FROM CEREBRAL BLOOD FLOW MODELING TO VASCULAR UNITS MAP IN PRIMATE CORTEX

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INTRODUCTION

The amazing topological and geometrical complexity of micro-vascular networks in the brain, and in other organs, has challenged many researchers for decades. Since the brain's vascular system is structured by a highly reticulated pial surface network which plunges down into a set of penetrating vessels, it is tempting to attribute a vascular unit to each penetrating arteriole. Recent experimental analysis have led to a breakthrough on the properties of the blood supply in the brain [1]. Penetrating arterioles have been identified as the bottleneck of brain perfusion [2]. Furthermore, it has also been realized that targeted clots of penetrating arterioles are not compensated by active changes in the diameter of their neighbor arteries [3]. This observation suggests passive compensatory mechanisms resulting from the couplings between arteriolar territories consistent with other recent observations of active blood flow reorganization via collateral vessels (inter-arterial connections) [4]. A systematic investigation of the three-dimensional extent of compensation is not possible with experimental measurements but in silico simulations permit a systematic investigation of the spatial distribution of the brain perfusion. The direct computation of blood flow considering a complete mechanical description of its components interactions (red blood cells, plasma, vessel shape, Endothelial Surface Layer – ESL –) over several cubic millimeters of tissue is a more than challenging task for any computer at present. Approximate methods are needed to provide a realistic picture of blood distribution inside tissues [5]. Such approximate network method have permitted to realize that vessel shape, realistic boundary conditions, and in vivo (ESL included) effective apparent viscosity are important ingredient for the pressure and blood flux distributions [5]. We analyze here the functional topological and spatial couplings of arteriolar and venous inputs/outputs.

VASCULAR TERRITORIES ANALYSIS

Definition

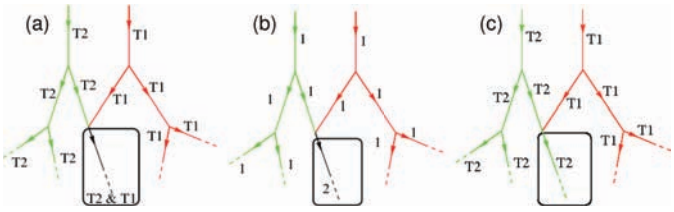

Figure 1. (a) Illustration of Perfusion/Drainage Territory and (b) Robustness Index (RI).

- *Perfusion-Drainage Territory* (PDT) is defined as the entire region either spanned through perfusion (Arterial PDT), or drained by perfusion (Venular PDT) (see Figure 1a) which are possibly overlapping.
- *Arterial/Venular Robustness Map* (ARM, VRM) quantifies the redundancy of the perfusion at one point (see Figure 1b). Arterial Robustness Map (ARM) provides, for each segment, the number of input penetrating arteries which contribute to its perfusion, a number called Arterial Robustness Index (ARI).

Vascular territories evaluation

We analyze the territories of 37 penetrating arterioles and 24 draining venules resulting from the analysis of 18 cubic millimeters of monkey cerebral cortex where the blood perfusion has been previously evaluated [5]. Figures 2a,c and Figures 2b,d illustrate the arterial and venous Perfusion/Drainage Territories (PDT) respectively.

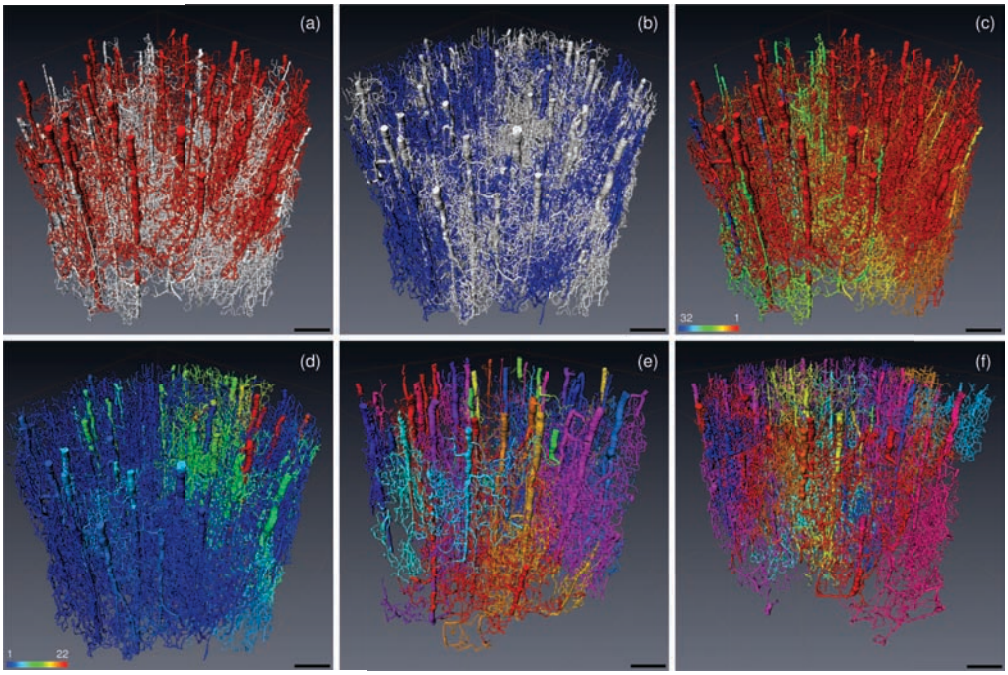

Figure 2. (a) Non overlapping Arterial Preferential Drainage Territory regions are displayed in red whilst overlapping one are represented in white, (b) same convention as (a) for Venous Preferential Drainage Territory with blue instead of red, (c) Arteriolar Robustness Map (ARM) and (d) Venular Robustness Map (VRM). (e) Arteriolar PT (APT), (f) Venular PT (VPT).

CONCLUDING REMARKS

These estimations support the classical picture of preferential neighbors hemodynamics interactions of vascular territories, either inside the network, or between pial input/output penetrating vessels. Although we found very localized functional couplings between preferential arterio/venular partners, we also brought to the fore important potential collateral supplies which can be distributed over a surprisingly large spatial extent.

References

[1] Schaffer CB, et al. (2006) Two-photon imaging of cortical surface microvessels reveals a robust redistribution in blood flow after vascular occlusion. *PLoS Biol.* 4:258–270.

[2] Nishimura N, Schaffer CB, Friedman B, Lyden PD, Kleinfeld D (2006) Penetrating arterioles are a bottleneck in the perfusion of neocortex. *P. Natl. Acad. Sci. USA* 104:365–370.

[3] Nishimura N, Rosidi NL, Iadecola C, Schaffer CB (2010) Limitations of collateral flow after occlusion of a single cortical penetrating arteriole. *J. Cerebr. Blood F. Met.* p doi:10.1038/jcbfm.2010.157.

[4] C. C. Lay, M. F. Davis CHCB, Frostig RD (1981) Mild sensory stimulation completely protects the adult rodent cortex from ischemic stroke. *Plos one* 7:519–579.

[5] Guibert R, Fonta C, Plouraboué F (2010) Cerebral blood flow modeling in primate cortex. *J. Cerebr. Blood F. Met.* 30:1860–1873.