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► **To cite this version:**

Amy F. Smith, Anne Larue, Myriam Peyrounette, Sylvie Lorthois. Structural and hemodynamic comparison of synthetic and anatomical cerebral capillary networks. 22nd Congress of the European Society of Biomechanics, Jul 2016, Lyon, France. pp.0. hal-03660260

HAL Id: hal-03660260

<https://hal.science/hal-03660260v1>

Submitted on 5 May 2022

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To cite this version : Smith, Amy and Larue, Anne and Peyrounette, Myriam and Lorthois, Sylvie *Structural and hemodynamic comparison of synthetic and anatomical cerebral capillary networks*. In: 22nd Congress of the European Society of Biomechanics, 10 July 2016 - 13 July 2016 (Lyon, France). (Unpublished)

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STRUCTURAL AND HEMODYNAMIC COMPARISON OF SYNTHETIC AND ANATOMICAL CEREBRAL CAPILLARY NETWORKS

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Introduction

A method for developing 3D synthetic capillary networks representative of the geometric, topological and functional properties of the cerebral microcirculation is presented. Previous methods [2, 4] have lacked quantitative comparison against anatomical cerebral networks.

It is hypothesised that healthy capillary networks are space-filling, ensuring that the maximum separation of each tissue cell from the nearest vessel is less than a certain length, linked to the diffusion limited distance of oxygen transport in oxygen consuming tissue. Building on this theory, Lorthois & Cassot [3] constructed 2D synthetic space-filling networks by randomly placing one point in each cell of an $n \times n$ grid. From this set of points, representing the centres of tissue cells, Voronoi diagrams were extracted with the edges producing a 2D network of capillaries with three segments at each node, a characteristic feature of cerebral capillaries networks (see Figure 1, left). The goal of the present work is to extend this approach to 3D and to compare the resulting structural and hemodynamic properties to the properties of anatomical cerebral capillary networks.

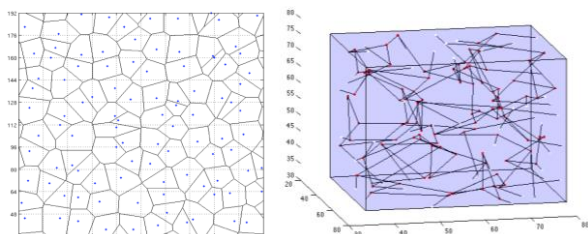


Figure 1(left): 2D Voronoi diagram constructed on a 10×10 grid from [3]; (right): 3D synthetic capillary network constructed on a $3 \times 3 \times 3$ grid.

Methods

In 3D, Voronoi diagrams produce polyhedrons with more than three edges (capillaries) at each node. To improve the connectivity, clusters of nodes were systematically merged. Segments were then pruned randomly while ensuring no less than three edges per node, with special care taken near the boundaries. The structure of the resulting networks was compared to a region of interest of a human anatomical capillary network extracted previously [1] (see Figure 2).

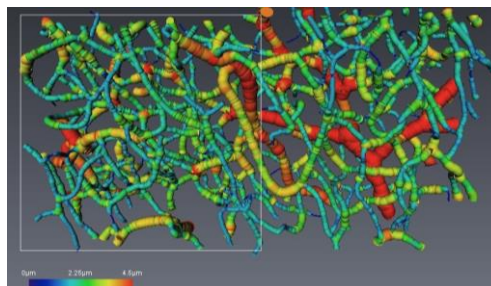


Figure 2: 3D Anatomical network [1].

Results

By pruning excess segments, this method reproduced the expected connectivity of three segments per node, while ensuring, by construction, the space-filling nature of the network (see Figure 1, right). Considering capillary loops sufficiently far from the boundaries to avoid truncation effects, their mean number of edges and mean cumulative length was very close to that of the anatomical network. Comparison of other structural and hemodynamic parameters (e.g. permeability) will be presented.

Discussion

A computational method was developed to generate random synthetic cerebral capillary networks with physiologically-relevant structures. These networks will be used in future to reveal the dominant structural features of cerebral capillary networks, enabling us to investigate the effect of changing these features to model different brain regions or pathological states such as Alzheimer's disease. They will also be used in models of blood flow and mass transport in the cerebral microcirculation. By generating larger capillary networks than can currently be extracted using high-resolution imaging modalities, these can then be coupled to lower-resolution anatomical data sets (capillaries unresolved) of whole-brain vascular structure, or used to derive and validate equivalent continuum models.

References

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Acknowledgements

This work was supported by ERC BrainMicroFlow GA61510.