# Hemodynamics of the cerebral border zone regions in healthy, young volunteers

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**Targeted audience** Researchers and clinicians interested in new developments in ASL and compartmentalization of spins.

**Purpose** The tissue regions supplied by the distal end branches of the cerebral arteries are called the cerebral border zone or watershed regions. It is known that these regions are more vulnerable to ischemia and infarction and have a longer arterial transit time (ATT) compared to the central regions of the flow territories[1]. It is, however, unclear whether transport through the microvascular tissue is also delayed. In this study we employed time encoded (aka. Hadamard encoded) pseudo Continuous Arterial Spin Labeling (te-pCASL)[2] combined with $T_2$-Relaxation-Under-Spin-Tagging (TRUST)[3] to evaluate the hemodynamics of the posterior and middle cerebral artery (MCA) border zone region, which lies between the cortical branches of the MCA and the posterior cerebral artery. The aim of this study was to assess hemodynamic properties of the border zone regions in the brains of young healthy volunteers.

**Methods** Eight healthy volunteers (age 21-30 y, 5 female, 3 male) were scanned at 3T (Achieva, Philips Healthcare) with a 32-channel head coil. te-pCASL was combined with TRUST to distinguish spin transition from the vasculature to the tissue compartment based on their $T_2$. This method is more time efficient, while still keeping an equal SNR, compared with separate multi-time point pCASL scans[4]. For te-pCASL, the total labeling duration of 3700 ms was divided into 7 blocks of 1300, 600, 3x400 and 2x300 ms, comprising 8 encoding patterns, followed by a minimum post labeling delay (PLD) of 265 ms. The $T_2$-preparation module was performed at 4 effective echo times (eTE): 0, 40, 80 and 160 ms (0, 4, 8, and 16 composite 180° pulses with their signs arranged in an MLEV pattern). General te-pCASL-TRUST protocol: imaging module with single shot FFE-EPI, 3.2×3.2×7 mm voxel size, 11 slices and TR/TE/fa = 4423ms/17ms/90°, background suppression FOCI pulses at 1900 and 3400 ms. 72 acquisitions (9x8 encodings) were acquired with vascular crushing ($V_C$ = 5 cm/s) in a total scan time of 22:34 min. After subtraction, according to the appropriate Hadamard scheme, the ASL signal was calculated for the different eTEs and PLDs. A Regional Perfusion Imaging scan was performed to determine the 3 major flow territories: left and right MCA flow territory and posterior flow territory. 10 voxels were selected on either side of the posterior border and in the central region of each flow territory. The average signal in these voxels was fitted to the kinetic perfusion model of Buxton[5] to estimate CBF and ATT. For each PLD the $T_2$ was calculated with a mono-exponential fit on the average signal of these voxels. The hemodynamic properties were statistically compared using paired t-tests.

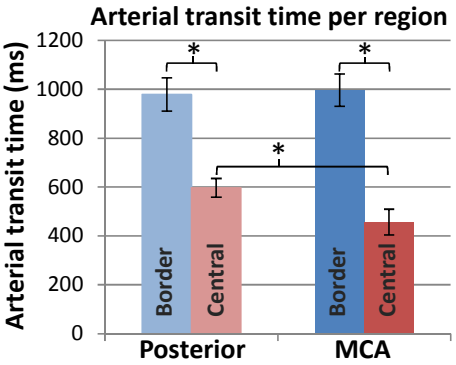


**Figure 1** Arterial transit time in the posterior and MCA flow territory sampled from the border and central regions. * is p<0.05

**Results and discussion** On average, the ATT was 1.9 times longer in the border regions compared with the central regions, as shown in figure 1. The ATT in the central posterior region was also significantly longer than in the central MCA region (p<0.05). A significantly lower CBF was found in the border region compared with the central region: 37.8 ± 2.5 (mean±sem) and 47.8 ± 2.5 in the posterior flow territory, and 38.6 ± 2.6 and 50.1 ± 2.6 mL/100g/min in the MCA flow territory. In figure 2 a clear delay and lower ASL signal can be seen in the border regions. The same delay as in the ATT was found in the moment of transition of the signal from the vascular to the tissue compartment, as can be concluded from figure 3 by the significantly later decrease of the $T_2$ in the border zones ($T_2$ around 165 ms is expected for the labeled spins in the arteries and 90 ms for spins in the grey matter tissue[3]). To see whether the transition of the label from the vascular to tissue compartment occurs with the same timing, the $T_2$-curve of the border zone is shifted by the difference in ATT between the border and central part of that flow territory (shown in green in figure 3). This shows that the central and border zone regions seem to provide similar timing of the $T_2$-curves, although at a PLD around 1650 ms a slightly higher $T_2$ can be observed.

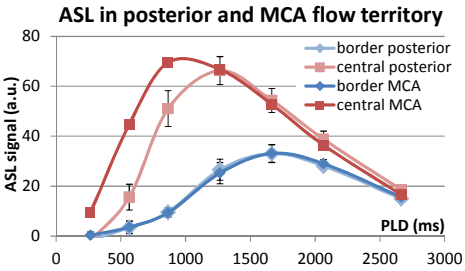


**Figure 2** The ASL signal in the posterior and MCA flow territory sampled from the border and central regions.

**Conclusion** The arterial transit time in the border zone is significantly longer compared to the central region. However, the exchange of the label from the arterial to the tissue compartment appears to be at a similar rate.

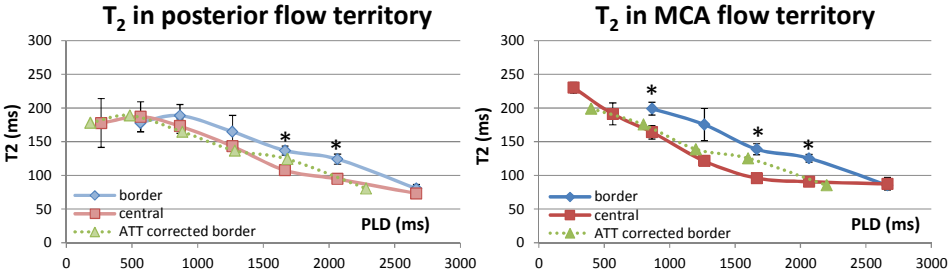


**Figure 3** The $T_2$ in the posterior (left) and MCA (right) flow territory over time sampled from the border and central regions (* is p<0.05). The arterial transit time corrected border $T_2$ is the $T_2$-curve of the border zone is shifted by the difference in ATT between the border and central part of that flow territory.

**References**
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