanding of flow restoration, and that there will be a detectable difference on ASL perfusion during carotid occlusion. In this study we simulated an occlusion in a canine model with endovascular devices and then analyzed the difference of perfusion between different vascular territories.

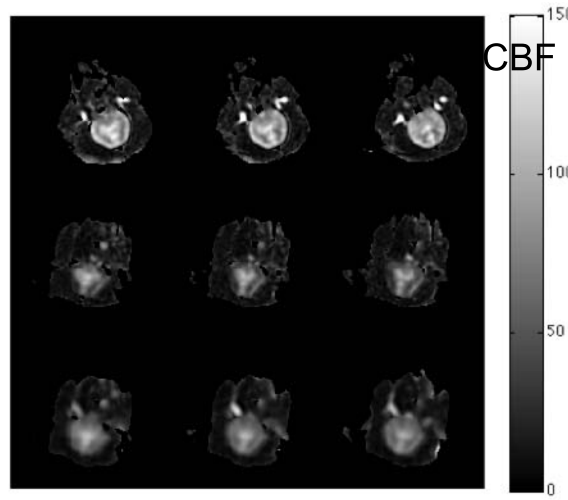

Fig 1: Example CBF measures generated at baseline (Row 1), when the balloon was deflated (Row 2), and when the balloon was inflated (Row 3).

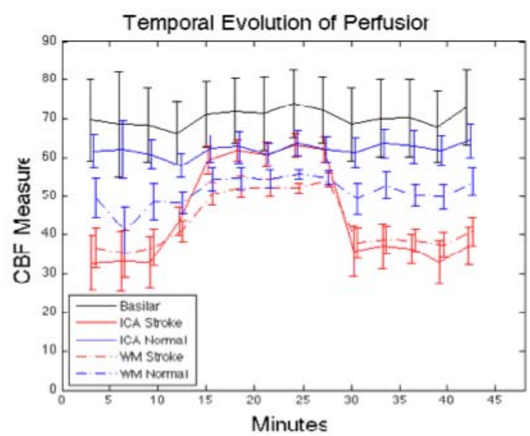

Fig 2: Plot of the temporal course of perfusion during the simulated stroke for the different vascular regions.

Methods: Permission was obtained through our institution's animal care committee to use canines for this exploratory work. Anesthesia was induced with Pentothal and maintained with 1.5% to 2.0% Isoflurane. All MR imaging was performed with a 3T MR scanner (Discovery 750, GE Healthcare, WN, USA) and x-ray portions were performed with a portable C-arm (Series 9800, Varian, CA, USA). Baseline MR imaging was first performed to assess the canine in a healthy state (pseudo continuous ASL, EPIC v22M3: axial, spiral trajectory of 4 arms, 36 slices 4 mm thick, 22 cm^2 FOV, tag delay of 1500 ms, and a NEX of 3, ~3 min scan time). Under fluoroscopic guidance and with a right femoral artery puncture, we advanced a 5 F catheter (Envoy, Cordis Corp., Markham, Ontario, Canada) to the common carotid artery (CCA). A 4 mm $\times$ 7 mm balloon/guidewire pair (Hyperform by EV3, Irvine, CA, USA) were inserted through the 5 F catheter to the mid CCA. Rapid ASL imaging was then performed, the balloon was inflated at 10 min mark to fully occlude the vessel and deflated at the 15 min mark to restore flow. Analysis was performed by placing regions of interest (ROI) across different territories of the brain: basilar, internal carotid artery (ICA) stroke/normal sides, and white matter (WM) stroke/normal sides.

Results: Example perfusion measures are shown in Fig 1; baseline imaging shows expected perfusion (Row 1), after the balloon was insert but before it was inflated the perfusion is observed to decrease even with no occlusion (Row 2), when the balloon is inflated perfusion on the stroke side is measured to increase. The temporal perfusion measures during the occlusion process are plotted with the standard error in Fig 2. Numerical measures are reported in Table 1. Detectable differences were observed between all vascular regions during occlusion except the ICA fed stroke and normal sides.

Discussion: This work is the first to demonstrate transient perfusion measurement during neurovascular intervention. The low transient perfusion shown in Fig 1 and Fig 2 during the non-occlusion phase result from a reduction of the tagging efficiency due to susceptibility effects of having the catheter in the artery (*i.e.*, blood flowing by the catheter when the balloon is not inflated is poorly tagged). This model also demonstrates the effect of collateral flow between different vascular territories during the occlusion phase, sufficient collateral flow exists to maintain perfusion across cortical structures but not the WM structures where there is less vessel redundancy.

Table 1: Measured perfusion values during the different phases of the transient stroke.

ROI	3 min mark		21 min mark		36 min mark	
	mean	*std error*	*mean*	*std error*	*mean*	*std error*
Basilar	69.69	0.09	71.26	0.08	70.16	0.09
ICA Stroke	32.82	0.09	60.75	0.04	36.41	0.05
ICA Normal	61.63	0.04	60.84	0.03	62.89	0.04
WM Stroke	36.64	0.23	52.18	0.10	38.55	0.13
WM Normal	49.64	0.07	54.52	0.12	50.20	0.08

References:

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[5] Chalela, *et al.*, Stroke, 2000