



UvA-DARE (Digital Academic Repository)

Modelling cerebral blood flow and perfusion during acute ischaemic stroke

Padmos, R.M.

Publication date
2022

[Link to publication](#)

Citation for published version (APA):

Padmos, R. M. (2022). *Modelling cerebral blood flow and perfusion during acute ischaemic stroke*. [Thesis, fully internal, Universiteit van Amsterdam].

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, P.O. Box 19185, 1000 GD Amsterdam, The Netherlands. You will be contacted as soon as possible.

Bibliography

- [1] E. E. Weinmann and E. W. Salzman. Deep-Vein Thrombosis. *New England Journal of Medicine*, 331(24):1630–1641, 12 1994.
- [2] E. J. Benjamin et al. Heart Disease and Stroke Statistics—2018 Update: A Report From the American Heart Association. *Circulation*, 137(12):E67–E492, 3 2018.
- [3] E. S. Donkor. Stroke in the 21st Century: A Snapshot of the Burden, Epidemiology, and Quality of Life. *Stroke Research and Treatment*, 2018, 2018.
- [4] H. Wang et al. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet*, 388(10053):1459–1544, 10 2016.
- [5] J. L. Saver. Time is brain - Quantified. *Stroke*, 37(1):263–266, 1 2006.
- [6] S. Jung et al. Relevance of the cerebral collateral circulation in ischaemic stroke: time is brain, but collaterals set the pace. *Swiss Medical Weekly*, 147(4950):1–28, 12 2017.
- [7] D. B. Fogel. Factors associated with clinical trials that fail and opportunities for improving the likelihood of success: A review. *Contemporary Clinical Trials Communications*, 11(July):156–164, 9 2018.
- [8] C. Miller et al. In Silico Trials for Treatment of Acute Ischemic Stroke:

- Design and Implementation. *Computers in Biology and Medicine*, pp. 104802, 8 2021.
- [9] B. Eftekhari et al. Are the distributions of variations of circle of Willis different in different populations? – Results of an anatomical study and review of literature. *BMC Neurology*, 6(1):22, 12 2006.
- [10] V. Papantchev et al. The role of willis circle variations during unilateral selective cerebral perfusion: A study of 500 circles. *European Journal of Cardio-thoracic Surgery*, 44(4):743–753, 2013.
- [11] L. B. Hindenes et al. Variations in the Circle of Willis in a large population sample using 3D TOF angiography: The Tromsø Study. *PLOS ONE*, 15(11):e0241373, 11 2020.
- [12] M. Brozic et al. Anatomy and Functionality of Leptomeningeal Anastomoses: A Review. *Stroke*, 34(11):2750–2762, 11 2003.
- [13] D. S. Liebeskind. Collateral circulation. *Stroke*, 34(9):2279–2284, 2003.
- [14] H. M. Vander Eecken and R. D. Adams. The anatomy and functional significance of the meningeal arterial anastomoses of the human brain. *Journal of Neuropathology and Experimental Neurology*, 12(2):132–157, 4 1953.
- [15] J. J. Kim et al. Regional Angiographic Grading System for Collateral Flow. *Stroke*, 35(6):1340–1344, 6 2004.
- [16] A. M. Boers et al. Collateral status and tissue outcome after intra-arterial therapy for patients with acute ischemic stroke. *Journal of Cerebral Blood Flow and Metabolism*, 37(11):3589–3598, 11 2017.
- [17] E. Seyman et al. The collateral circulation determines cortical infarct volume in anterior circulation ischemic stroke. *BMC Neurology*, 16(1):206, 12 2016.
- [18] A. Vagal et al. Collateral Clock Is More Important Than Time Clock for Tissue Fate. *Stroke*, 49(9):2102–2107, 9 2018.

- [19] E. R. Kimmel et al. Absence of Collaterals is Associated with Larger Infarct Volume and Worse Outcome in Patients with Large Vessel Occlusion and Mild Symptoms. *Journal of Stroke and Cerebrovascular Diseases*, pp. 1–6, 4 2019.
- [20] J. M. Lee et al. Brain tissue responses to ischemia. *Journal of Clinical Investigation*, 106(6):723–731, 9 2000.
- [21] M. Najm et al. Defining CT Perfusion Thresholds for Infarction in the Golden Hour and With Ultra-Early Reperfusion. *Canadian Journal of Neurological Sciences / Journal Canadien des Sciences Neurologiques*, 45(3):339–342, 5 2018.
- [22] P. Blinder et al. Topological basis for the robust distribution of blood to rodent neocortex. *Proceedings of the National Academy of Sciences*, 107(28):12670–12675, 7 2010.
- [23] H. Duvernoy et al. Cortical blood vessels of the human brain. *Brain Research Bulletin*, 7(5):519–579, 11 1981.
- [24] P. R. Konduri et al. In-Silico Trials for Treatment of Acute Ischemic Stroke. *Frontiers in Neurology*, 11, 9 2020.
- [25] M. Viceconti et al. in silico Clinical Trials: How Computer Simulation will Transform the Biomedical Industry. Research and Technological Development Roadmap, Avicenna Consortium. *Avicenna Consortium*, 2016.
- [26] P. Bradley. The history of simulation in medical education and possible future directions. *Medical Education*, 40(3):254–262, 3 2006.
- [27] M. Viceconti and P. Hunter. The Virtual Physiological Human: Ten Years After. *Annual Review of Biomedical Engineering*, 18(1):103–123, 7 2016.
- [28] A. G. Hoekstra et al. Virtual physiological human 2016: translating the virtual physiological human to the clinic. *Interface Focus*, 8(1):20170067, 2 2018.

- [29] A. G. Hoekstra et al. The Virtual Physiological Human Conference 2016. *Journal of Computational Science*, 24:65–67, 1 2018.
- [30] R. A. Gray and P. Pathmanathan. Patient-Specific Cardiovascular Computational Modeling: Diversity of Personalization and Challenges. *Journal of Cardiovascular Translational Research*, 11(2):80–88, 4 2018.
- [31] F. Gueyffier et al. Contribution of Modeling Approaches and Virtual Populations in Transposing the Results of Clinical Trials into Real Life and in Enlightening Public Health Decisions. *Thérapie*, 67(4):367–374, 7 2012.
- [32] W. K. El-Bouri and S. J. Payne. Multi-scale homogenization of blood flow in 3-dimensional human cerebral microvascular networks. *Journal of Theoretical Biology*, 380:40–47, 2015.
- [33] F. Mut et al. Morphometric, geographic, and territorial characterization of brain arterial trees. *International Journal for Numerical Methods in Biomedical Engineering*, 30(7):755–766, 7 2014.
- [34] S. N. Wright et al. Digital reconstruction and morphometric analysis of human brain arterial vasculature from magnetic resonance angiography. *NeuroImage*, 82:170–181, 11 2013.
- [35] N. S. Hartkamp et al. Mapping of cerebral perfusion territories using territorial arterial spin labeling: techniques and clinical application. *NMR in Biomedicine*, 26(8):901–912, 8 2013.
- [36] J. Alastruey et al. Modelling the circle of Willis to assess the effects of anatomical variations and occlusions on cerebral flows. *Journal of Biomechanics*, 40(8):1794–1805, 1 2007.
- [37] V. Akgun et al. Normal Anatomical Features and Variations of the Vertebrobasilar Circulation and Its Branches: An Analysis with 64-Detector Row CT and 3T MR Angiographies. *The Scientific World Journal*, 2013:1–7, 2013.

-
- [38] J. Alastruey et al. Arterial pulse wave haemodynamics. *11th International Conference on Pressure Surges*, pp. 401 – 443, 2012.
- [39] F. N. van de Vosse and N. Stergiopulos. Pulse Wave Propagation in the Arterial Tree. *Annual Review of Fluid Mechanics*, 43(1):467–499, 2011.
- [40] V. Milišić and A. Quarteroni. Analysis of lumped parameter models for blood flow simulations and their relation with 1D models. *ESAIM: Mathematical Modelling and Numerical Analysis*, 38(4):613–632, 7 2004.
- [41] S. J. Sherwin et al. One-dimensional modelling of a vascular network in space-time variables. *Journal of Engineering Mathematics*, 47(3-4):217–250, 2003.
- [42] E. Boileau et al. A benchmark study of numerical schemes for one-dimensional arterial blood flow modelling. *International Journal for Numerical Methods in Biomedical Engineering*, 31(10):e02732, 10 2015.
- [43] P. Reymond et al. Validation of a One-Dimensional Model of the Systemic Arterial Tree. *American Journal of Physiology - Heart and Circulatory Physiology*, 297:208–222, 2009.
- [44] P. J. Blanco et al. An Anatomically Detailed Arterial Network Model for One-Dimensional Computational Hemodynamics. *IEEE Transactions on Biomedical Engineering*, 62(2):736–753, 2 2015.
- [45] N. Xiao et al. A systematic comparison between 1-D and 3-D hemodynamics in compliant arterial models. *International Journal for Numerical Methods in Biomedical Engineering*, 30(2):204–231, 2 2014.
- [46] D. DeMers and D. Wachs. Physiology, Mean Arterial Pressure. In *StatPearls [Internet]*. StatPearls Publishing, 2019.
- [47] L. R. Williams and R. W. Leggett. Reference values for resting blood flow to organs of man. *Clinical Physics and Physiological Measurement*, 10(3):187–217, 8 1989.

- [48] C. D. Murray. The Physiological Principle of Minimum Work: I. The Vascular System and the Cost of Blood Volume. *Proceedings of the National Academy of Sciences of the United States of America*, 12(3):207–214, 3 1926.
- [49] J. Alastruey et al. Reduced modelling of blood flow in the cerebral circulation: Coupling 1-D, 0-D and cerebral auto-regulation models. *International Journal for Numerical Methods in Fluids*, 56(8):1061–1067, 3 2008.
- [50] D. Garcia-Gonzalez et al. On the mechanical behaviour of PEEK and HA cranial implants under impact loading. *Journal of the Mechanical Behavior of Biomedical Materials*, 69(January):342–354, 5 2017.
- [51] N. S. Hartkamp et al. Relationship between haemodynamic impairment and collateral blood flow in carotid artery disease. *Journal of Cerebral Blood Flow & Metabolism*, 38(11):2021–2032, 11 2018.
- [52] H. J. M. M. Mutsaerts et al. Cerebral Perfusion Measurements in Elderly with Hypertension Using Arterial Spin Labeling. *PLOS ONE*, 10(8):e0133717, 8 2015.
- [53] L. Tatu et al. Arterial territories of the human brain: Cerebral hemispheres. *Neurology*, 50(6):1699–1708, 6 1998.
- [54] R. Karch et al. Staged Growth of Optimized Arterial Model Trees. *Annals of Biomedical Engineering*, 28(5):495–511, 5 2000.
- [55] R. Karch et al. A three-dimensional model for arterial tree representation, generated by constrained constructive optimization. *Computers in Biology and Medicine*, 29(1):19–38, 1 1999.
- [56] W. Schreiner and P. Buxbaum. Computer-optimization of vascular trees. *IEEE Transactions on Biomedical Engineering*, 40(5):482–491, 5 1993.
- [57] K. Hayashi et al. Stiffness and elastic behavior of human intracranial and extracranial arteries. *Journal of Biomechanics*, 13(2):175–184, 1 1980.

- [58] E. Michel and B. Zernikow. Gosling's Doppler Pulsatility Index Revisited. *Ultrasound in Medicine & Biology*, 24(4):597–599, 5 1998.
- [59] Y. Kim et al. The effect of pulsatility index on infarct volume in acute lacunar stroke. *Yonsei Medical Journal*, 57(4):950–955, 2016.
- [60] C. S. Kidwell et al. Transcranial Doppler Pulsatility Indices as a Measure of Diffuse Small-Vessel Disease. *Journal of Neuroimaging*, 11(3):229–235, 7 2001.
- [61] T.-Y. Xu et al. Blood Flow Pattern in the Middle Cerebral Artery in Relation to Indices of Arterial Stiffness in the Systemic Circulation. *American Journal of Hypertension*, 25(3):319–324, 3 2012.
- [62] A. Ghorbani et al. The value of transcranial Doppler derived pulsatility index for diagnosing cerebral small-vessel disease. *Advanced Biomedical Research*, 4(1):54, 2015.
- [63] A. Kwater et al. Is blood flow in the middle cerebral artery determined by systemic arterial stiffness? *Blood Pressure*, 18(3):130–134, 1 2009.
- [64] G. F. Mitchell et al. Arterial stiffness, pressure and flow pulsatility and brain structure and function: The Age, Gene/Environment Susceptibility-Reykjavik Study. *Brain*, 134(11):3398–3407, 11 2011.
- [65] A. Melis et al. Bayesian sensitivity analysis of a 1D vascular model with Gaussian process emulators. *International Journal for Numerical Methods in Biomedical Engineering*, 33(12):e2882, 12 2017.
- [66] T. W. Okell et al. Cerebral Blood Flow Quantification Using Vessel-Encoded Arterial Spin Labeling. *Journal of Cerebral Blood Flow & Metabolism*, 33(11):1716–1724, 11 2013.
- [67] J. H. G. Helthuis et al. Branching Pattern of the Cerebral Arterial Tree. *The Anatomical Record*, 302(8):1434–1446, 8 2019.

- [68] P. J. Blanco et al. A computational approach to generate concurrent arterial networks in vascular territories. *International Journal for Numerical Methods in Biomedical Engineering*, 29(5):601–614, 5 2013.
- [69] T. I. Józsa et al. A porous circulation model of the human brain for in silico clinical trials in ischaemic stroke. *Interface Focus*, 11(1):20190127, 2 2021.
- [70] S. J. Sherwin et al. Computational modelling of 1D blood with variable mechanical properties and its application to the simulation of wave propagation in the human arterial system. *Int. J. Numer. Meth. Fluids*, 43(January):673–700, 2003.
- [71] H. Yu et al. An In-Vitro Flow Study Using an Artificial Circle of Willis Model for Validation of an Existing One-Dimensional Numerical Model. *Annals of Biomedical Engineering*, 47(4):1023–1037, 4 2019.
- [72] E. Hodneland et al. A new framework for assessing subject-specific whole brain circulation and perfusion using MRI-based measurements and a multi-scale continuous flow model. *PLOS Computational Biology*, 15(6):e1007073, 6 2019.
- [73] C. Michler et al. A computationally efficient framework for the simulation of cardiac perfusion using a multi-compartment Darcy porous-media flow model. *International Journal for Numerical Methods in Biomedical Engineering*, 29(2):217–232, 2 2013.
- [74] C. N. Hall et al. Capillary pericytes regulate cerebral blood flow in health and disease. *Nature*, 508(7494):55–60, 4 2014.
- [75] N. Arrarte Terreros et al. From perviousness to permeability, modelling and measuring intra-thrombus flow in acute ischemic stroke. *Journal of Biomechanics*, 111:110001, 8 2020.
- [76] T. Sorimachi et al. Blood pressure measurement in the artery proximal and distal to an intra-arterial embolus during thrombolytic therapy. *Journal of NeuroInterventional Surgery*, 3(1):43–46, 3 2011.

-
- [77] N. P. Smith et al. An anatomically based model of transient coronary blood flow in the heart. *SIAM Journal on Applied mathematics*, 62(3):990–1018, 2002.
- [78] M. S. Olufsen. Structured tree outflow condition for blood flow in larger systemic arteries. *American Journal of Physiology-Heart and Circulatory Physiology*, 276(1):H257–H268, 1 1999.
- [79] C. Chen et al. Thresholds for infarction vary between gray matter and white matter in acute ischemic stroke: A CT perfusion study. *Journal of Cerebral Blood Flow and Metabolism*, 39(3):536–546, 3 2019.
- [80] M. Peyrounette et al. Multiscale modelling of blood flow in cerebral microcirculation: Details at capillary scale control accuracy at the level of the cortex. *PLOS ONE*, 13(1):e0189474, 1 2018.
- [81] E. R. Hyde et al. Multi-scale parameterisation of a myocardial perfusion model using whole-organ arterial networks. *Annals of Biomedical Engineering*, 42(4):797–811, 4 2014.
- [82] C. Iadecola. The Neurovascular Unit Coming of Age: A Journey through Neurovascular Coupling in Health and Disease. *Neuron*, 96(1):17–42, 9 2017.
- [83] P. Perdikaris et al. An Effective Fractal-Tree Closure Model for Simulating Blood Flow in Large Arterial Networks. *Annals of Biomedical Engineering*, 43(6):1432–1442, 6 2015.
- [84] A. Linninger et al. Mathematical synthesis of the cortical circulation for the whole mouse brain-part I. theory and image integration. *Computers in Biology and Medicine*, 110(February):265–275, 2019.
- [85] N. Tariq and R. Khatri. Leptomeningeal collaterals in acute ischemic stroke. *Journal of vascular and interventional neurology*, 1(4):91–5, 10 2008.

- [86] O. A. Berkhemer et al. A Randomized Trial of Intraarterial Treatment for Acute Ischemic Stroke. *New England Journal of Medicine*, 372(1):11–20, 1 2015.
- [87] P. Seners et al. Better Collaterals Are Independently Associated With Post-Thrombolysis Recanalization Before Thrombectomy. *Stroke*, 50(4):867–872, 4 2019.
- [88] K. Malhotra and D. S. Liebeskind. Collaterals in ischemic stroke. *Brain Hemorrhages*, 1(1):6–12, 3 2020.
- [89] D. D. Stromberg and J. R. Fox. Pressures in the Pial Arterial Microcirculation of the Cat during Changes in Systemic Arterial Blood Pressure. *Circulation Research*, 31(2):229–239, 8 1972.
- [90] G. A. Armitage et al. Laser Speckle Contrast Imaging of Collateral Blood Flow during Acute Ischemic Stroke. *Journal of Cerebral Blood Flow & Metabolism*, 30(8):1432–1436, 8 2010.
- [91] D. Chalothorn et al. Collateral density, remodeling, and VEGF-A expression differ widely between mouse strains. *Physiological Genomics*, 30(2):179–191, 7 2007.
- [92] F. O. Lima et al. The Pattern of Leptomeningeal Collaterals on CT Angiography Is a Strong Predictor of Long-Term Functional Outcome in Stroke Patients With Large Vessel Intracranial Occlusion. *Stroke*, 41(10):2316–2322, 10 2010.
- [93] F. K. McConnell and S. Payne. The dual role of cerebral autoregulation and collateral flow in the circle of willis after major vessel occlusion. *IEEE Transactions on Biomedical Engineering*, 64(8):1793–1802, 2017.
- [94] S. Safaei et al. Bond Graph Model of Cerebral Circulation: Toward Clinically Feasible Systemic Blood Flow Simulations. *Frontiers in Physiology*, 9(March):1–15, 2018.

-
- [95] D. Garcia-Gonzalez et al. Cognition based bTBI mechanistic criteria; A tool for preventive and therapeutic innovations. *Scientific Reports*, 8(1):10273, 12 2018.
- [96] D. F. Heijtel et al. Accuracy and precision of pseudo-continuous arterial spin labeling perfusion during baseline and hypercapnia: A head-to-head comparison with ^{15}O H $_2\text{O}$ positron emission tomography. *NeuroImage*, 92:182–192, 5 2014.
- [97] R. M. Padmos et al. Coupling one-dimensional arterial blood flow to three-dimensional tissue perfusion models for in silico trials of acute ischaemic stroke. *Interface Focus*, 11(1):20190125, 2 2021.
- [98] G. Karypis and V. Kumar. A fast and high quality multilevel scheme for partitioning irregular graphs. *SIAM Journal of Scientific Computing*, 20(1):359–392, 1 1998.
- [99] F. Schmid et al. Vascular density and distribution in neocortex. *NeuroImage*, 197:792–805, 8 2019.
- [100] G. Závodszy et al. Cellular level in-silico modeling of blood rheology with an improved material model for red blood cells. *Frontiers in Physiology*, 8(AUG):1–14, 8 2017.
- [101] S. Fantini et al. Cerebral blood flow and autoregulation: current measurement techniques and prospects for noninvasive optical methods. *Neurophotonics*, 3(3):031411, 6 2016.
- [102] H. Shapiro et al. Dynamic pressures in the pial arterial microcirculation. *American Journal of Physiology-Legacy Content*, 221(1):279–283, 7 1971.
- [103] S. H. Ahn et al. Occult Anterograde Flow Is an Under-Recognized but Crucial Predictor of Early Recanalization with Intravenous Tissue-Type Plasminogen Activator. *Stroke*, 46(4):968–975, 4 2015.
- [104] N. Nishimura et al. Penetrating arterioles are a bottleneck in the perfusion of neocortex. *Proceedings of the National Academy of Sciences*, 104(1):365–370, 2007.

- [105] T. G. Phan et al. Computer modeling of anterior circulation stroke: Proof of concept in cerebrovascular occlusion. *Frontiers in Neurology*, 5(September), 2014.
- [106] L. Meng and A. W. Gelb. Regulation of Cerebral Autoregulation by Carbon Dioxide. *Anesthesiology*, 122(1):196–205, 1 2015.
- [107] S. Payne. *Cerebral Autoregulation*. Number 95 in SpringerBriefs in Bioengineering. Springer International Publishing, Cham, 2016.
- [108] C. K. Willie et al. Integrative regulation of human brain blood flow. *The Journal of Physiology*, 592(5):841–859, 3 2014.
- [109] W. A. Copen et al. MR Perfusion Imaging in Acute Ischemic Stroke. *Neuroimaging Clinics of North America*, 21(2):259–283, 5 2011.
- [110] H. C. Alves et al. Associations between collateral status and thrombus characteristics and their impact in anterior circulation stroke. *Stroke*, 49(2):391–396, 2 2018.
- [111] Z. Chen et al. Thrombus permeability on dynamic CTA predicts good outcome after reperfusion therapy. *American Journal of Neuroradiology*, 39(10):1854–1859, 10 2018.
- [112] J. C. Benson et al. Clot permeability and histopathology: Is a clot’s perviousness on CT imaging correlated with its histologic composition? *Journal of NeuroInterventional Surgery*, 12(1):38–42, 1 2020.
- [113] E. M. Santos et al. Permeable Thrombi Are Associated with Higher Intravenous Recombinant Tissue-Type Plasminogen Activator Treatment Success in Patients with Acute Ischemic Stroke. *Stroke*, 47(8):2058–2065, 8 2016.
- [114] S. L. Diamond and S. Anand. Inner clot diffusion and permeation during fibrinolysis. *Biophysical Journal*, 65(6):2622–2643, 12 1993.
- [115] U. Fischer et al. Impact of Thrombolysis on Stroke Outcome at 12 Months in a Population. *Stroke*, 43(4):1039–1045, 4 2012.

- [116] E. M. Santos et al. Thrombus Permeability Is Associated with Improved Functional Outcome and Recanalization in Patients with Ischemic Stroke. *Stroke*, 47(3):732–741, 3 2016.
- [117] R. M. Padmos et al. Modelling the leptomeningeal collateral circulation during acute ischaemic stroke. *Medical Engineering and Physics*, 91:1–11, 5 2021.
- [118] A. M. Boers et al. Automated cerebral infarct volume measurement in follow-up noncontrast CT scans of patients with acute ischemic stroke. *American Journal of Neuroradiology*, 34(8):1522–1527, 8 2013.
- [119] L. Røhl et al. Viability thresholds of ischemic penumbra of hyperacute stroke defined by perfusion-weighted MRI and apparent diffusion coefficient. *Stroke*, 32(5):1140–1146, 5 2001.
- [120] J.-C. Baron. Perfusion Thresholds in Human Cerebral Ischemia: Historical Perspective and Therapeutic Implications. *Cerebrovascular Diseases*, 11(1):2–8, 2001.
- [121] M. Radzina et al. Perfusion computed tomography relative threshold values in definition of acute stroke lesions. *Acta Radiologica Short Reports*, 2(3):204798161348609, 4 2013.
- [122] S. Staessens et al. Structural analysis of ischemic stroke thrombi: histological indications for therapy resistance. *Haematologica*, pp. haematol.2019.219881, 5 2019.
- [123] R. C. Rennert et al. Epidemiology, Natural History, and Clinical Presentation of Large Vessel Ischemic Stroke. *Neurosurgery*, 85(suppl_1):S4–S8, 7 2019.
- [124] Y. Xue et al. Modelling the effects of cerebral microthrombi on tissue oxygenation and cell death. *Journal of Biomechanics*, 127:110705, 10 2021.

- [125] I. G. Gould et al. The capillary bed offers the largest hemodynamic resistance to the cortical blood supply. *Journal of Cerebral Blood Flow & Metabolism*, 37(1):52–68, 1 2017.
- [126] G. Hartung et al. Simulations of blood as a suspension predicts a depth dependent hematocrit in the circulation throughout the cerebral cortex. *PLOS Computational Biology*, 14(11):e1006549, 11 2018.
- [127] A. Wufsus et al. The Hydraulic Permeability of Blood Clots as a Function of Fibrin and Platelet Density. *Biophysical Journal*, 104(8):1812–1823, 4 2013.
- [128] R. A. Tahir et al. Quantification of pial collateral pressure in acute large vessel occlusion stroke: basic concept with patient outcomes. *Neuroradiology*, 1 2021.
- [129] S. Wu et al. Early Prediction of Malignant Brain Edema After Ischemic Stroke. *Stroke*, 49(12):2918–2927, 12 2018.
- [130] J. A. Stokum et al. Molecular pathophysiology of cerebral edema. *Journal of Cerebral Blood Flow & Metabolism*, 36(3):513–538, 3 2016.
- [131] S. H. Rezkalla and R. A. Kloner. No-Reflow Phenomenon. *Circulation*, 105(5):656–662, 2 2002.
- [132] J. Kaesmacher et al. Risk of Thrombus Fragmentation during Endovascular Stroke Treatment. *American Journal of Neuroradiology*, 38(5):991–998, 5 2017.
- [133] J.-Y. Chueh et al. Risk of distal embolization with stent retriever thrombectomy and ADAPT. *Journal of NeuroInterventional Surgery*, 8(2):197–202, 2 2016.
- [134] W. K. El-Bouri et al. Modelling the impact of clot fragmentation on the microcirculation after thrombectomy. *PLoS Computational Biology*, 17(3):e1008515, 3 2021.