Combined assessment of vascular territories and haemodynamic parameter maps

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Introduction: Defining watershed (WS) areas – the border zone regions supplied by the most distal branches of the cerebral arteries – is critical as these regions are most susceptible to haemodynamic ischaemia, and may even play a role in thrombo-embolic stroke due to reduced wash-out of capacity. Territorial arterial spin labelling (TASL) has been shown to provide a method of selectively labelling individual cerebral arteries to spatially map the perfusion territory of the internal carotid arteries (RICA and LICA) and basilar artery (BA) [1]. Multiphase ASL data provides a method to estimate of haemodynamic parameters of perfusion rate (f), arterial blood volume (CBV_a) and arterial (Δ) and tissue (δ) transit times [2]. It has been suggested that transit time maps can provide a method to distinguish the cerebral watershed areas from main territory regions, due to the increased transit time of blood to the distal branches of the cerebral arteries. Here we assess the correspondence between these methods, additionally mapping the anterior cerebral artery (ACA) territory. Probabilistic TASL maps and mean haemodynamic parameter maps are formed, with the aim of generating an MNI atlas of these haemodynamic parameter estimates and territories as a reference for comparison with disease, such as steno-occlusive carotid disease, where cerebral haemodynamics are altered [3].

Methods: This study was approved by the local ethics committee and all subjects gave written, informed consent. Six healthy subjects (age 27 ± 3 yrs) were scanned on a Philips Achieva 3.0T MRI scanner in a single session for complete assessment of territories, and haemodynamic parameters (f, CBV_a, Δ and δ). Coronal and sagittal phase contrast angiograms (PCA) and a time of flight (TOF) MRA were collected to plan selective labelling for TASL. TASL images were acquired using a STAR sequence with in-plane WET pre- and post-saturation pulses and a post-label delay (TI) of 1.2 s, the TR per label/control pair was 6 s. Selective inversion slabs were positioned to label RICA, LICA, and BA as described previously [1]. In addition the anterior cerebral artery (ACA) was selectively labelled using a narrow slab applied in the sagittal plane. 40 pairs of images were acquired per territory. Multiphase ASL data sets was then collected (TI = 300 ms, TA = 300 ms, 7 phases) with no vascular crushing to form arterial transit time (Δ) and CBV_a maps, and with vascular crushing (bipolar gradient V_{enc} = 5 cm/s) to estimate tissue transit time (δ) and form perfusion (f) maps. TASL and multiphase data sets were acquired for a 10 slice data set with 192 x 192 FOV and 3 x 3 mm^2 with 8 mm slice thickness. The complete assessment took ~ 30 minutes.

Data Analysis: TASL tag and control images were realigned and perfusion weighted difference images calculated to form maps of vascular territories (RICA, LICA, BA and ACA). Non-vascular crushed multiphase data was fitted on a voxel-voxel basis to form arterial transit time (Δ) and CBV_a maps [3] and vascular crushed data fitted to form capillary transit time (δ) and perfusion (f) maps [3]. Territory and haemodynamic parameter maps were then transformed into MNI space using the FLIRT linear registration tool (FSL, Oxford). Each vascular territory was threshold at 0.2 % signal and group probability maps formed, average and standard deviation haemodynamic parameter group maps were computed from the multiphase ASL data. WS areas were defined as those regions displaying lengthened transit times and classified as anterior, posterior and internal WS zones. Correspondence between territories and the WS zones were assessed as percentage overlap (Table 1). In addition, the vascular supply and parameters assessed for anatomically defined masks using MNI atlas.

Watershed	Territory	% overlap
Posterior	BA	7.0
Posterior	ICA (L+R)	9.2
Anterior	ACA	18.8
Anterior	ICA (L+R)	28.2
Interior	ICA	60.5
Interior	BA	16.6

Table 1: *Percentage overlap of arterial territories onto watershed regions.*

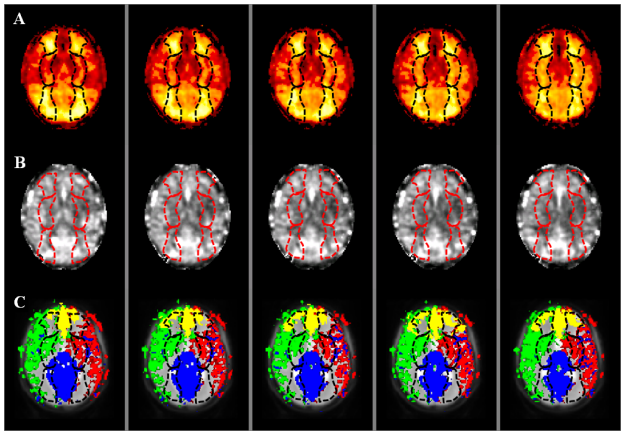

Figure 1: **(**A) *Mean capillary transit maps (B) Perfusion Map and (C) Vascular territories maps (RICA-green, LICA- red, BA - blue, ACA- yellow) shown for in MNI co-ordinates for z = 2 to 10). Defined anterior, posterior and interior watershed areas outlined.*

Results: Figure 1 shows the mean capillary transit time (A) and perfusion map (B) with WS zones outlined; and associated threshold vascular territory maps (C). Capillary transit time maps showed improved delineation of the anterior, posterior and interior border zones compared to the arterial transit maps (Table 2). The BA territory was found to have a significantly lengthened transit time compared to LICA/RICA and ACA, with the ACA showing a shortened transit. Perfusion rates in the border zones were slightly reduced compared to mean values for the vascular territories. Assessing specified anatomical regions, the caudate and putamen we found to have the shortest transit time, with the occipital lobe showing the largest (Table 2).

Region	Δ (ms)	δ (ms)	CBF (ml/100g/min)
LICA	683 (25)	746 (27)	76 (6)
RICA	789 (13)	795 (15)	69 (8)
BA	1081 (24)	1092	75 (12)
ACA	433 (27)	563 (17)	74 (7)
Anterior	1396	1296	64 (8)
Interior	937 (17)	973 (18)	65 (9)
Posterior	1420 (31)	1456	74 (6)

Table 2: *Haemodynamic parameters measured in territories (grey) and watershed regions (mean ± sterr).*

Discussion: The combination of multiphase and territorial ASL allows one to construct informative individual vascular maps that can be combined to build reference atlases of both region-specific perfusion levels and position and functional effects of watershed areas. This in turn will provide a useful basis to study the haemodynamic effects of cerebrovascular disease, but also physiological effects from aging, blood pressure changes or drugs known to affect autoregulation. Watershed areas can be assessed from the perimeter of vascular territories and increased transit times. Future studies will further assess the length of vascular paths in combination with MR angiograms.

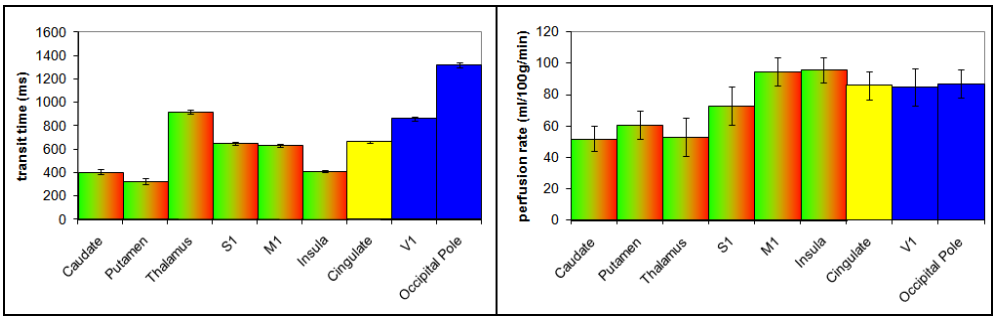

Figure 2: *Mean transit time and perfusion in selected anatomical brain areas (colours indicate territories).*

References: 1. Hendrikse, Stroke, 35; 882-887, 2004. 2. Hendrikse, Radiology, 246; 572-580, 2009. 3. Goode et al., ISMRM, 2007.