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### Cell resolved blood flow modeling with the Lattice Boltzmann method

*Cell deformability and transport in diseases*

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## References

- [1] W.F. Boron and E.L. Boulpaep. *Medical Physiology*. Elsevier Health Sciences, 2008.
- [2] Colin Gerald Caro. *The mechanics of the circulation*. Cambridge University Press, 2012.
- [3] Sven Erik Björkman. A new method for enumeration of platelets. *Acta haematologica*, 22(6):377–379, 1959.
- [4] Jonathan B Freund. Numerical simulation of flowing blood cells. *Annual review of fluid mechanics*, 46:67–95, 2014.
- [5] Jason H Haga, Armand J Beaudoin, James G White, and John Strony. Quantification of the passive mechanical properties of the resting platelet. *Annals of biomedical engineering*, 26(2):268–277, 1998.
- [6] Nicolas Unsain, Fernando D Stefani, and Alfredo Cáceres. The actin/spectrin membrane-associated periodic skeleton in neurons. *Frontiers in synaptic neuroscience*, 10:10, 2018.
- [7] Luca Formaggia, Alfio Quarteroni, and Allesandro Veneziani. *Cardiovascular Mathematics: Modeling and simulation of the circulatory system*, volume 1. Springer Science & Business Media, 2010.
- [8] Igor V Pivkin, Zhangli Peng, George E Karniadakis, Pierre A Buffet, Ming Dao, and Subra Suresh. Biomechanics of red blood cells in human spleen and consequences for physiology and disease. *Proceedings of the National Academy of Sciences*, page 201606751, 2016.
- [9] Vann Bennett. The spectrin-actin junction of erythrocyte membrane skeletons. *Biochimica et Biophysica Acta (BBA) - Reviews on Biomembranes*, 988(1):107 – 121, 1989.
- [10] N. Gov, A. G. Zilman, and S. Safran. Cytoskeleton confinement and tension of red blood cell membranes. *Phys. Rev. Lett.*, 90:228101, Jun 2003.
- [11] M Dao, J Li, and S Suresh. Molecularly based analysis of deformation of spectrin network and human erythrocyte. *Materials Science and Engineering: C*, 26(8):1232–1244, 2006.
- [12] Rick Huisjes, Anna Bogdanova, Wouter W van Solinge, Raymond M Schiffelers, Lars Kaestner, and Richard Van Wijk. Squeezing for life—properties of red blood cell deformability. *Frontiers in physiology*, 9:656, 2018.
- [13] Shu Chien. Biophysical behavior of red cells in suspensions. *The red blood cell*, 2:1031–1133, 1975.
- [14] Timothy W. Secomb. Blood flow in the microcirculation. *Annual Review of Fluid Mechanics*, 49(1):443–461, 2017.

- [15] Mike de Haan, Gabor Závodszy, Victor Azizi, and Alfons Hoekstra. Numerical investigation of the effects of red blood cell cytoplasmic viscosity contrasts on single cell and bulk transport behaviour. *Applied Sciences*, 8(9):1616, 2018.
- [16] Thomas M. Fischer. Shape memory of human red blood cells. *Biophysical Journal*, 86(5):3304 – 3313, 2004.
- [17] Jens G Danielczok, Emmanuel Terriac, Laura Hertz, Polina Petkova-Kirova, Franziska Lautenschläger, Matthias W Laschke, and Lars Kaestner. Red blood cell passage of small capillaries is associated with transient  $ca^{2+}$ -mediated adaptations. *Frontiers in physiology*, 8:979, 2017.
- [18] A Yahia, S Mantellato, and RJ Flatt. Concrete rheology: a basis for understanding chemical admixtures. In *Science and Technology of Concrete Admixtures*, pages 97–127. Elsevier, 2016.
- [19] Peter R Hoskins, Patricia V Lawford, and Barry J Doyle. *Cardiovascular biomechanics*. Springer, 2017.
- [20] Robin Fåhræus and Torsten Lindqvist. The viscosity of the blood in narrow capillary tubes. *American Journal of Physiology–Legacy Content*, 96(3):562–568, 1931.
- [21] Chaouqi Misbah. Vacillating breathing and tumbling of vesicles under shear flow. *Phys. Rev. Lett.*, 96:028104, Jan 2006.
- [22] Jules Dupire, Marius Socol, and Annie Viallat. Full dynamics of a red blood cell in shear flow. *Proceedings of the National Academy of Sciences*, 109(51):20808–20813, 2012.
- [23] Manouk Abkarian, Magalie Faivre, and Annie Viallat. Swinging of red blood cells under shear flow. *Phys. Rev. Lett.*, 98:188302, Apr 2007.
- [24] Hiroshi Noguchi. Swinging and synchronized rotations of red blood cells in simple shear flow. *Phys. Rev. E*, 80:021902, Aug 2009.
- [25] Himanish Basu, Aditya K. Dharmadhikari, Jayashree A. Dharmadhikari, Shobhona Sharma, and Deepak Mathur. Tank treading of optically trapped red blood cells in shear flow. *Biophysical Journal*, 101(7):1604 – 1612, 2011.
- [26] J. M. Skotheim and T. W. Secomb. Red blood cells and other nonspherical capsules in shear flow: Oscillatory dynamics and the tank-treading-to-tumbling transition. *Phys. Rev. Lett.*, 98:078301, Feb 2007.
- [27] Badr Kaoui, George Biros, and Chaouqi Misbah. Why do red blood cells have asymmetric shapes even in a symmetric flow? *Phys. Rev. Lett.*, 103:188101, Oct 2009.
- [28] Robert L Letcher, Shu Chien, Thomas G Pickering, Jean E Sealey, and John H Laragh. Direct relationship between blood pressure and blood viscosity in normal and hypertensive subjects: role of fibrinogen and concentration. *The American journal of medicine*, 70(6):1195–1202, 1981.

- [29] AR Pries, TW Secomb, T Gessner, MB Sperandio, JF Gross, and P Gaehtgens. Resistance to blood flow in microvessels in vivo. *Circulation research*, 75(5):904–915, 1994.
- [30] Timothy W Secomb and Axel R Pries. Blood viscosity in microvessels: Experiment and theory. *Comptes Rendus Physique*, 14(6):470–478, 2013.
- [31] Roe E Wells and Edward W Merrill. Shear rate dependence of the viscosity of whole blood and plasma. *Science*, 133(3455):763–764, 1961.
- [32] James H Barbee. The effect of temperature on the relative viscosity of human blood. *Biorheology*, 10(1):1–5, 1973.
- [33] Shu Chien, Shunichi Usami, Harry M Taylor, John L Lundberg, and Magnus I Gregersen. Effects of hematocrit and plasma proteins on human blood rheology at low shear rates. *Journal of Applied Physiology*, 21(1):81–87, 1966.
- [34] M Joly, C Lacombe, and JC Lelievre. Tentative application of the tangent simple system method to the study of the viscoelastic behaviour of blood. *Biorheology*, 20(5):663–676, 1983.
- [35] Dietmar Lerche, Georgios Vlastos, Brigitte Koch, Manfred Pohl, and Klaus Affeld. Viscoelastic behaviour of human blood and polyacrylamide model fluids for heart valve testing. *Journal de Physique III*, 3(6):1283–1289, 1993.
- [36] Edward W Merrill, Edwin R Gilliland, TS Lee, and Edwin W Salzman. Blood rheology: effect of fibrinogen deduced by addition. *Circulation Research*, 18(4):437–446, 1966.
- [37] RW Samsel and AS Perelson. Kinetics of rouleau formation. ii. reversible reactions. *Biophysical journal*, 45(4):805–824, 1984.
- [38] D Schneditz, F Rainer, and T Kenner. Viscoelastic properties of whole blood. influence of fast sedimenting red blood cell aggregates. *Biorheology*, 24(1):13–22, 1987.
- [39] Jean-Luc Gennisson, Sophie Lerouge, and Guy Cloutier. Assessment by transient elastography of the viscoelastic properties of blood during clotting. *Ultrasound in medicine & biology*, 32(10):1529–1537, 2006.
- [40] Oguz Baskurt, Björn Neu, and Herbert J Meiselman. *Red blood cell aggregation*. CRC Press, 2011.
- [41] Thomas M Fischer, M Stohr-Lissen, and Holger Schmid-Schonbein. The red cell as a fluid droplet: tank tread-like motion of the human erythrocyte membrane in shear flow. *Science*, 202(4370):894–896, 1978.
- [42] Leopold Dintenfass. Internal viscosity of the red cell and a blood viscosity equation. *Nature*, 219(5157):956–958, 1968.

- [43] Shu Chien. Shear dependence of effective cell volume as a determinant of blood viscosity. *Science*, 168(3934):977–979, 1970.
- [44] Ohwon Kwon, Mahesh Krishnamoorthy, Young I Cho, John M Sankovic, and Rupak K Banerjee. Effect of blood viscosity on oxygen transport in residual stenosed artery following angioplasty. *Journal of Biomechanical Engineering*, 130(1), 2008.
- [45] Dmitry A Fedosov, Bruce Caswell, Aleksander S Popel, and George Em Karniadakis. Blood flow and cell-free layer in microvessels. *Microcirculation*, 17(8):615–628, 2010.
- [46] HL Goldsmith. Red cell motions and wall interactions in tube flow. In *Fed. Proc.*, volume 30, pages 1578–1588, 1971.
- [47] Harry L Goldsmith, Giles R Cokelet, and Peter Gaehtgens. Robin fahraeus: evolution of his concepts in cardiovascular physiology. *American Journal of Physiology-Heart and Circulatory Physiology*, 257(3):H1005–H1015, 1989.
- [48] Giles R Cokelet and Harry L Goldsmith. Decreased hydrodynamic resistance in the two-phase flow of blood through small vertical tubes at low flow rates. *Circulation research*, 68(1):1–17, 1991.
- [49] Piero Olla. The lift on a tank-treading ellipsoidal cell in a shear flow. *Journal de Physique II*, 7(10):1533–1540, 1997.
- [50] Aleksander S Popel and Paul C Johnson. Microcirculation and hemorrheology. *Annu. Rev. Fluid Mech.*, 37:43–69, 2005.
- [51] Norihiko Tateishi, Yoji Suzuki, Masao Soutani, and Nobuji Maeda. Flow dynamics of erythrocytes in microvessels of isolated rabbit mesentery: cell-free layer and flow resistance. *Journal of biomechanics*, 27(9):1119–1125, 1994.
- [52] Sangho Kim, Robert L Kong, Aleksander S Popel, Marcos Intaglietta, and Paul C Johnson. Temporal and spatial variations of cell-free layer width in arterioles. *American Journal of Physiology-Heart and Circulatory Physiology*, 293(3):H1526–H1535, 2007.
- [53] Axel R Pries, D Neuhaus, and P Gaehtgens. Blood viscosity in tube flow: dependence on diameter and hematocrit. *American Journal of Physiology-Heart and Circulatory Physiology*, 263(6):H1770–H1778, 1992.
- [54] Erik J Carboni, Brice H Bognet, Grant M Bouchillon, Andrea L Kadilak, Leslie M Shor, Michael D Ward, and Anson WK Ma. Direct tracking of particles and quantification of margination in blood flow. *Biophysical journal*, 111(7):1487–1495, 2016.
- [55] Gábor Zavodszky, Britt van Rooij, Victor Azizi, Saad Alowayyed, and Alfons Hoekstra. Hemocell: a high-performance microscopic cellular library. *Procedia Computer Science*, 108:159–165, 2017.

- [56] Benjamin Czaja, Gábor Závodszy, Victor Azizi Tarksalooyeh, and Alfons G Hoekstra. Cell-resolved blood flow simulations of saccular aneurysms: effects of pulsatility and aspect ratio. *Journal of The Royal Society Interface*, 15(146):20180485, 2018.
- [57] Prosenjit Bagchi. Mesoscale simulation of blood flow in small vessels. *Biophysical journal*, 92(6):1858–1877, 2007.
- [58] Cindy A. Owen and Mitzi Roberts. Arterial vascular hemodynamics. *Journal of Diagnostic Medical Sonography*, 23(3):129–140, 2007.
- [59] L Mountrakis, E Lorenz, and AG Hoekstra. Scaling of shear-induced diffusion and clustering in a blood-like suspension. *EPL (Europhysics Letters)*, 114(1):14002, 2016.
- [60] Gábor Závodszy, Britt van Rooij, Ben Czaja, Victor Azizi, David de Kanter, and Alfons G Hoekstra. Red blood cell and platelet diffusivity and margination in the presence of cross-stream gradients in blood flows. *Physics of Fluids*, 31(3):031903, 2019.
- [61] Robert HP McGregor, Dominik Szczerba, and Gábor Székely. A multiphysics simulation of a healthy and a diseased abdominal aorta. In *International Conference on Medical Image Computing and Computer-Assisted Intervention*, pages 227–234. Springer, 2007.
- [62] PS Zun, AJ Narracott, Claudio Chiastra, J Gunn, and AG Hoekstra. Location-specific comparison between a 3d in-stent restenosis model and micro-ct and histology data from porcine in vivo experiments. *Cardiovascular engineering and technology*, 10(4):568–582, 2019.
- [63] Juan R Cebal, Marcelo A Castro, James E Burgess, Richard S Pergolizzi, Michael J Sheridan, and Christopher M Putman. Characterization of cerebral aneurysms for assessing risk of rupture by using patient-specific computational hemodynamics models. *American Journal of Neuroradiology*, 26(10):2550–2559, 2005.
- [64] Steffen Oeltze-Jafra, Juan R Cebal, Gábor Janiga, and Bernhard Preim. Cluster analysis of vortical flow in simulations of cerebral aneurysm hemodynamics. *IEEE transactions on visualization and computer graphics*, 22(1):757–766, 2016.
- [65] Miguel O Bernabeu, Yang Lu, Omar Abu-Qamar, Lloyd Paul Aiello, and Jennifer K Sun. Estimation of diabetic retinal microaneurysm perfusion parameters based on computational fluid dynamics modeling of adaptive optics scanning laser ophthalmoscopy. *Frontiers in physiology*, 9:989, 2018.
- [66] Dmitry A Fedosov, Julia Fornleitner, and Gerhard Gompper. Margination of white blood cells in microcapillary flow. *Physical review letters*, 108(2):028104, 2012.
- [67] Gábor Závodszy, Benjámín Csippa, György Paál, and István Szikora. A novel virtual flow diverter implantation method with realistic deployment mechanics and

- validated force response. *International Journal for Numerical Methods in Biomedical Engineering*, page e3340, 2020.
- [68] Manouk Abkarian, Magalie Faivre, Renita Horton, Kristian Smistrup, Catherine A Best-Popescu, and Howard A Stone. Cellular-scale hydrodynamics. *Biomedical materials*, 3(3):034011, 2008.
- [69] Alexandra Homsy, Peter D van der Wal, Werner Doll, Roland Schaller, Stefan Korstako, Maria Ratzler, Martin Ellmerer, Thomas R Pieber, Andreas Nicol, and Nico F De Rooij. Development and validation of a low cost blood filtration element separating plasma from undiluted whole blood. *Biomicrofluidics*, 6(1):012804, 2012.
- [70] Jeongho Kim, Mehrdad Massoudi, James F Antaki, and Alberto Gandini. Removal of malaria-infected red blood cells using magnetic cell separators: a computational study. *Applied mathematics and computation*, 218(12):6841–6850, 2012.
- [71] JR Womersley. The mathematical analysis of the arterial circulation in a state of oscillatory motion. *Wright Air Development Center Technical Report WADC-TR-56-614*, 1957.
- [72] PJ Hoogerbrugge and JMVA Koelman. Simulating microscopic hydrodynamic phenomena with dissipative particle dynamics. *EPL (Europhysics Letters)*, 19(3):155, 1992.
- [73] MB Liu, GR Liu, LW Zhou, and JZ Chang. Dissipative particle dynamics (dpd): an overview and recent developments. *Archives of Computational Methods in Engineering*, 22(4):529–556, 2015.
- [74] Steve Plimpton. Fast parallel algorithms for short-range molecular dynamics. *Journal of computational physics*, 117(1):1–19, 1995.
- [75] Inge Wijayanti Budiawan and Sudi Mungkasi. Finite volume numerical solution to a blood flow problem in human artery. In *Journal of Physics: Conference Series*, volume 795, page 012042. IOP Publishing, 2017.
- [76] Matthias Müller, Simon Schirm, and Matthias Teschner. Interactive blood simulation for virtual surgery based on smoothed particle hydrodynamics. *Technology and Health Care*, 12(1):25–31, 2004.
- [77] Nobuatsu Tanaka and Tatsuo Takano. Microscopic-scale simulation of blood flow using sph method. *International Journal of Computational Methods*, 2(04):555–568, 2005.
- [78] Sauro Succi. *The lattice Boltzmann equation: for fluid dynamics and beyond*. Oxford university press, 2001.
- [79] Shiyi Chen and Gary D Doolen. Lattice boltzmann method for fluid flows. *Annual review of fluid mechanics*, 30(1):329–364, 1998.

- [80] Fuat Yilmaz and Mehmet Yasar Gundogdu. A critical review on blood flow in large arteries; relevance to blood rheology, viscosity models, and physiologic conditions. *Korea-Australia Rheology Journal*, 20(4):197–211, 2008.
- [81] AL Zydney, JD Oliver III, and CK Colton. A constitutive equation for the viscosity of stored red cell suspensions: Effect of hematocrit, shear rate, and suspending phase. *Journal of Rheology*, 35(8):1639–1680, 1991.
- [82] Barbara M Johnston, Peter R Johnston, Stuart Corney, and David Kilpatrick. Non-newtonian blood flow in human right coronary arteries: steady state simulations. *Journal of biomechanics*, 37(5):709–720, 2004.
- [83] S-W Lee and David A Steinman. On the relative importance of rheology for image-based cfd models of the carotid bifurcation. *Journal of Biomechanics*, (39):S283, 2006.
- [84] Noreen Sher Akbar and S Nadeem. Carreau fluid model for blood flow through a tapered artery with a stenosis. *Ain Shams Engineering Journal*, 5(4):1307–1316, 2014.
- [85] Walter P Walawender, Te Yu Chen, and David F Cala. An approximate casson fluid model for tube flow of blood. *Biorheology*, 12(2):111–119, 1975.
- [86] FJH Gijzen, E Allanic, FN Van de Vosse, and JD Janssen. The influence of the non-newtonian properties of blood on the flow in large arteries: unsteady flow in a 90 curved tube. *Journal of biomechanics*, 32(7):705–713, 1999.
- [87] HC Brinkman. The viscosity of concentrated suspensions and solutions. *The Journal of Chemical Physics*, 20(4):571–571, 1952.
- [88] Amin Shariatkhah, Mahmood Norouzi, and Mohammad Reza Heyrani Nobari. Numerical simulation of blood flow through a capillary using a non-linear viscoelastic model. *Clinical Hemorheology and Microcirculation*, 62(2):109–121, 2016.
- [89] S Suresh. Mechanical response of human red blood cells in health and disease: some structure-property-function relationships. *Journal of materials research*, 21(8):1871–1877, 2006.
- [90] Dmitry A Fedosov, Bruce Caswell, and George Em Karniadakis. A multiscale red blood cell model with accurate mechanics, rheology, and dynamics. *Biophysical journal*, 98(10):2215–2225, 2010.
- [91] Gábor Závodszy, Britt van Rooij, Victor Azizi, and Alfons Hoekstra. Cellular level in-silico modeling of blood rheology with an improved material model for red blood cells. *Frontiers in physiology*, 8:563, 2017.
- [92] Lindsay M Crowl and Aaron L Fogelson. Computational model of whole blood exhibiting lateral platelet motion induced by red blood cells. *International journal for numerical methods in biomedical engineering*, 26(3-4):471–487, 2010.

- [93] Lampros Mountrakis, Eric Lorenz, and Alfons G. Hoekstra. Validation of an efficient two-dimensional model for dense suspensions of red blood cells. *International Journal of Modern Physics C*, 25(12):1441005, 2014.
- [94] Igor V Pivkin and George Em Karniadakis. Accurate coarse-grained modeling of red blood cells. *Physical review letters*, 101(11):118105, 2008.
- [95] Prabhu Lal Bhatnagar, Eugene P Gross, and Max Krook. A model for collision processes in gases. i. small amplitude processes in charged and neutral one-component systems. *Physical review*, 94(3):511, 1954.
- [96] In Chan Kim. Second order bounce back boundary condition for the lattice boltzmann fluid simulation. *Journal of Mechanical Science and Technology*, 14(1):84–92, 2000.
- [97] Qisu Zou and Xiaoyi He. On pressure and velocity boundary conditions for the lattice boltzmann bgk model. *Physics of fluids*, 9(6):1591–1598, 1997.
- [98] AJC Ladd and R Verberg. Lattice-boltzmann simulations of particle-fluid suspensions. *Journal of statistical physics*, 104(5-6):1191–1251, 2001.
- [99] Charles S Peskin. The immersed boundary method. *Acta numerica*, 11:479–517, 2002.
- [100] BJM van Rooij, G Závodszy, VW Azizi Tarksalooyeh, and AG Hoekstra. Identifying the start of a platelet aggregate by the shear rate and the cell-depleted layer. *Journal of the Royal Society Interface*, 16(159):20190148, 2019.
- [101] AP Avolio. Multi-branched model of the human arterial system. *Medical and Biological Engineering and Computing*, 18(6):709–718, 1980.
- [102] Brooke N Steele, Jing Wan, Joy P Ku, Thomas JR Hughes, and Charles A Taylor. In vivo validation of a one-dimensional finite-element method for predicting blood flow in cardiovascular bypass grafts. *IEEE Transactions on Biomedical Engineering*, 50(6):649–656, 2003.
- [103] Frans N Van de Vosse and Nikos Stergiopoulos. Pulse wave propagation in the arterial tree. *Annual Review of Fluid Mechanics*, 43:467–499, 2011.
- [104] Dmitry A Fedosov, Hiroshi Noguchi, and Gerhard Gompper. Multiscale modeling of blood flow: from single cells to blood rheology. *Biomechanics and modeling in mechanobiology*, 13(2):239–258, 2014.
- [105] Alfons G Hoekstra, Saad Alowayyed, Eric Lorenz, Natalia Melnikova, Lampros Mountrakis, Britt van Rooij, Andrew Svitenkov, Gábor Závodszy, and Pavel Zun. Towards the virtual artery: a multiscale model for vascular physiology at the physics–chemistry–biology interface. *Phil. Trans. R. Soc. A*, 374(2080):20160146, 2016.

- [106] Alfio Quarteroni, Alessandro Veneziani, and Christian Vergara. Geometric multi-scale modeling of the cardiovascular system, between theory and practice. *Computer Methods in Applied Mechanics and Engineering*, 302:193–252, 2016.
- [107] Vasilina Filonova, Hamidreza Gharahi, Nitesh Nama, Seungik Baek, and C Alberto Figueroa. A multiscale framework for defining homeostasis in distal vascular trees: Applications to the pulmonary circulation. *arXiv preprint arXiv:2001.04880*, 2020.
- [108] Paris Perdikaris, Leopold Grinberg, and George Em Karniadakis. Multiscale modeling and simulation of brain blood flow. *Physics of Fluids*, 28(2):021304, 2016.
- [109] Sean T O’connell and Peter A Thompson. Molecular dynamics–continuum hybrid computations: a tool for studying complex fluid flows. *Physical Review E*, 52(6):R5792, 1995.
- [110] Nicolas G Hadjiconstantinou. Hybrid atomistic–continuum formulations and the moving contact-line problem. *Journal of Computational Physics*, 154(2):245–265, 1999.
- [111] EG Flekkøy, G Wagner, and J Feder. Hybrid model for combined particle and continuum dynamics. *EPL (Europhysics Letters)*, 52(3):271, 2000.
- [112] Thomas Werder, Jens H Walther, and Petros Koumoutsakos. Hybrid atomistic–continuum method for the simulation of dense fluid flows. *Journal of Computational Physics*, 205(1):373–390, 2005.
- [113] Assyr Abdulle, E Weinan, Björn Engquist, and Eric Vanden-Eijnden. The heterogeneous multiscale method. *Acta Numerica*, 21:1–87, 2012.
- [114] Li-Tien Cheng and E Weinan. The heterogeneous multi-scale method for interface dynamics. *Contemporary Mathematics*, 330:43–54, 2003.
- [115] Weinan E and Bjorn Engquist. The heterogenous multiscale methods. *Commun. Math. Sci.*, 1(1):87–132, 03 2003.
- [116] Weinan E, Bjorn Engquist, and Zhongyi Huang. Heterogeneous multiscale method: A general methodology for multiscale modeling. *Phys. Rev. B*, 67:092101, Mar 2003.
- [117] Achi Brandt. Multi-level adaptive solutions to boundary-value problems. *Mathematics of computation*, 31(138):333–390, 1977.
- [118] Jinchao Xu. Two-grid discretization techniques for linear and nonlinear pdes. *SIAM Journal on Numerical Analysis*, 33(5):1759–1777, 1996.
- [119] Benjamin Czaja, Mario Gutierrez, Gábor Závodszy, David de Kanter, Alfons Hoekstra, and Omolola Eniola-Adefeso. The influence of red blood cell deformability on hematocrit profiles and platelet margination. *PLOS Computational Biology*, 16(3):e1007716, 2020.

- [120] Kevin de Vries, Anna Nikishova, Benjamin Czaja, Gábor Závodszy, and Alfons G. Hoekstra. Inverse uncertainty quantification of a cell model using a gaussian process metamodel. *International Journal for Uncertainty Quantification*, 10(4):333–349, 2020.
- [121] David C Rees, Thomas N Williams, and Mark T Gladwin. Sickle-cell disease. *The Lancet*, 376(9757):2018–2031, 2010.
- [122] William A Eaton and James Hofrichter. Sickle cell hemoglobin polymerization. In *Advances in protein chemistry*, volume 40, pages 63–279. Elsevier, 1990.
- [123] Peter G Vekilov. Sickle-cell haemoglobin polymerization: is it the primary pathogenic event of sickle-cell anaemia? *British journal of haematology*, 139(2):173–184, 2007.
- [124] Erica N Chirico and Vincent Pialoux. Role of oxidative stress in the pathogenesis of sickle cell disease. *IUBMB life*, 64(1):72–80, 2012.
- [125] Danilo Grunig Humberto Silva, Edis Belini Junior, Eduardo Alves De Almeida, and Claudia Regina Bonini-Domingos. Oxidative stress in sickle cell disease: an overview of erythrocyte redox metabolism and current antioxidant therapeutic strategies. *Free Radical Biology and Medicine*, 65:1101–1109, 2013.
- [126] Deepa Manwani and Paul S Frenette. Vaso-occlusion in sickle cell disease: pathophysiology and novel targeted therapies. *Blood*, 122(24):3892–3898, 2013.
- [127] Subra Suresh, J Spatz, JP Mills, Alexandre Micoulet, M Dao, CT Lim, M Beil, and T Seufferlein. Connections between single-cell biomechanics and human disease states: gastrointestinal cancer and malaria. *Acta biomaterialia*, 1(1):15–30, 2005.
- [128] Vinod Kumar Katiyar and Demeke Fisseha. Analysis of mechanical behavior of red blood cell membrane with malaria infection. *World Journal of Mechanics*, 1(03):100, 2011.
- [129] Fiona K Glenister, Ross L Coppel, Alan F Cowman, Narla Mohandas, and Brian M Cooke. Contribution of parasite proteins to altered mechanical properties of malaria-infected red blood cells. *Blood*, 99(3):1060–1063, 2002.
- [130] Dario Giugliano, Anthonio Ceriello, and Giuseppe Paolisso. Oxidative stress and diabetic vascular complications. *Diabetes care*, 19(3):257–267, 1996.
- [131] Sehyun Shin, Yun-Hee Ku, Jian-Xun Ho, Yu-Kyung Kim, Jang-Soo Suh, and Megha Singh. Progressive impairment of erythrocyte deformability as indicator of microangiopathy in type 2 diabetes mellitus. *Clinical hemorheology and microcirculation*, 36(3):253–261, 2007.
- [132] Rupesh Agrawal, Thomas Smart, João Nobre-Cardoso, Christopher Richards, Rhythm Bhatnagar, Adnan Tufail, David Shima, Phil H Jones, and Carlos Pavesio. Assessment of red blood cell deformability in type 2 diabetes mellitus and diabetic retinopathy by dual optical tweezers stretching technique. *Scientific reports*, 6:15873, 2016.

- [133] Alisa Kim, Hajir Dadgostar, Gary N Holland, Rosalinda Wenby, Fei Yu, Brian G Terry, and Herbert J Meiselman. Hemorheologic abnormalities associated with hiv infection: altered erythrocyte aggregation and deformability. *Investigative ophthalmology & visual science*, 47(9):3927–3932, 2006.
- [134] Alexander V Ivanov, Vladimir T Valuev-Elliston, Olga N Ivanova, Sergey N Kochetkov, Elizaveta S Starodubova, Birke Bartosch, and Maria G Isagulians. Oxidative stress during hiv infection: mechanisms and consequences. *Oxidative medicine and cellular longevity*, 2016, 2016.
- [135] Peter Jenner. Oxidative stress in parkinson's disease. *Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society*, 53(S3):S26–S38, 2003.
- [136] Jiaqi Liu, Fan Zhang, Lianqing Zhu, Daping Chu, and Xinghua Qu. Mechanical properties of rbcs under oxidative stress measured by optical tweezers. *Optics Communications*, 442:56–59, 2019.
- [137] Silverio Perrotta, Patrick G Gallagher, and Narla Mohandas. Hereditary spherocytosis. *The Lancet*, 372(9647):1411–1426, 2008.
- [138] Hussam Ghoti, Eitan Fibach, Mutaz Dana, Mohammad Abu Shaban, Hisham Jead, Andrei Braester, Zipora Matas, and Eliezer Rachmilewitz. Oxidative stress contributes to hemolysis in patients with hereditary spherocytosis and can be ameliorated by fermented papaya preparation. *Annals of hematology*, 90(5):509–513, 2011.
- [139] Yuanyuan Chen, Donghai Li, Yongjian Li, Jiandi Wan, Jiang Li, and Haosheng Chen. Margination of stiffened red blood cells regulated by vessel geometry. *Scientific reports*, 7(1):15253, 2017.
- [140] Han Wei Hou, Ali Asgar S Bhagat, Alvin Guo Lin Chong, Pan Mao, Kevin Shyong Wei Tan, Jongyoon Han, and Chwee Teck Lim. Deformability based cell margination—a simple microfluidic design for malaria-infected erythrocyte separation. *Lab on a Chip*, 10(19):2605–2613, 2010.
- [141] Cécile Iss, Dorian Midou, Alexis Moreau, Delphine Held, Anne Charrier, Simon Mendez, Annie Viallat, and Emmanuèle Helfer. Self-organization of red blood cell suspensions under confined 2d flows. *Soft matter*, 15(14):2971–2980, 2019.
- [142] Tim Watts, Mostafa Barigou, and Gerard B Nash. Comparative rheology of the adhesion of platelets and leukocytes from flowing blood: why are platelets so small? *American Journal of Physiology-Heart and Circulatory Physiology*, 304(11):H1483–H1494, 2013.
- [143] Mario Gutierrez, Margaret B Fish, Alexander W Golinski, and Omolola Eniola-Adefeso. Presence of rigid red blood cells in blood flow interferes with the vascular wall adhesion of leukocytes. *Langmuir*, 34(6):2363–2372, 2018.

- [144] DA Fedosov, B Caswell, S Suresh, and GE Karniadakis. Quantifying the biophysical characteristics of plasmodium-falciparum-parasitized red blood cells in microcirculation. *Proceedings of the National Academy of Sciences*, 108(1):35–39, 2011.
- [145] Huan Lei and George E Karniadakis. Probing vasoocclusion phenomena in sickle cell anemia via mesoscopic simulations. *Proceedings of the National Academy of Sciences*, 110(28):11326–11330, 2013.
- [146] Victor Azizi Tarksalooyeh, Gábor Závodszy, and Alfons G Hoekstra. Optimizing parallel performance of the cell based blood flow simulation software hemocell. In *International Conference on Computational Science*, pages 537–547. Springer, 2019.
- [147] Monika Bargieł and Jacek Mościński. C-language program for the irregular close packing of hard spheres. *Computer Physics Communications*, 64(1):183–192, 1991.
- [148] Alexander Bezrukov, Monika Bargieł, and Dietrich Stoyan. Statistical analysis of simulated random packings of spheres. *Particle & Particle Systems Characterization: Measurement and Description of Particle Properties and Behavior in Powders and Other Disperse Systems*, 19(2):111–118, 2002.
- [149] Catherine Rice-Evans, Erol Baysal, D Paul Pashby, and Paul Hochstein. t-butyl hydroperoxide-induced perturbations of human erythrocytes as a model for oxidant stress. *Biochimica et Biophysica Acta (BBA)-Biomembranes*, 815(3):426–432, 1985.
- [150] AC Maritim, aRA Sanders, and JB Watkins Iii. Diabetes, oxidative stress, and antioxidants: a review. *Journal of biochemical and molecular toxicology*, 17(1):24–38, 2003.
- [151] DJ Valtis and AC Kennedy. Defective gas-transport function of stored red blood-cells. *The Lancet*, 263(6803):119–125, 1954.
- [152] Alireza ZK Yazdani, R Murthy Kalluri, and Prosenjit Bagchi. Tank-treading and tumbling frequencies of capsules and red blood cells. *Physical Review E*, 83(4):046305, 2011.
- [153] Michiel JW Jansen. Analysis of variance designs for model output. *Computer Physics Communications*, 117(1-2):35–43, 1999.
- [154] A. Saltelli, P. Annoni, I. Azzini, F. Campolongo, M. Ratto, and S. Tarantola. Variance based sensitivity analysis of model output. Design and estimator for the total sensitivity index. *Computer Physics Communications*, 181(2):259–270, 2010.
- [155] Il'ya Meerovich Sobol'. On sensitivity estimation for nonlinear mathematical models. *Matematicheskoe modelirovanie*, 2(1):112–118, 1990.
- [156] Patrizia Caprari, Argante Bozzi, Walter Malorni, Alessandra Bottini, Francesca Iosi, Maria Teresa Santini, and Anna Maria Salvati. Junctional sites of erythrocyte skeletal proteins are specific targets of tert-butylhydroperoxide oxidative damage. *Chemico-biological interactions*, 94(3):243–258, 1995.

- [157] Giles R Cokelet and Herbert J Meiselman. Rheological comparison of hemoglobin solutions and erythrocyte suspensions. *Science*, 162(3850):275–277, 1968.
- [158] Gábor Késmárky, Péter Kenyeres, Miklós Rábai, and Kálmán Tóth. Plasma viscosity: a forgotten variable. *Clinical hemorheology and microcirculation*, 39(1–4):243–246, 2008.
- [159] Amit Kumar and Michael D Graham. Segregation by membrane rigidity in flowing binary suspensions of elastic capsules. *Physical Review E*, 84(6):066316, 2011.
- [160] Piero Olla. The role of tank-treading motions in the transverse migration of a spheroidal vesicle in a shear flow. *Journal of Physics A: Mathematical and General*, 30(1):317, 1997.
- [161] Timm Krüger. Effect of tube diameter and capillary number on platelet margination and near-wall dynamics. *Rheologica Acta*, 55(6):511–526, 2016.
- [162] Andreas Passos, Joseph M Sherwood, Efstathios Kaliviotis, Rupesh Agrawal, Carlos Pavesio, and Stavroula Balabani. The effect of deformability on the microscale flow behavior of red blood cell suspensions. *Physics of Fluids*, 31(9):091903, 2019.
- [163] Hung-Yu Chang, Xuejin Li, and George Em Karniadakis. Modeling of biomechanics and biorheology of red blood cells in type 2 diabetes mellitus. *Biophysical journal*, 113(2):481–490, 2017.
- [164] Hung-Yu Chang, Alireza Yazdani, Xuejin Li, Konstantinos AA Douglas, Christos S Mantzoros, and George Em Karniadakis. Quantifying platelet margination in diabetic blood flow. *Biophysical journal*, 115(7):1371–1382, 2018.
- [165] T Hänscheid. Diagnosis of malaria: a review of alternatives to conventional microscopy. *Clinical & Laboratory Haematology*, 21(4):235–245, 1999.
- [166] Max R Hardeman, Geert AJ Besselink, Iwan Ebbing, Dirk De Korte, Can Ince, and Arthur J Verhoeven. Laser-assisted optical rotational cell analyzer measurements reveal early changes in human rbc deformability induced by photodynamic treatment. *Transfusion*, 43(11):1533–1537, 2003.
- [167] Oguz Baskurt, Michel Boynard, Giles Cokelet, Philippe Connes, Brian M Cooke, Sandro Forconi, Fulong Liao, Max Hardeman, Friedrich Jung, Herbert Meiselman, et al. New guidelines for hemorheological laboratory techniques. 2009.
- [168] Benjamin Czaja, Jonathan de Bouter, Morgan Heisler, Gábor Závodszy, Sonja Karst, Marinko Sarunic, David Maberley, and Alfons Hoekstra. Cell induced wall shear stress in a diabetic retinal microaneurysm. *Journal of Biomechanics*, Under Review, 2020.
- [169] Diabetes Care et al. Diagnosis and classification of diabetes mellitus. *Diabetes care*, 2006.

- [170] J M Tarr, K Kaul, M Chopra, M E Kohner, and R Chibber. Pathophysiology of diabetic retinopathy. *Diabetic Retinopathy: Evidence-Based Management*, 2013:1–30, 2010.
- [171] Haseeb Ahsan. Diabetic retinopathy - Biomolecules and multiple pathophysiology. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, 9(1):51–54, 2015.
- [172] John H. Kempen, Benita J. O’Colmain, M. Cristina Leske, Steven M. Haffner, Ronald Klein, Scot E. Moss, Hugh R. Taylor, and Richard F. Hamman. The prevalence of diabetic retinopathy among adults in the United States. *Archives of ophthalmology*, 122(4):552–563, 2004.
- [173] K. Ogurtsova, J. D. da Rocha Fernandes, Y. Huang, U. Linnenkamp, L. Guariguata, N. H. Cho, D. Cavan, J. E. Shaw, and L. E. Makaroff. IDF Diabetes Atlas: Global estimates for the prevalence of diabetes for 2015 and 2040. *Diabetes Research and Clinical Practice*, 128:40–50, 2017.
- [174] CP Wilkinson, Frederick L Ferris III, Ronald E Klein, Paul P Lee, Carl David Agardh, Matthew Davis, Diana Dills, Anselm Kampik, R Pararajasegaram, Juan T Verdager, et al. Proposed international clinical diabetic retinopathy and diabetic macular edema disease severity scales. *Ophthalmology*, 110(9):1677–1682, 2003.
- [175] D. S. Fong, G. Blankenship, R. Klein, G. L. King, T. W. Gardner, J. D. Cavigliaro, L. Aiello, and F. L. Ferris. Retinopathy in Diabetes. Technical Report Supplement 1, American Diabetes Association, 2007.
- [176] Thomas A Ciulla, Armando G Amador, and Bernard Zinman. Diabetic retinopathy and diabetic macular edema: pathophysiology, screening, and novel therapies. *Diabetes care*, 26(9):2653–2664, 2003.
- [177] R.L. Engerman. The pathogenesis of diabetic retinopathy. *Australian and New Zealand Journal of Ophthalmology*, 24(2):97–104, 1996.
- [178] R. Williams, M. Airey, H. Baxter, J. Forrester, T. Kennedy-Martin, and A. Girach. Epidemiology of diabetic retinopathy and macular oedema: A systematic review. *Eye*, 18(10):963–983, 2004.
- [179] Michael Dubow, Alexander Pinhas, Nishit Shah, Robert F Cooper, Alexander Gan, Ronald C Gentile, Vernon Hendrix, Yusufu N Sulai, Joseph Carroll, Toco YP Chui, et al. Classification of human retinal microaneurysms using adaptive optics scanning light ophthalmoscope fluorescein angiography. *Investigative ophthalmology & visual science*, 55(3):1299–1309, 2014.
- [180] Oliver Faust, Rajendra Acharya U., E. Y. K. Ng, Kwan-Hoong Ng, and Jasjit S. Suri. Algorithms for the Automated Detection of Diabetic Retinopathy Using Digital Fundus Images: A Review. *Journal of Medical Systems*, 36(1):145–157, feb 2012.
- [181] R Klein and B E K Klein. Blood pressure control and diabetic retinopathy. *British Journal of Ophthalmology*, 86(4):365–367, 2002.

- [182] Anselm Hennis, Suh-Yuh Wu, Barbara Nemesure, M Cristina Leske, Barbados Eye Studies Group, et al. Hypertension, diabetes, and longitudinal changes in intraocular pressure. *Ophthalmology*, 110(5):908–914, 2003.
- [183] Ruth B Caldwell, Manuela Bartoli, M Ali Behzadian, Azza EB El-Remessy, Mohamed Al-Shabrawey, Daniel H Platt, and R William Caldwell. Vascular endothelial growth factor and diabetic retinopathy: pathophysiological mechanisms and treatment perspectives. *Diabetes/metabolism research and reviews*, 19(6):442–455, 2003.
- [184] Anthony P Adamis, Joan W Miller, Maria-Teresa Bernal, Donald J D’Amico, Judah Folkman, Tet-Kin Yeo, and Kiang-Teck Yeo. Increased vascular endothelial growth factor levels in the vitreous of eyes with proliferative diabetic retinopathy. *American journal of ophthalmology*, 118(4):445–450, 1994.
- [185] Michaela Kunz Mathews, Carol Merges, D Scott McLeod, and Gerard A Luttly. Vascular endothelial growth factor and vascular permeability changes in human diabetic retinopathy. *Investigative ophthalmology & visual science*, 38(13):2729–2741, 1997.
- [186] ANN Hoeben, Bart Landuyt, Martin S Highley, Hans Wildiers, Allan T Van Oosterom, and Ernst A De Bruijn. Vascular endothelial growth factor and angiogenesis. *Pharmacological reviews*, 56(4):549–580, 2004.
- [187] Lloyd Paul Aiello, Eric A Pierce, Eliot D Foley, Hitoshi Takagi, Helen Chen, Lavon Riddle, Napoleone Ferrara, George L King, and LE Smith. Suppression of retinal neovascularization in vivo by inhibition of vascular endothelial growth factor (vegf) using soluble vegf-receptor chimeric proteins. *Proceedings of the National Academy of Sciences*, 92(23):10457–10461, 1995.
- [188] Sayon Roy, John Ha, Kyle Trudeau, and Ekaterina Beglova. Vascular basement membrane thickening in diabetic retinopathy. *Current eye research*, 35(12):1045–1056, 2010.
- [189] Lloyd Paul Aiello, Robert L Avery, Paul G Arrigg, Bruce A Keyt, Henry D Jampel, Sabera T Shah, Louis R Pasquale, Hagen Thieme, Mami A Iwamoto, John E Park, et al. Vascular endothelial growth factor in ocular fluid of patients with diabetic retinopathy and other retinal disorders. *New England Journal of Medicine*, 331(22):1480–1487, 1994.
- [190] Lloyd Paul Aiello, Jill M Northrup, Bruce A Keyt, Hitoshi Takagi, and Mami A Iwamoto. Hypoxic regulation of vascular endothelial growth factor in retinal cells. *Archives of ophthalmology*, 113(12):1538–1544, 1995.
- [191] N Gupta, S Mansoor, A Sharma, A Sapkal, J Sheth, P Falatoonzadeh, BD Kuppermann, and MC Kenney. Diabetic retinopathy and vegf. *The open ophthalmology journal*, 7:4, 2013.

- [192] Barbara J Ballermann, Alan Dardik, Eudora Eng, and Ailian Liu. Shear stress and the endothelium. *Kidney International*, 54:S100–S108, 1998.
- [193] Ayelet Shay-Salit, Moran Shushy, Efrat Wolfovitz, Hava Yahav, Ferruccio Breviario, Elisabetta Dejana, and Nitzan Resnick. Vegf receptor 2 and the adherens junction as a mechanical transducer in vascular endothelial cells. *Proceedings of the National Academy of Sciences*, 99(14):9462–9467, 2002.
- [194] Nathaniel G dela Paz, Tony E Walshe, Lyndsay L Leach, Magali Saint-Geniez, and Patricia A D’Amore. Role of shear-stress-induced vegf expression in endothelial cell survival. *J Cell Sci*, 125(4):831–843, 2012.
- [195] EM Kohner. The retinal blood flow in diabetes. *Diabetes & metabolisme*, 19(5):401–404, 1993.
- [196] Daniel M Sforza, Christopher M Putman, and Juan Raul Cebral. Hemodynamics of cerebral aneurysms. *Annual review of fluid mechanics*, 41:91–107, 2009.
- [197] Daniel M Sforza, Christopher M Putman, and Juan R Cebral. Computational fluid dynamics in brain aneurysms. *International journal for numerical methods in biomedical engineering*, 28(6-7):801–808, 2012.
- [198] P Bhogal, M AlMatter, V Hellstern, O Ganslandt, H Bätzner, H Henkes, and M Aguilar Pérez. Difference in aneurysm characteristics between ruptured and unruptured aneurysms in patients with multiple intracranial aneurysms. *Surgical neurology international*, 9, 2018.
- [199] Hiroshi Ujiie, Yoshinori Tamano, Kuri Sasaki, and Tomokatsu Hori. Is the aspect ratio a reliable index for predicting the rupture of a saccular aneurysm? *Neurosurgery*, 48(3):495–503, 2001.
- [200] H. Meng, V. M. Tutino, J. Xiang, and A. Siddiqui. High WSS or Low WSS? Complex interactions of hemodynamics with intracranial aneurysm initiation, growth, and rupture: Toward a unifying hypothesis. *American Journal of Neuroradiology*, 35(7):1254–1262, 2014.
- [201] Yang Lu, Miguel O Bernabeu, Jan Lammer, Charles C Cai, Martin L Jones, Claudio A Franco, Lloyd Paul Aiello, and Jennifer K Sun. Computational fluid dynamics assisted characterization of parafoveal hemodynamics in normal and diabetic eyes using adaptive optics scanning laser ophthalmoscopy. *Biomedical optics express*, 7(12):4958–4973, 2016.
- [202] Konstantina Sampani, Omar Abu-Qamar, Nilesh Raval, Yang Lu, Miguel O. Bernabeu, Ward Fickweiler, Lloyd P. Aiello, and Jennifer K. Sun. Optical Coherence Tomography Angiography (OCTA) Visibility of Diabetic Microaneurysms (MAs): Associations With Wall Characteristics And Blood Flow Parameters. *The New England Ophthalmological Society Meeting*, 2018.

- [203] Elishai Ezra, Eliezer Keinan, Yossi Mandel, Michael E Boulton, and Yaakov Nahmias. Non-dimensional analysis of retinal microaneurysms: critical threshold for treatment. *Integrative Biology*, 5(3):474–480, 2013.
- [204] L Mountrakis, E Lorenz, and AG Hoekstra. Where do the platelets go? a simulation study of fully resolved blood flow through aneurysmal vessels. *Interface focus*, 3(2):20120089, 2013.
- [205] B. J. M. Van Rooij, G. Závodszy, V. W. Azizi Tarksalooyeh, and A. G. Hoekstra. Identifying the start of a platelet aggregate by the shear rate and the cell-depleted layer. *Journal of the Royal Society Interface*, 16(159), 2019.
- [206] Myeong Jin Ju, Morgan Heisler, Daniel Wahl, Yifan Jian, and Marinko V Sarunic. Multiscale sensorless adaptive optics oct angiography system for in vivo human retinal imaging. *Journal of biomedical optics*, 22(12):121703, 2017.
- [207] Morgan Heisler, Myeong Jin Ju, Mahadev Bhalla, Nathan Schuck, Arman Athwal, Eduardo V Navajas, Mirza Faisal Beg, and Marinko V Sarunic. Automated identification of cone photoreceptors in adaptive optics optical coherence tomography images using transfer learning. *Biomedical optics express*, 9(11):5353–5367, 2018.
- [208] J Moore, S Bagley, G Ireland, D McLeod, and ME Boulton. Three dimensional analysis of microaneurysms in the human diabetic retina. *The Journal of Anatomy*, 194(1):89–100, 1999.
- [209] Marco Lombardo, Mariacristina Parravano, Sebastiano Serrao, Pietro Ducoli, Mario Stirpe, and Giuseppe Lombardo. Analysis of retinal capillaries in patients with type 1 diabetes and nonproliferative diabetic retinopathy using adaptive optics imaging. *Retina*, 33(8):1630–1639, 2013.
- [210] Victor W. Azizi Tarksalooyeh, Gábor Závodszy, Britt J. M. van Rooij, and Alfons G. Hoekstra. Inflow and outflow boundary conditions for 2d suspension simulations with the immersed boundary lattice boltzmann method. *Computers & Fluids*, 2018.
- [211] R Byron Bird, Warren E Stewart, and Edwin N Lightfoot. *Transport phenomena*. John Wiley & Sons, 2007.
- [212] Boyu Gu, Xiaolin Wang, Michael D. Twa, Johnny Tam, Christopher A. Girkin, and Yuhua Zhang. Noninvasive in vivo characterization of erythrocyte motion in human retinal capillaries using high-speed adaptive optics near-confocal imaging. *Biomedical Optics Express*, 9(8):3653, aug 2018.
- [213] Alberto de Castro, Gang Huang, Lucie Sawides, Ting Luo, and Stephen A. Burns. Rapid high resolution imaging with a dual-channel scanning technique. *Optics Letters*, 41(8):1881, 2016.
- [214] M Garnier, J R Attali, P Valensi, E Delatour-Hanss, F Gaudey, and D Koutsouris. Erythrocyte deformability in diabetes and erythrocyte membrane lipid composition. *Metabolism*, 39(8):794–798, 1990.

- [215] Kosuke Tsukada, Eiichi Sekizuka, Chikara Oshio, and Haruyuki Minamitani. Direct measurement of erythrocyte deformability in diabetes mellitus with a transparent microchannel capillary model and high-speed video camera system. *Microvascular research*, 61(3):231–239, 2001.
- [216] Krüger Timm, H Kusumaatmaja, and A Kuzmin. The lattice boltzmann method: principles and practice, 2016.
- [217] Timm Krüger, Fathollah Varnik, and Dierk Raabe. Shear stress in lattice boltzmann simulations. *Physical Review E*, 79(4):046704, 2009.
- [218] B Stahl, Bastien Chopard, and Jonas Latt. Measurements of wall shear stress with the lattice boltzmann method and staircase approximation of boundaries. *Computers & Fluids*, 39(9):1625–1633, 2010.
- [219] Mahsa Dabagh and Amanda Randles. Role of deformable cancer cells on wall shear stress-associated-vegf secretion by endothelium in microvasculature. *PLoS one*, 14(2):e0211418, 2019.
- [220] Manouk Abkarian, Colette Lartigue, and Annie Viallat. Tank treading and unbinding of deformable vesicles in shear flow: determination of the lift force. *Physical review letters*, 88(6):068103, 2002.
- [221] Isabelle Cantat and Chaouqi Misbah. Lift force and dynamical unbinding of adhering vesicles under shear flow. *Physical review letters*, 83(4):880, 1999.
- [222] Stephen J White, Elaine M Hayes, Stéphanie Lehoux, Jamie Y Jeremy, Anton JG Horrevoets, and Andrew C Newby. Characterization of the differential response of endothelial cells exposed to normal and elevated laminar shear stress. *Journal of cellular physiology*, 226(11):2841–2848, 2011.
- [223] Taiji Nagaoka and Akitoshi Yoshida. Noninvasive evaluation of wall shear stress on retinal microcirculation in humans. *Investigative ophthalmology & visual science*, 47(3):1113–1119, 2006.
- [224] Juan Raul Cebal, Monica Hernandez, Alejandro Frangi, Christopher Putman, Richard Pergolizzi, and James Burgess. Subject-specific modeling of intracranial aneurysms. In *Medical Imaging 2004: Physiology, Function, and Structure from Medical Images*, volume 5369, pages 319–328. International Society for Optics and Photonics, 2004.
- [225] Gabriel J. E. Rinkel, Mamuka Djibuti, Ale Algra, and J. van Gijn. Prevalence and risk of rupture of intracranial aneurysms. *Stroke*, 29(1):251–256, 1998.
- [226] FHH Linn, GJE Rinkel, A Algra, and J Van Gijn. Incidence of subarachnoid hemorrhage. *Stroke*, 27(4):625–629, 1996.
- [227] Bryce Weir. Unruptured intracranial aneurysms: a review. *Journal of neurosurgery*, 96(1):3–42, 2002.

- [228] Richard D Brownlee, Bruce I Tranmer, Robert J Sevick, Grigory Karmy, and Bernadette J Curry. Spontaneous thrombosis of an unruptured anterior communicating artery aneurysm. *Stroke*, 26(10):1945–1949, 1995.
- [229] David A Steinman, Jaques S Milner, Chris J Norley, Stephen P Lownie, and David W Holdsworth. Image-based computational simulation of flow dynamics in a giant intracranial aneurysm. *American Journal of Neuroradiology*, 24(4):559–566, 2003.
- [230] Tamer Hassan, Masayuki Ezura, Eugene V Timofeev, Teiji Tominaga, Tsutomu Saito, Akira Takahashi, Kazuyoshi Takayama, and Takashi Yoshimoto. Computational simulation of therapeutic parent artery occlusion to treat giant vertebrobasilar aneurysm. *American journal of neuroradiology*, 25(1):63–68, 2004.
- [231] Gábor Závodszy and György Paál. Validation of a lattice boltzmann method implementation for a 3d transient fluid flow in an intracranial aneurysm geometry. *International Journal of Heat and Fluid Flow*, 44:276–283, 2013.
- [232] Nicole Varble, Gabriel Trylesinski, Jianping Xiang, Kenneth Snyder, and Hui Meng. Identification of vortex structures in a cohort of 204 intracranial aneurysms. *Journal of The Royal Society Interface*, 14(130):20170021, 2017.
- [233] JJ Schneiders, HA Marquering, P Van Ooij, R Van Den Berg, AJ Nederveen, D Verbaan, WP Vandertop, M Pourquie, GJE Rinkel, CBLM Majoie, et al. Additional value of intra-aneurysmal hemodynamics in discriminating ruptured versus unruptured intracranial aneurysms. *American Journal of Neuroradiology*, 36(10):1920–1926, 2015.
- [234] Fernando G Basombrío, Enzo A Dari, Gustavo C Buscaglia, and Raúl A Feijóo. Numerical experiments in complex haemodynamic flows. non-newtonian effects. *International Journal of Computational Fluid Dynamics*, 16(4):231–246, 2002.
- [235] Juan R Cebal, Marcelo Adrián Castro, Sunil Appanaboyina, Christopher M Putman, Daniel Millan, and Alejandro F Frangi. Efficient pipeline for image-based patient-specific analysis of cerebral aneurysm hemodynamics: technique and sensitivity. *IEEE transactions on medical imaging*, 24(4):457–467, 2005.
- [236] S Moore, T David, JG Chase, J Arnold, and J Fink. 3d models of blood flow in the cerebral vasculature. *Journal of biomechanics*, 39(8):1454–1463, 2006.
- [237] Changsung Sean Kim, Cetin Kiris, Dochan Kwak, and Tim David. Numerical simulation of local blood flow in the carotid and cerebral arteries under altered gravity. *Journal of biomechanical engineering*, 128(2):194–202, 2006.
- [238] Jörg Bernsdorf and Dinan Wang. Non-newtonian blood flow simulation in cerebral aneurysms. *Computers & Mathematics with Applications*, 58(5):1024–1029, 2009.
- [239] Timm Krüger, Halim Kusumaatmaja, Alexandr Kuzmin, Orest Shardt, Goncalo Silva, and Erlend Magnus Viggen. *The Lattice Boltzmann Method*. Springer, 2017.

- [240] Rafik Ouared and Bastien Chopard. Lattice boltzmann simulations of blood flow: non-newtonian rheology and clotting processes. *Journal of statistical physics*, 121(1-2):209–221, 2005.
- [241] B. Chopard, R. Ouared, D. A. Ruefenacht, and H. Yilmaz. Lattice boltzmann modeling of thrombosis in giant aneurysms. *International Journal of Modern Physics C*, 18(04):712–721, 2007.
- [242] Bastien Chopard, Rafik Ouared, and Daniel A. Rüfenacht. A lattice boltzmann simulation of clotting in stented aneurysms and comparison with velocity or shear rate reductions. *Mathematics and Computers in Simulation*, 72(2):108 – 112, 2006. Discrete Simulation of Fluid Dynamics in Complex Systems.
- [243] R. Ouared, B. Chopard, B. Stahl, D.A. Rüfenacht, H. Yilmaz, and G. Courbebaisse. Thrombosis modeling in intracranial aneurysms: a lattice boltzmann numerical algorithm. *Computer Physics Communications*, 179(1):128 – 131, 2008. Special issue based on the Conference on Computational Physics 2007.
- [244] O. Malaspinas, A. Turjman, D. Ribeiro de Sousa, G. Garcia-Cardena, M. Raes, P-T. T. Nguyen, Y. Zhang, G. Courbebaisse, C. Lelubre, K. Zouaoui Boudjeltia, and B. Chopard. A spatio-temporal model for spontaneous thrombus formation in cerebral aneurysms. *Journal of Theoretical Biology*, 394:68 – 76, 2016.
- [245] Daniel Ribeiro de Sousa, Carolina Vallecilla, Kamil Chodzyski, Ricardo Corredor Jerez, Orestis Malaspinas, Omer Faruk Eker, Rafik Ouared, Luc Vanhamme, Alexandre Legrand, Bastien Chopard, et al. Determination of a shear rate threshold for thrombus formation in intracranial aneurysms. *Journal of neurointerventional surgery*, 2015.
- [246] Dmitry A Fedosov, Bruce Caswell, and George Em Karniadakis. Systematic coarse-graining of spectrin-level red blood cell models. *Computer Methods in Applied Mechanics and Engineering*, 199(29-32):1937–1948, 2010.
- [247] Timm Krüger, Fathollah Varnik, and Dierk Raabe. Efficient and accurate simulations of deformable particles immersed in a fluid using a combined immersed boundary lattice boltzmann finite element method. *Computers & Mathematics with Applications*, 61(12):3485–3505, 2011.
- [248] Tamer Hassan, Eugene V Timofeev, Tsutomu Saito, Hiroaki Shimizu, Masayuki Ezura, Yasushi Matsumoto, Kazuyoshi Takayama, Teiji Tominaga, and Akira Takahashi. A proposed parent vessel geometry-based categorization of saccular intracranial aneurysms: computational flow dynamics analysis of the risk factors for lesion rupture. *Journal of neurosurgery*, 103(4):662–680, 2005.
- [249] Armelle C Burleson, Charles M Strother, and Vincent T Turitto. Computer modeling of intracranial saccular and lateral aneurysms for the study of their hemodynamics. *Neurosurgery*, 37(4):774–784, 1995.



- [262] David Hardman, Barry J Doyle, Scott IK Semple, Jennifer MJ Richards, David E Newby, William J Easson, and Peter R Hoskins. On the prediction of monocyte deposition in abdominal aortic aneurysms using computational fluid dynamics. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 227(10):1114–1124, 2013.
- [263] VL Rayz, L Boussel, L Ge, JR Leach, AJ Martin, MT Lawton, C McCulloch, and D Saloner. Flow residence time and regions of intraluminal thrombus deposition in intracranial aneurysms. *Annals of biomedical engineering*, 38(10):3058–3069, 2010.
- [264] Benjamin Czaja, Gábor Závodszy, and Alfons Hoekstra. A heterogeneous multi-scale model for blood flow. In *International Conference on Computational Science*, pages 403–409. Springer, 2020.
- [265] Daan van Ingen, Benjamin Czaja, Gábor Závodszy, and Alfons Hoekstra. Lees-edwards boundary conditions within the cell resolved lattice boltzmann framework hemocell. *Under Preparation*, 2020.
- [266] G Barshtein, D Wajnblum, and S Yedgar. Kinetics of linear rouleaux formation studied by visual monitoring of red cell dynamic organization. *Biophysical journal*, 78(5):2470–2474, 2000.
- [267] S. Alowayyed, G. Závodszy, V. Azizi, and A. G. Hoekstra. Load balancing of parallel cell-based blood flow simulations. *Journal of Computational Science*, 24:1–7, 2018.
- [268] J Latt. Palabos, parallel lattice boltzmann solver, 2009.
- [269] Adam Updegrove, Nathan M Wilson, Jameson Merkow, Hongzhi Lan, Alison L Marsden, and Shawn C Shadden. Simvascular: An open source pipeline for cardiovascular simulation. *Annals of biomedical engineering*, 45(3):525–541, 2017.
- [270] S Nadeem, Noreen Sher Akbar, Awatif A Hendi, and Tasawar Hayat. Power law fluid model for blood flow through a tapered artery with a stenosis. *Applied Mathematics and Computation*, 217(17):7108–7116, 2011.
- [271] Feby Abraham, Marek Behr, and Matthias Heinkenschloss. Shape optimization in steady blood flow: a numerical study of non-newtonian effects. *Computer methods in biomechanics and biomedical engineering*, 8(2):127–137, 2005.
- [272] JM Jung, DH Lee, KT Kim, MS Choi, YG Cho, HS Lee, SI Choi, SR Lee, and DS Kim. Reference intervals for whole blood viscosity using the analytical performance-evaluated scanning capillary tube viscometer. *Clinical biochemistry*, 47(6):489–493, 2014.
- [273] B. J. M. van Rooij. *Platelet adhesion and aggregation in high shear blood flow*. PhD thesis, 2020.
- [274] Sheikh Mohammad Shavik, Christopher Tossas-Betancourt, C Alberto Figueroa, Seungik Baek, and Lik Chuan Lee. Multiscale modeling framework of ventricular-arterial bi-directional interactions in the cardiopulmonary circulation. *Frontiers in physiology*, 11:2, 2020.

- [275] Saad A Alowayyed, Maxime Vassaux, Ben Czaja, Peter V Coveney, and Alfons G Hoekstra. Towards heterogeneous multi-scale computing on large scale parallel supercomputers. *Supercomputing Frontiers and Innovations*, 6(4):20–43, 2020.
- [276] Jonas Latt, Orestis Malaspinas, Dimitrios Kontaxakis, Andrea Parmigiani, Daniel Lagrava, Federico Brogi, Mohamed Ben Belgacem, Yann Thorimbert, Sébastien Leclaire, Sha Li, et al. Palabos: Parallel lattice boltzmann solver. *Computers & Mathematics with Applications*, 2020.
- [277] Lilit Axner, Jörg Bernsdorf, Thomas Zeiser, Peter Lammers, Jan Linxweiler, and Alfons G Hoekstra. Performance evaluation of a parallel sparse lattice boltzmann solver. *Journal of Computational Physics*, 227(10):4895–4911, 2008.
- [278] Peter Vennemann, Ralph Lindken, and Jerry Westerweel. In vivo whole-field blood velocity measurement techniques. *Experiments in fluids*, 42(4):495–511, 2007.
- [279] DJ Thomson. Criteria for the selection of stochastic models of particle trajectories in turbulent flows. *Journal of fluid mechanics*, 180:529–556, 1987.
- [280] D Spivakovskaya, AW Heemink, GN Milstein, and JGM Schoenmakers. Simulation of the transport of particles in coastal waters using forward and reverse time diffusion. *Advances in water resources*, 28(9):927–938, 2005.
- [281] Eric Lorenz and Alfons G Hoekstra. Heterogeneous multiscale simulations of suspension flow. *Multiscale Modeling & Simulation*, 9(4):1301–1326, 2011.
- [282] Gui-Rong Liu and Moubin B Liu. *Smoothed particle hydrodynamics: a meshfree particle method*. World scientific, 2003.
- [283] Chunmiao Zheng, Gordon D Bennett, et al. *Applied contaminant transport modeling*, volume 2. Wiley-Interscience New York, 2002.
- [284] Janez Perko and Ravi A Patel. Single-relaxation-time lattice boltzmann scheme for advection-diffusion problems with large diffusion-coefficient heterogeneities and high-advection transport. *Physical Review E*, 89(5):053309, 2014.
- [285] Irina Ginzburg, Dominique d’Humières, and Alexander Kuzmin. Optimal stability of advection-diffusion lattice boltzmann models with two relaxation times for positive/negative equilibrium. *Journal of Statistical Physics*, 139(6):1090–1143, 2010.
- [286] MT Dhotre, NG Deen, B Niceno, Z Khan, and JB Joshi. Large eddy simulation for dispersed bubbly flows: a review. *International Journal of Chemical Engineering*, 2013, 2013.
- [287] Zhifeng Yan, Xiaofan Yang, Siliang Li, and Markus Hilpert. Two-relaxation-time lattice boltzmann method and its application to advective-diffusive-reactive transport. *Advances in water resources*, 109:333–342, 2017.
- [288] Jia Wang, Donghai Wang, Pierre Lallemand, and Li-Shi Luo. Lattice boltzmann simulations of thermal convective flows in two dimensions. *Computers & Mathematics with Applications*, 65(2):262–286, 2013.

- [289] Carsten Funck, Frederik Bernd Laun, and Andreas Wetscherek. Characterization of the diffusion coefficient of blood. *Magnetic resonance in medicine*, 79(5):2752–2758, 2018.
- [290] RMH Merks, AG Hoekstra, and PMA Sloot. The moment propagation method for advection–diffusion in the lattice boltzmann method: validation and pécelet number limits. *Journal of Computational Physics*, 183(2):563–576, 2002.
- [291] Stanley E Charm and George S Kurland. *Blood flow and microcirculation*. Wiley, 1974.
- [292] Jonas Latt and Bastien Chopard. Lattice boltzmann method with regularized non-equilibrium distribution functions. *arXiv preprint physics/0506157*, 2005.
- [293] Jonas Latt and Bastien Chopard. Lattice boltzmann method with regularized pre-collision distribution functions. *Mathematics and Computers in Simulation*, 72(2-6):165–168, 2006.
- [294] Lei Wang, Baochang Shi, and Zhenhua Chai. Regularized lattice boltzmann model for a class of convection-diffusion equations. *Physical Review E*, 92(4):043311, 2015.
- [295] Geoffrey Ingram Taylor. Dispersion of soluble matter in solvent flowing slowly through a tube. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 219(1137):186–203, 1953.
- [296] Eric Lorenz, Alfons G Hoekstra, and Alfonso Caiazzo. Lees-edwards boundary conditions for lattice boltzmann suspension simulations. *Physical Review E*, 79(3):036706, 2009.
- [297] Peng Kai Ong, Bumseok Namgung, Paul C Johnson, and Sangho Kim. Effect of erythrocyte aggregation and flow rate on cell-free layer formation in arterioles. *American Journal of Physiology-Heart and Circulatory Physiology*, 298(6):H1870–H1878, 2010.
- [298] AW Lees and SF Edwards. The computer study of transport processes under extreme conditions. *Journal of Physics C: Solid State Physics*, 5(15):1921, 1972.
- [299] Alexander J Wagner and Ignacio Pagonabarraga. Lees–edwards boundary conditions for lattice boltzmann. *Journal of Statistical Physics*, 107(1-2):521–537, 2002.
- [300] AJ Wagner and JM Yeomans. Phase separation under shear in two-dimensional binary fluids. *Physical Review E*, 59(4):4366, 1999.
- [301] Robert M MacMeccan, JR Clausen, GP Neitzel, and CK Aidun. Simulating deformable particle suspensions using a coupled lattice-boltzmann and finite-element method. *Journal of Fluid Mechanics*, 618:13–39, 2009.
- [302] SV Lishchuk, I Halliday, and CM Care. Shear viscosity of bulk suspensions at low reynolds number with the three-dimensional lattice boltzmann method. *Physical review E*, 74(1):017701, 2006.

- [303] Anthony JC Ladd. Numerical simulations of particulate suspensions via a discretized boltzmann equation. part 1. theoretical foundation. *Journal of fluid mechanics*, 271:285–309, 1994.
- [304] Anthony JC Ladd. Numerical simulations of particulate suspensions via a discretized boltzmann equation. part 2. numerical results. *Journal of fluid mechanics*, 271:311–339, 1994.
- [305] R Verberg and AJC Ladd. Lattice-boltzmann model with sub-grid-scale boundary conditions. *Physical review letters*, 84(10):2148, 2000.
- [306] Lampros Mountrakis, Eric Lorenz, Orestis Malaspinas, Saad Alowayyed, Bastien Chopard, and Alfons G Hoekstra. Parallel performance of an ib-lbm suspension simulation framework. *Journal of Computational Science*, 9:45–50, 2015.
- [307] Cyrus K Aidun, Yannan Lu, and E-Jiang Ding. Direct analysis of particulate suspensions with inertia using the discrete boltzmann equation. *Journal of Fluid Mechanics*, 373:287–311, 1998.
- [308] Cyrus K Aidun and Yannan Lu. Lattice boltzmann simulation of solid particles suspended in fluid. *Journal of statistical physics*, 81(1-2):49–61, 1995.
- [309] E-Jiang Ding and Cyrus K Aidun. Extension of the lattice-boltzmann method for direct simulation of suspended particles near contact. *Journal of statistical physics*, 112(3-4):685–708, 2003.
- [310] LD Landau and EM Lifshitz. Fluid mechanics pergamon. *New York*, 61, 1959.
- [311] Erica M Cherry and John K Eaton. Shear thinning effects on blood flow in straight and curved tubes. *Physics of Fluids*, 25(7):073104, 2013.
- [312] William Pollack and Rudolph P Reckel. A reappraisal of the forces involved in hemagglutination. *International Archives of Allergy and Immunology*, 54(1):29–42, 1977.
- [313] Heloise Pöckel Fernandes, Carlos Lenz Cesar, and Maria de Lourdes Barjas-Castro. Electrical properties of the red blood cell membrane and immunohematological investigation. *Revista brasileira de hematologia e hemoterapia*, 33(4):297–301, 2011.
- [314] Ronen Ben-Ami, Gershon Barshtein, Tamar Mardi, Varda Deutch, Ori Elkayam, Saul Yedgar, and Shlomo Berliner. A synergistic effect of albumin and fibrinogen on immunoglobulin-induced red blood cell aggregation. *American Journal of Physiology-Heart and Circulatory Physiology*, 285(6):H2663–H2669, 2003.
- [315] GB Nash, RB Wenby, SO Sowemimo-Coker, and HJ Meiselman. Influence of cellular properties on red cell aggregation. *Clinical Hemorheology and Microcirculation*, 7(1):93–108, 1987.

- [316] Markus Gross, Timm Krüger, and Fathollah Varnik. Fluctuations and diffusion in sheared athermal suspensions of deformable particles. *EPL (Europhysics Letters)*, 108(6):68006, 2015.
- [317] Alexey A Tokarev, AA Butylin, EA Ermakova, EE Shnol, GP Panasenko, and FI Ataulakhanov. Finite platelet size could be responsible for platelet margination effect. *Biophysical journal*, 101(8):1835–1843, 2011.
- [318] A Jordan, T David, S Homer-Vanniasinkam, A Graham, and P Walker. The effects of margination and red cell augmented platelet diffusivity on platelet adhesion in complex flow. *Biorheology*, 41(5):641–653, 2004.
- [319] Marmar Mehrabadi, David N Ku, and Cyrus K Aidun. A continuum model for platelet transport in flowing blood based on direct numerical simulations of cellular blood flow. *Annals of biomedical engineering*, 43(6):1410–1421, 2015.
- [320] Anthony J Roberts and Ioannis G Kevrekidis. General tooth boundary conditions for equation free modeling. *SIAM Journal on Scientific Computing*, 29(4):1495–1510, 2007.
- [321] C William Gear, Ju Li, and Ioannis G Kevrekidis. The gap-tooth method in particle simulations. *Physics Letters A*, 316(3-4):190–195, 2003.
- [322] Lourens E Veen and Alfons G Hoekstra. Easing multiscale model design and coupling with muscle 3. In *International Conference on Computational Science*, pages 425–438. Springer, 2020.
- [323] Narla Mohandas and Evan Evans. Mechanical properties of the red cell membrane in relation to molecular structure and genetic defects. *Annual review of biophysics and biomolecular structure*, 23(1):787–818, 1994.
- [324] Fenfang Li, Chon U Chan, and Claus Dieter Ohl. Yield strength of human erythrocyte membranes to impulsive stretching. *Biophysical journal*, 105(4):872–879, 2013.
- [325] M Brust, C Schaefer, R Doerr, L Pan, M Garcia, PE Arratia, and C Wagner. Rheology of human blood plasma: Viscoelastic versus newtonian behavior. *Physical Review Letters*, 110(7):078305, 2013.
- [326] Louis J Durlofsky and John F Brady. Dynamic simulation of bounded suspensions of hydrodynamically interacting particles. *Journal of Fluid Mechanics*, 200:39–67, 1989.
- [327] Hua Zhou and C Pozrikidis. The flow of ordered and random suspensions of two-dimensional drops in a channel. *Journal of Fluid Mechanics*, 255:103–127, 1993.
- [328] Benjamin Czaja, Gábor Závodszy, and Alfons Hoekstra. A heterogeneous multi-scale model for blood flow. In *preparation for Journal of Computational Science*, 2020.