Structural and hemodynamic comparison of synthetic and anatomical cerebral capillary networks

Authors

***A. SMITH**, M. PEYROUNETTE, A. LARUE, V. DOYEUX, Y. DAVIT, S. LORTHOIS; Inst. De Mecanique Des Fluides De Toulouse, Toulouse, France

Disclosures

A. Smith: None. **M. Peyrounette:** None. **A. Larue:** None. **V. Doyeux:** None. **Y. Davit:** None. **S. Lorthois:** None.

Abstract

A computational method is presented for generating 3D synthetic, random capillary networks which match the topological, geometrical and functional properties of the cerebral microcirculation. This enables production of larger capillary networks than can currently be extracted using high-resolution imaging modalities. These networks can then be coupled to lower-resolution data sets of whole-brain vasculature (capillaries unresolved) to model blood flow and mass transport, and to validate equivalent continuum/hybrid models. Another motivation is to reveal the dominant structural features of cerebral capillary networks, enabling us to tune these features to model different brain regions or pathological states such as Alzheimer's disease. Previous works (Linninger et al, Ann Biomed Eng, 2013; Su et al, Microcirc, 2012) lacked physiological basis, and although resulting networks conformed to expected global morphometric properties, they were not subjected to thorough topological or functional analysis.

In contrast, our approach is based on the physiological assumption that the maximum separation of tissue cells from the nearest capillary is limited by the diffusion distance of oxygen (Lorthois & Cassot, J Theor Biol, 2010). Previously, synthetic, space-filling 2D networks were constructed by placing one point randomly in each cell of an n × n grid; from this set of points, Voronoi diagrams were extracted with the edges producing a 2D capillary network with mainly three capillaries per vertex, a characteristic feature of cerebral capillary networks. Here, we present a 3D extension of this approach and compare the resulting structural and hemodynamic properties to those of anatomical cerebral capillary networks.

In 3D, Voronoi diagrams produce polyhedrons with many capillaries at each vertex. To derive a network with only bifurcations, clusters of vertices were systematically merged and capillaries were then randomly removed. The resulting network structures were compared to capillary regions extracted from human and mouse anatomical data sets (Cassot et al, Microcirc, 2006; Tsai et al, J NeuroSci, 2009; Blinder et al, Nat Neurosci, 2013), showing excellent agreement. Geometrical metrics included the mean/S.D. of capillary lengths and edge/length/vertex densities. To measure the interconnected network topology, capillary loops were identified and the mean number of edges per loop, loop length, and number of loops per edge were compared. The spatial arrangement of capillaries was compared by studying the distribution of extravascular distances. Finally, the permeability was computed as a hemodynamic measure of blood flow conductivity.