

My Findings

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Chapter 4

Molecular Biology

Here in this chapter, I will be covering the basics of the relevant molecular biology concepts. This chapter will serve as a reference for the biological claims throughout the document, as well as the foundation for the review chapters of my thesis.

4.1 Molecular Mechanism of Angiogenesis

Blood vessels and the vascular structure are formed by the differentiation of the cells in the mesoderm layer during the embryo development (the layer which also give rise to blood cells, kidney, liver, connective tissue, etc.) ?.

4.1.1 A Brief Anatomy of Vessels

Endothelial cells line all of the vessels. Blood vessels (like the arteries and the veins that are the largest vessels of the body) have a thick and tough wall of connective tissue with several layers of smooth muscles. The wall is lined by a very thin layer of endothelial cells (i.e. the endothelium) separated from the outer surrounding layers by basal lamina ?. It is worth noting that the amount of connective tissue and smooth muscle depends on the diameter of the blood vessel as well as its function, **but the endothelial lining is always present**. In the finest branches of the vasculature (i.e. capillaries and sinusoids) the wall is just made up of endothelial cells and basal lamina. One of the major roles of the endothelial cells is to control to transport of material in an out of the bloodstream.

A study of embryo development reveals that the even larger vessels (like arteries and veins) start developing from smaller vessels that has only endothelial cells and basal lamina. The connective tissue, smooth muscles and pericytes are added later on, by the signaling from endothelial cells. In particular, the recruitment of pericytes are driven by PDGF (platelet driven growth factor) secreted by the endothelial cells.

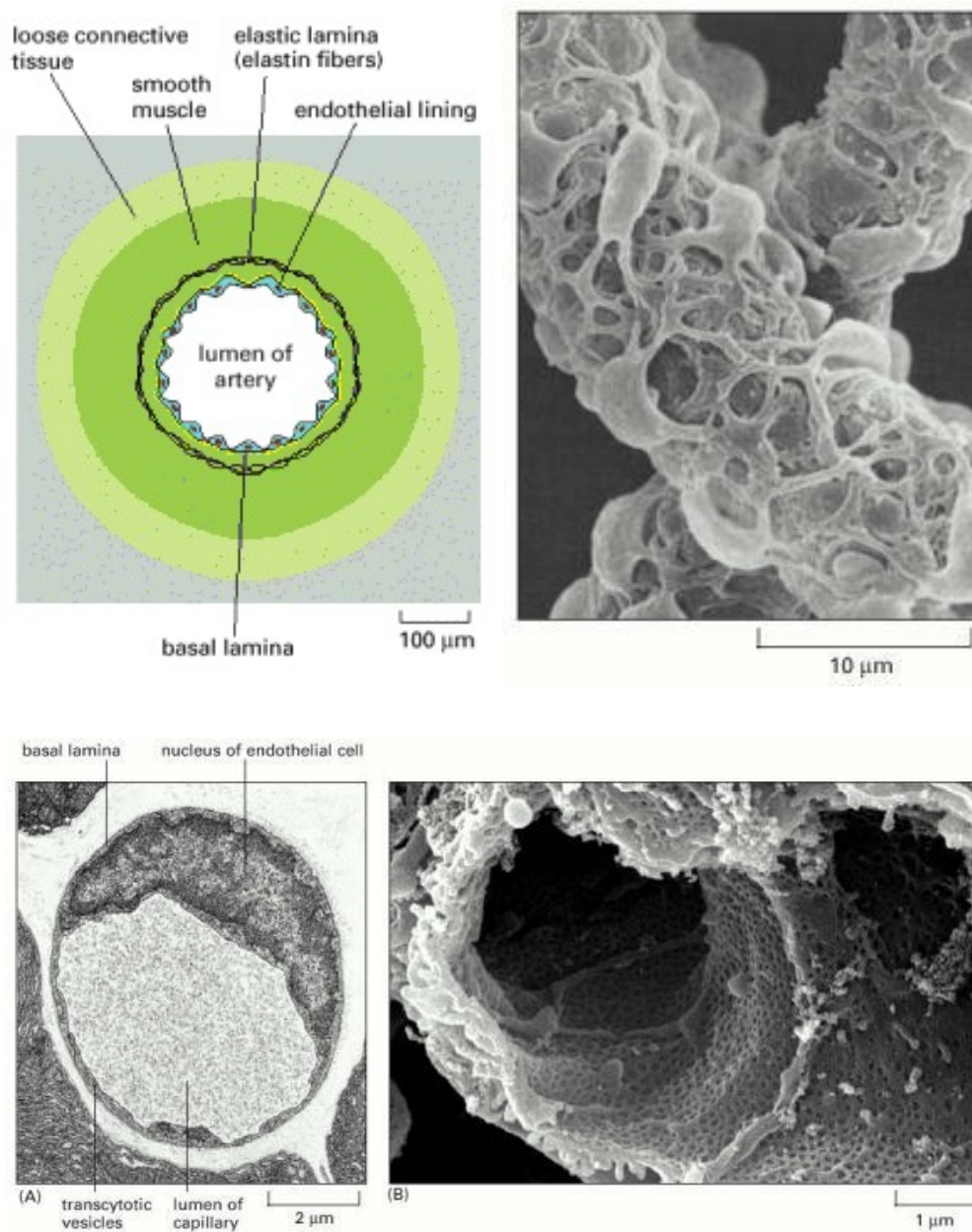


Figure 4.1.1: **Figure Top Left:** This figure shows the anatomy of a large vessel, like vein or arteries. Note that smaller vessels, like capillaries as well as sinusoids consists of only endothelial cells and basal lamina, except for some scattered pericytes wrapped around the walls (see figure Top Left). **Figure Top Right:** Electron micro graph showing small pericytes wrapped around small blood vessels. **Figure Bottom Left:** A capillary that its wall consists of only endothelial cell and basal lamina. **Figure Bottom Right:** Electron micro graph showing a cross section of small capillary in pancreas. All of the figures are from ?

Also, the following figure summarizes the cross section of different types of vasculature.

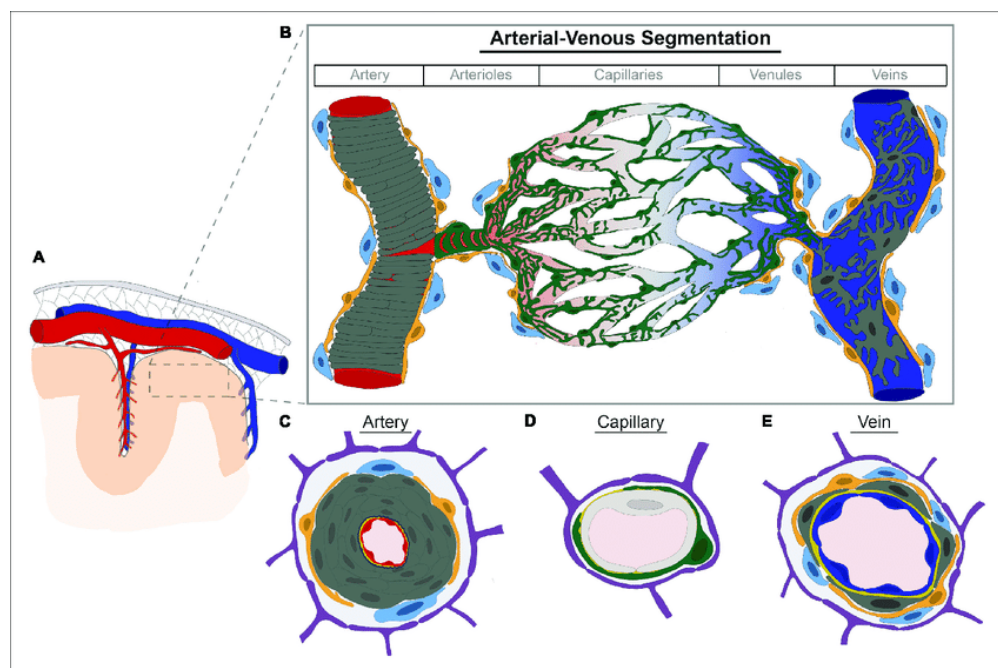


Figure 4.1.2: The cross section of vessels in the form of arteries, capillaries, and vein. Note the single lining of the endothelial cells for the capillary.

4.1.2 Molecular Biology of Vascular Structure

New vessels in the adults originate as capillaries, which sprout from the existing small vessels. Endothelial cells on the arterial and venous side of the developing networks of vessels differ in their surface properties. In the embryo at least, the plasma membrane of the arterial cells contains trans membrane protein ephrine-B2, while the membrane of the venous cells contain the corresponding receptor protein Eph-B4, which is a receptor tyrosine kinase. These molecules mediate a signal delivered at sites of cell-cell contact, and they are essential for the development of a properly organized network of vessels. One suggestion is that they somehow define the rules for joining one piece of growing capillary tube to another ?.

Observation 4.1.1 The difference in the surface properties of endothelial cells on the arterial and venous side of the developing networks of vessels control the rate at which one piece of growing capillary tube joins another. This becomes very interesting if we consider it along the observations in Köry u.a. (2024). They observed that the blunt-ended capillaries with small diameter are more susceptible for degradation after irradiation. And since the presence of blunt-ended vessels with small diameter increase the flow resistance of the network, pruning these branches “normalizes” the blood flow, hence increase the perfusion after irradiation.

Steps involved in angiogenesis

Individual endothelial cells responds to the signals produced by the organ that they invade. The signal is complex, but the main part of the signal is vascular endothelial growth factor (**VEGF**) (which is a distant relative of platelet driven growth factor (**PDGF**)). The control on the production of VEGF is through its mRNA stability and its rate of transcription. Under a low oxygen concentration, the intracellular concentration of an active form of gene regulatory protein called

hypoxia inducible factor 1 (HIF-1) increases. HIF-1 stimulates the transcription of VEGF gene (and the production of other genes that are needed when the oxygen supply is low). When the VEGF protein is secreted, it is then diffuses through the tissue and acts on nearby endothelial cells.

Endothelial cells that are to form a new capillary, grow out from the side of an existing capillary by forming long pseudopodia pioneering the formation of new capillary sprout that hallow out to form a tube. This process continues until the sprout encounters another capillary, where they merge. In the tumor micro environment, The growth rate of tumor increases abruptly as soon as the vessels reach it.

There are two general balancing forces acting on the angiogenesis

- Inhibitors:
 - endostatin
 - angiostatin
 - thrombospondin
- Angiogens
 - VEGF: Vascular Endothelial Growth Factors.
 - bFGF: Basic Fibroblast Growth Factor.
 - PDGF: Platelet Driven Growth Factor.

The Response of Endothelial Cells to VEGF

The response of endothelial cells to VEGF has four components. First, they produce proteases to digest through the basal lamina of the parent vessels. For the second step, they migrate towards the source of VEGF, and for the third step they proliferate. Finally, they form hallow tubes. It is worth mentioning that VEGF stimulates endothelial cells selectively, while other angiogens, like fibroblast growth factor stimulates other cell types as well. The following figure summarizes these steps.

Controlling Capillary Joining Process

In the following text from ?, there is some vague hints about the mechanisms that are controlling capillary joining to each other

Observations such as these reveal that endothelial cells that are to form a new capillary grow out from the side of an existing capillary or small venule by extending long pseudopodia, pioneering the formation of a capillary sprout that hollows out to form a tube (Figure 22-25). This process continues until the sprout encounters another capillary, with which it connects, allowing blood to circulate. Endothelial cells on the arterial and venous sides of the developing network of vessels differ in their surface properties, in the embryo at least: the plasma membranes of the arterial cells contain the transmembrane protein ephrin-B2 (see Chapter 15), while the membranes of the venous cells contain the corresponding receptor protein, Eph-B4, which is a receptor tyrosine kinase (discussed in Chapter 15). These molecules mediate a signal delivered at sites of cell-cell contact, and they are essential for the development of a properly organized network of vessels. One suggestion is that they somehow define the rules for joining one piece of growing capillary tube to another.

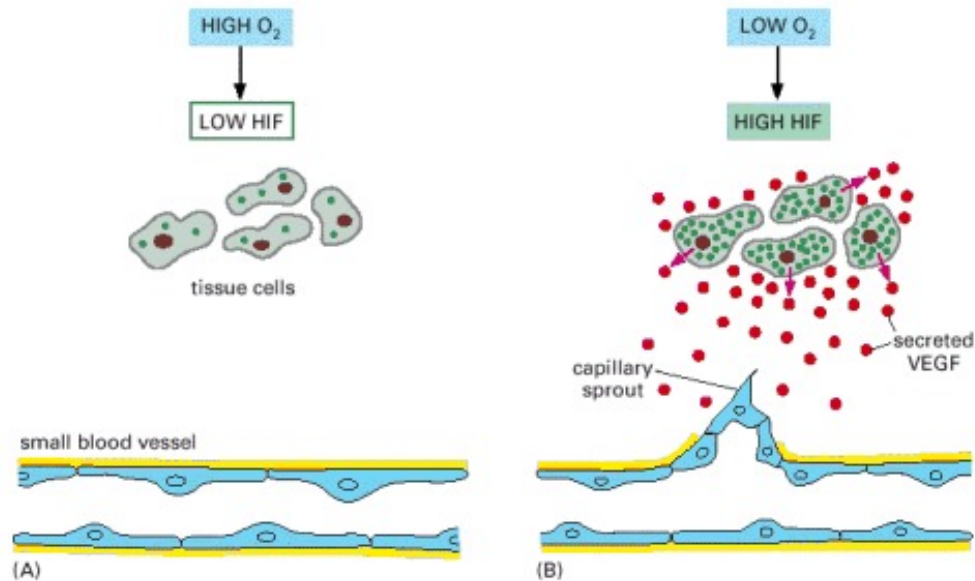


Figure 4.1.3: A summary of the response of the endothelial cells to VEGF. Under low oxygen concentration, the intracellular concentration of HIF-1 increases. This gene regulatory protein in turn increases the transcription of VEGF protein. Then VEGF diffuses through the tissue and stimulates the endothelial cells lining the vessels. Figure is from ?.

Formation of tube structures by endothelial cells

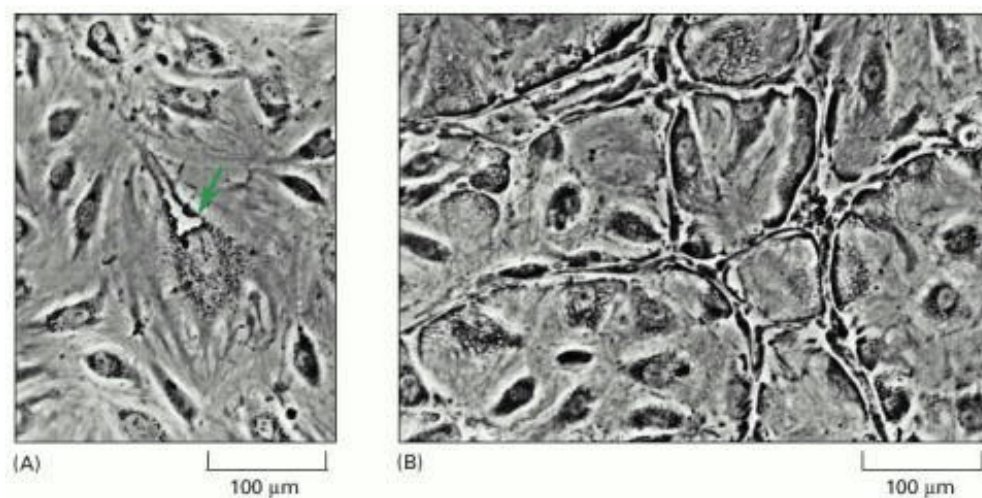


Figure 4.1.4: The endothelial cells, when supported by suitable growth medium and signals, start to form hollow structure, that do not contain any blood, and not fluid passes through them. This indicates that the no mechanical trigger (i.e. pressure) is required to form the hollow structure for the new vessels. Image from ?.

It was one of my main concerns that what is the process in which a single lining of endothelial cells following a tip cell forms a hollow tube (i.e. vessel). The following text from ? explains this clearly. This process has also been described in [angiogenesis Youtube](#).

Experiments in culture show that endothelial cells in a medium containing suitable growth factors will spontaneously form capillary tubes, even if they are isolated from all other types of cells (Figure 22-26). The capillary tubes that develop do not contain blood, and nothing travels through them, indicating that blood flow and pressure are not required for the initiation of a new capillary network. Endothelial cells in culture spontaneously develop internal vacuoles that appear to join up from cell to cell, giving rise to a network of capillary tubes. These photographs show successive stages in the process.

4.2 Biological Assays to Study Angiogenesis

4.2.1 Corneal Micropocket Assay

This is one of the simple and reproducible assays to study angiogenesis in a eye. The process involves introducing growth factors in the eye ball of mouse, and then letting the vascular network to form. This is a video from JOVE explaining the details of the protocol ([cornealMicroPocketAssayJOVE](#))

4.3 Some Histology

In short, histology is the study of the animal tissue in the microscopic scale (which is also known as the microscopic anatomy or micro anatomy). Studying different types of animal tissue falls in the realm of histology.

There are four types of animal tissue

(i) Epithelium

- squamous: endothelial lining of the vascular structure is of this type.
- cuboidal
- columnar

(ii) Muscle tissue

- smooth muscle
- skeletal muscle
- cardiac muscle

(iii) Connective tissue

- cartilage
- bone
- blood
- lymph
- hemopoietic

(iv) Nervous tissue

- central nervous system
- peripheral nervous system

Among this list of the four basic types of the animal tissue, we will focus on the Epithelium.

4.3.1 Epithelium

Epithelium forms continuous sheets of cells that line internal surfaces and cover the external surfaces of the organs. A **basement membrane** separates an epithelium from the underlying connective tissue.

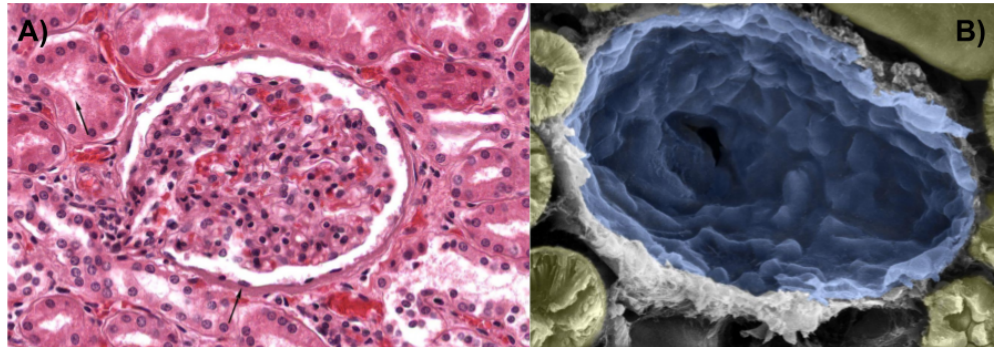


Figure 4.3.1: A) A microscopic image of renal corpuscle that contains a glomerulus (a tuft of capillaries) surrounded by Bowman's capsule. The interior of the capsule, is lined with a simple squamous epithelium that rests on a thick basement membrane. The only part of these cells visible is their nuclei bulging into the interior. B) Scanning electron microscope of renal corpuscle that its glomerulus is removed. The simple squamous epithelium can be seen in blue (borders of individual cells are not visible). Both images are from histologyguide.com.



Figure 4.3.2: A pathology image of bile duct (the large lumen at the center). There are many blood vessels in the surrounding connective tissue. Blood vessels are lined with simple squamous epithelium. The only part of these cells visible is their flattened nuclei. **Epithelium that lines blood vessels, heart, and lymphatic vessels is also known as endothelium.**

4.4 Important Random Facts

- The over expression of ANG1 (angiopoietin1) induces vascular remodeling that leads to the formation of vessels with a wider diameter ([Augustin u. a. \(2009\)](#)).
- TIE2-mediated EC activation controls the expression of endothelial apelin, which in turn acts in an autocrine manner on EC-expressed G-protein-coupled APJ receptors, the downstream signalling of which contributes to the control of vessel diameter ([Augustin u. a. \(2009\)](#); [Kidoya u. a. \(2008\)](#)).
- Differences in arterio-venous shear stress also control Ang–Tie signalling ([Augustin u. a. \(2009\)](#)).
- The quiescent EC phenotype is maintained by constitutive ANG1–TIE2 signalling. ANG1 clusters TIE2 junctionally at inter-endothelial cell junctions in trans to transduce survival signals. Differences in arterio-venous shear stress also control Ang–Tie signalling. During the transition from the quiescent to the activated phenotype, ECs liberate their endogenously stored pools of ANG2, and this antagonizes ANG1–TIE2 signalling to facilitate EC responsiveness to exogenous cytokines. As such, the absence or presence of stored ANG2 contributes to the control of the **adaptive plasticity of the vascular endothelium** ([Augustin u. a. \(2009\)](#)).
- Oscillatory flow has also been measured in humans and reported in [Rodgers u. a. \(1984\)](#) ([Carr u. a. \(2005\)](#)).
- Observed oscillation frequencies range up to 240 cycles per minute. High frequency oscillations (greater than 50 cycles per minute) have been attributed to either heart pulse or breathing rhythms. Lower frequency oscillations are thought to be caused by vasomotion. Observed frequencies of vasomotion have been reported to range from 2.7 to 32 cycles per minute.^{6,23} Recent analysis of RBC velocities and arteriole diameter dynamics by Parthimos et al. suggests, however, that low frequency oscillations may not be solely due to vasomotion. Their analysis demonstrates that two important measures (correlation dimension and Lyapunov exponent) of the RBC velocity oscillations depends on whether vasomotion is present or not. This indicates that something other than vasomotion is also driving the RBC velocity dynamics [Carr u. a. \(2005\)](#)
- The responses outlined above lead to continued vessel shrinking and eventually to pruning of vessels that are nonfunctional with respect to both convective and diffusive transport. Typically, such vessels have low shear stress and moderate or high oxygen levels and therefore receive a negative net growth stimulus, causing decrease in diameter [Pries und Secomb \(2014\)](#).
- The need for distribution of capillaries throughout the tissue implies the presence of both short and long flow pathways connecting the feeding arteriole to the draining venule. As illustrated in FIGURE 4, a short pathway has a very high pressure drop per length and thus very high wall shear stress compared with the feeding arteriole from which it branches. On the other hand, the local oxygen partial pressure and metabolic environment of the two segments are similar. Responses to local signals alone would therefore favor growth in the short pathway, generating a functional arterio-venous (A-V) shunt. To avoid such behavior, an additional mechanism is required that signals differences between arterioles supplying a large number of capillaries and those forming short A-V connections. This mechanism must provide transfer

of information upstream along arterioles within vascular networks. A similar consideration applies to vessels in the venular network, where information transfer in the downstream direction, from distal to proximal vessels, is necessary. In this case, convective transport of metabolites may provide the needed signals (55, 63). However, upstream information transfer is not so simply explained Pries und Secomb (2014).

- If the shrinking of a given vessel leads neither to local hypoxia nor to increased wall shear stress, then it receives no increasing growth stimulus and continues to shrink, eventually being pruned Pries und Secomb (2014).
- Conversely, shrinkage of a vessel that is needed for diffusive transport leads to hypoxia and an increased metabolic stimulus for growth, whereas shrinkage of a vessel that is needed for convective transport leads to increased wall shear stress, also a stimulus for vessel growth. In each case, the resulting negative feedback loop stabilizes vessel diameter Pries und Secomb (2014).
- Third, angiogenesis, remodeling, and pruning occur in parallel and not as separate processes Pries und Secomb (2014).
- An interesting prediction of the theory is that this system exhibits hysteresis: the increase in vascular density generated during a period of higher demand is only partially reversed if demand returns to its former level Pries und Secomb (2014).
- Under steady-state conditions, endothelial cells are relatively quiescent, exhibiting a turnover time in the range of 30–300 days (see reference 18,35 of Pries und Secomb (2014)).
- In tumors, the microvasculature is typically seen to be more tortuous and disorganized than in normal tissues. Tumors often show a relatively high proportion of hypoxic tissue, even if the vascular volume and perfusion are relatively high. This hypoxia has important effects on tumor responses to radiation and chemotherapies, generally reducing their effectiveness. Analysis of hemodynamics and remodeling in tumor microvessel networks suggests that poor oxygenation may result from functional shunting, i.e., failure to distribute flow appropriately between short and long flow pathways, as a consequence of impaired conducted responses (55, 56). Such impairment is plausible given that endogenous VEGF levels are typically elevated in tumor tissues and that VEGF has disruptive effects on vascular wall integrity and gap junction function (74) Pries und Secomb (2014).
- The dense but highly disordered and functionally deficient vascular networks often observed in tumors can be interpreted as the result of excessive angiogenesis combined with weak or defective remodeling and pruning. Similar patterns with increases of vessel density but not perfusion have been reported to result from VEGF overexpression (78) Pries und Secomb (2014).
- Therefore, understanding the formation of vascular networks requires consideration of the integrated processes of angiogenesis, structural adaptation, and pruning Pries und Secomb (2014).
- These structural adaptations may involve alterations in the dimensions and wall composition of individual vessel segments (remodelling), the growth of new segments (angiogenesis) and the loss of existing segments (pruning) Secomb u. a. (2012).

- in the development of hypertension, inward remodelling accompanied by wall thickening is a typical structural feature [Secomb u. a. \(2012\)](#).
- Some experimental references for the vascular remodeling and adaptation: Direct experimental approaches have provided much information about structural remodelling of blood vessels. Ex vivo perfusion systems allow manipulation of haemodynamic conditions and observation of resulting structural changes over periods of hours to days [3–5]. In vivo animal models can be used to observe structural responses to surgical alterations in flow conditions over periods of days to weeks [6–10]. Such experimental approaches have been used to investigate the responses of individual vessels (generally arteries) to mechanical stimuli, including fluid shear stress acting on the endothelial cell layer and circumferential and axial stresses acting on the wall, and to metabolic and pharmacological stimuli [Secomb u. a. \(2012\)](#).
- Early theories of structural adaptation assumed that the diameter of each segment is controlled so as to achieve a target level of the wall shear stress [18,19] [Secomb u. a. \(2012\)](#).
- However, analyses of microvascular networks in the rat mesentery [22] showed a systematic increase in wall shear stress with intravascular pressure from the venules to the arterioles. Such behaviour was incorporated in the model by assuming a pressure-dependent set point for wall shear stress. This implies that venous vessels are larger than corresponding arterial vessels carrying the same blood flow. Another consequence is that the pressure drop is much larger in the arterioles than in the venules, and capillary pressure is much lower than arterial pressure [Secomb u. a. \(2012\)](#).
- Analysis of the model under the assumption that diameters respond only to the haemodynamic signals of pressure and wall shear stress shows that parallel flow pathways are unstable (fig. 2A) [19]. Furthermore, this assumption neglects the obvious need for network structure to respond to metabolic needs. Introduction of a signal dependent on local oxygen level (fig. 1B) provides a metabolic response and can be shown to stabilize parallel pathways (fig. 2B). [Secomb u. a. \(2012\)](#)
- Mechanical parameters such as tissue elasticity, viscosity and friction can also specify time and length scales of morphogenetic processes (Fig. 1a). For instance, the length scale of stress propagation, the so-called hydrodynamic length, depends on the relative contribution of viscosity and friction within a cell [30] or a tissue. Viscosity can also define rates of deformation upon a given mechanical stress. The ratio between the viscous modulus and elastic modulus defines the Maxwell time, that is, the time above which deformations become irreversible, typical of a viscous response[31]. Mechanics can thus direct morphogenesis in a manner similar to biochemical information. For instance, dissipation of a localized stress by friction can generate gradients of stress similar to those better known for biochemical gradients of morphogens [32,33] [Collinet und Lecuit \(2021\)](#)
- We delineated two idealized and distinct modalities of information flow during morphogenesis. Programmes specify deterministically and hierarchically all operations required for the development of a shape. Programmed morphogenesis results explicitly and predictably from the spatially organized initial conditions, a pre-pattern, and relies upon deterministic rules. For instance, a genetically encoded morphogen gradient specifies a battery of downstream decisions that themselves dictate mechanical states in cells such as cell contractility. By contrast, self-organization is characterized by the emergence of ordered structures from a purely homogeneous initial state. It relies on stochastic rules, local activity associated with molecular

motors and dissipation of elastic energy, driving irreversible deformation and amplification of local activity via feedbacks that operate across scales. Thereby, the system transits to a steady state that minimizes its free energy [Collinet und Lecuit \(2021\)](#).

- Programmes are usually hard-wired and exhibit redundancy, such that they are mostly insensitive to genetic perturbations. However, once affected, for example by a mutation, they cannot be repaired to generate the expected shape because of the absence of feedbacks and a strict dependency on initial conditions, which may be lost as morphogenesis proceeds. By contrast, owing to their internal feedbacks, rapid dynamics and insensitivity to initial conditions, self-organized systems can reform after complete perturbations and constantly adapt to a changing environment. Thus, programmes may be most suited to robustly guide a few critical steps of morphogenesis where failing to properly time or position singular shape changes of the tissue may affect the entire subsequent steps of the morphogenesis, such as during embryo gastrulation or the specification of primary sulci in the developing brain cortex [Collinet und Lecuit \(2021\)](#).
- The energy minimisation formalism used here is consistent with Murray’s law. In Murray’s approach, it is assumed that there are two contributions to the energy cost of maintaining the flow: the power required to overcome viscous drag forces and the metabolic cost of maintaining the network structure, which is proportional to its volume [Almeida und Dilão \(2022\)](#).
- Animals and plants may benefit from loop structures in many ways. For example, loops are important in mitigating damages of networks [3] and optimizing energy consumption with fluctuating flow distributions [3,4][Hu und Cai \(2013\)](#).
- biological transport networks are thought to have undergone a process of gradual optimization through evolution [1], culminating in organizational principles such as Murray’s law [2–4]. A particular class of such networks that minimizes flow resistance under biologically relevant constraints has been studied to reveal a wealth of phenomena such as phase transitions [5,6], the interdependence of flow and conduit geometry [7], and predictions about allometric scaling relations in biology [8]. When the optimization models are generalized to require resilience to damage or to consider fluctuations in the load, optimal networks reproduce the reticulate network patterns observed in biological systems [9,10]. The optimality principles that often determine these networks also appear in nonbiological context, e.g., river basins [11,12], and are relevant for man-made systems such as gas or sewage pipe networks [13,14] [Ronellenfitsch und Katifori \(2016\)](#).
- The topology of such efficient networks is characterized by the tendency to reuse the same edge to supply large parts of the network, as opposed to directly connecting each node to the source. This is reflected in the mean number of edges between two bifurcations (the mean branch length). Efficient networks tend to exhibit fewer nonbranching nodes [Fig. 3(c)]. Temporally fluctuating sources (similar to [27]) during the adaptive process can produce loops [33], reminiscent of real reticulate biological networks. In addition, variable branching angles [7], growth anisotropies, and steric effects [33] may also play a role [Ronellenfitsch und Katifori \(2016\)](#).
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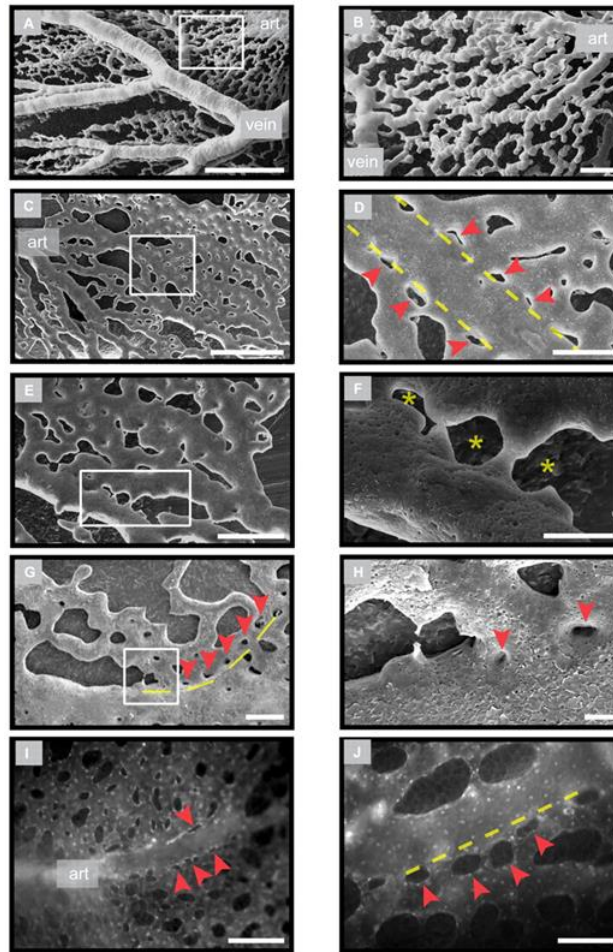


Figure 4.4.1: Splitting angiogenesis (intussusception) in ligation embryos. (A-H) Scanning electron micrographs of vascular corrosion casts of control (A,B) and ligation (C-H) chicken embryos. (A) Low magnification of the normal vasculature. The boxed region is shown at higher magnification in B. Splitting angiogenesis is not apparent. (C) Micrograph of ligation embryo showing extensive pillar formation. (D) Magnification of the boxed region in C, showing rows of pillars (red arrowheads) delineating the future arteriolar segment (dashed line). (E,F) Overview (E) and detail of the boxed area (F) showing fusion of pillars leading to segregation of the capillaries (asterisks). (G,H) Another example showing the advanced splitting by pillars (arrowheads); rows of pillars align (dashed line) and subsequent fusion will lead to separation of the feed vessel from the surrounding capillary plexus. (I,J) Fluorescent labeling of endothelial cells in vivo shows pillar formation (arrowheads) in distal arterioles and the connected capillary network. art, artery. Scale bars: 500 μm in A,C; 200 μm in E; 100 μm in B,D,G; 50 μm in F; 20 μm in H; 30 μm in I,J. Figure is from [Buschmann u. a. \(2010\)](#)

Bibliography

- [angiogenesisYoutube] : (73) *Angiogenesis - YouTube*. – URL <https://www.youtube.com/>. – Zugriffsdatum: 2024-01-27
- [conealMicroPocketAssayJOVE] : *The Corneal Micropocket Assay: A Model of Angiogenesis in the Mouse Eye*. – URL https://app.jove.com/the_corneal_micropocket_assay_a_model_of_angiogenesis_in_the_mouse_eye. – Zugriffsdatum: 2024-01-27
- [Alberts u. a. 2002] ALBERTS, Bruce ; JOHNSON, Alexander ; LEWIS, Julian ; RAFF, Martin ; ROBERTS, Keith ; WALTER, Peter: *Molecular Biology of the Cell*. 4th. Garland Science, 2002. – ISBN 9780815332183 9780815340720
- [Almeida und Dilão 2022] ALMEIDA, Rodrigo ; DILÃO, Rui: Adaptive Hagen–Poiseuille flows on graphs. In: *Physica D: Nonlinear Phenomena* 436 (2022), August, S. 133322. – URL <https://www.sciencedirect.com/science/article/pii/S0167278922001014>. – Zugriffsdatum: 2024-08-26. – ISSN 0167-2789
- [Anderson und Chaplain 1998] ANDERSON, A. R. A. ; CHAPLAIN, M. A. J.: Continuous and discrete mathematical models of tumor-induced angiogenesis. In: *Bulletin of Mathematical Biology* 60 (1998), September, Nr. 5, S. 857–899. – URL <https://doi.org/10.1006/bulm.1998.0042>. – Zugriffsdatum: 2024-01-21. – ISSN 1522-9602
- [Arnold und West 1991] ARNOLD, F. ; WEST, D. C.: Angiogenesis in wound healing. In: *Pharmacology & Therapeutics* 52 (1991), Dezember, Nr. 3, S. 407–422. – ISSN 0163-7258
- [Augustin u. a. 2009] AUGUSTIN, Hellmut G. ; YOUNG KOH, Gou ; THURSTON, Gavin ; ALITALO, Kari: Control of vascular morphogenesis and homeostasis through the angiopoietin–Tie system. In: *Nature Reviews Molecular Cell Biology* 10 (2009), März, Nr. 3, S. 165–177. – URL <https://www.nature.com/articles/nrm2639>. – Zugriffsdatum: 2024-08-21. – ISSN 1471-0080
- [Ausprunk und Folkman 1977] AUSPRUNK, D. H. ; FOLKMAN, J.: Migration and proliferation of endothelial cells in preformed and newly formed blood vessels during tumor angiogenesis. In: *Microvascular Research* 14 (1977), Juli, Nr. 1, S. 53–65. – ISSN 0026-2862
- [Bakker und van Bavel 2021] BAKKER, Erik N. T. P. ; BAVEL, Ed van: *Biomechanics in Small Artery Remodeling*. Cham : Springer International Publishing, 2021, S. 47–68. – URL https://doi.org/10.1007/978-3-030-63164-2_3. – Zugriffsdatum: 2024-08-21. – ISBN 9783030631642
- [Balding und McElwain 1985] BALDING, D. ; MCELWAIN, D. L. S.: A mathematical model of tumour-induced capillary growth. In: *Journal of Theoretical Biology* 114 (1985), Mai, Nr. 1, S. 53–73. – URL <https://www.sciencedirect.com/science/article/pii/S0022519385802551>. – Zugriffsdatum: 2024-01-21. – ISSN 0022-5193

- [Bauer u.a. 2007a] BAUER, A. ; JACKSON, T. ; JIANG, Yi: A cell-based model exhibiting branching and anastomosis during tumor-induced angiogenesis. In: *Biophysical journal* 92 9 (2007), S. 3105–21. – URL <https://consensus.app/papers/cellbased-model-exhibiting-branching-anastomosis-bauer/1756c0dc2c7850faad7b9a89f326dfdf/>. – Zugriffsdatum: 2024-03-02
- [Bauer u.a. 2007b] BAUER, Amy L. ; JACKSON, Trachette L. ; JIANG, Yi: A Cell-Based Model Exhibiting Branching and Anastomosis during Tumor-Induced Angiogenesis. In: *Biophysical Journal* 92 (2007), Mai, Nr. 9, S. 3105–3121. – URL <https://www.sciencedirect.com/science/article/pii/S0006349507711207>. – Zugriffsdatum: 2024-01-21. – ISSN 0006-3495
- [Bayrak u.a. 2015] BAYRAK, E. S. ; AKAR, B. ; XIAO, Nan ; MEHDIZADEH, Hamidreza ; SOMO, S. ; BREY, E. ; ÇINAR, A.: Agent-Based Modeling of Vascularization in Gradient Tissue Engineering Constructs. In: *IFAC-PapersOnLine* 48 (2015), S. 1240–1245. – URL <https://consensus.app/papers/modeling-vascularization-gradient-tissue-engineering-bayrak/d22174ffff62150c992548ba168de9446/>. – Zugriffsdatum: 2024-03-02
- [Birdwell u.a. 1978] BIRDWELL, C R. ; GOSPODAROWICZ, D ; NICOLSON, G L.: Identification, localization, and role of fibronectin in cultured bovine endothelial cells. In: *Proceedings of the National Academy of Sciences of the United States of America* 75 (1978), Juli, Nr. 7, S. 3273–3277. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC392757/>. – Zugriffsdatum: 2024-06-12. – ISSN 0027-8424
- [Birdwell u.a. 1980] BIRDWELL, Charles R. ; BRASIER, Allan R. ; TAYLOR, Lorna A.: Two-dimensional peptide mapping of fibronectins from bovine aortic endothelial cells and bovine plasma. In: *Biochemical and Biophysical Research Communications* 97 (1980), November, Nr. 2, S. 574–581. – URL <https://www.sciencedirect.com/science/article/pii/S0006291X80903022>. – Zugriffsdatum: 2024-06-12. – ISSN 0006-291X
- [Bookholt u.a. 2016] BOOKHOLT, F. D. ; MONSUUR, H. ; GIBBS, S. ; VERMOLEN, F.: Mathematical modelling of angiogenesis using continuous cell-based models. In: *Biomechanics and Modeling in Mechanobiology* 15 (2016), S. 1577–1600. – URL <https://consensus.app/papers/modelling-angiogenesis-using-cellbased-models-bookholt/3bfbd79589195fd18705ba3c8cd4efb6/>. – Zugriffsdatum: 2024-03-02
- [Bowersox und Sorgente 1982] BOWERSOX, J. C. ; SORGENTE, N.: Chemotaxis of aortic endothelial cells in response to fibronectin. In: *Cancer Research* 42 (1982), Juli, Nr. 7, S. 2547–2551. – ISSN 0008-5472
- [Bray 2000] BRAY, Dennis: *Cell Movements: From Molecules to Motility*. 2. New York : Garland Science, November 2000. – ISBN 9780203833582
- [Buschmann u.a. 2010] BUSCHMANN, Ivo ; PRIES, Axel ; STYP-REKOWSKA, Beata ; HILLMEISTER, Philipp ; LOUFRANI, Laurent ; HENRION, Daniel ; SHI, Yu ; DUELSNER, Andre ; HOEFER, Imo ; GATZKE, Nora ; WANG, Haitao ; LEHMANN, Kerstin ; ULM, Lena ; RITTER, Zully ; HAUFF, Peter ; HLUSHCHUK, Ruslan ; DJONOV, Valentin ; VEEN, Toon van ; NOBLE, Ferdinand le: Pulsatile shear and Gja5 modulate arterial identity and remodeling events during flow-driven arteriogenesis. In: *Development* 137 (2010), Juli, Nr. 13, S. 2187–2196. – URL <https://doi.org/10.1242/dev.045351>. – Zugriffsdatum: 2024-08-21. – ISSN 0950-1991

- [Byrne und Chaplain 1995a] BYRNE, H. M. ; CHAPLAIN, M. A. J.: Growth of nonnecrotic tumors in the presence and absence of inhibitors. In: *Mathematical Biosciences* 130 (1995), Dezember, Nr. 2, S. 151–181. – URL <https://www.sciencedirect.com/science/article/pii/0025556494001173>. – Zugriffsdatum: 2024-01-21. – ISSN 0025-5564
- [Byrne und Chaplain 1995b] BYRNE, H. M. ; CHAPLAIN, M. A. J.: Mathematical models for tumour angiogenesis: Numerical simulations and nonlinear wave solutions. In: *Bulletin of Mathematical Biology* 57 (1995), Mai, Nr. 3, S. 461–486. – URL <https://doi.org/10.1007/BF02460635>. – Zugriffsdatum: 2024-06-12. – ISSN 1522-9602
- [Byrne 2010] BYRNE, Helen M.: Dissecting cancer through mathematics: from the cell to the animal model. In: *Nature Reviews Cancer* 10 (2010), März, Nr. 3, S. 221–230. – URL <https://www.nature.com/articles/nrc2808>. – Zugriffsdatum: 2024-01-21. – ISSN 1474-1768
- [Cai u. a. 2017] CAI, H. ; LIU, X. ; ZHENG, J. ; XUE, Y. ; MA, J. ; LI, Z. ; XI, Z. ; LI, Z. ; BAO, M. ; LIU, Y.: Long non-coding RNA taurine upregulated 1 enhances tumor-induced angiogenesis through inhibiting microRNA-299 in human glioblastoma. In: *Oncogene* 36 (2017), Januar, Nr. 3, S. 318–331. – URL <https://www.nature.com/articles/onc2016212>. – Zugriffsdatum: 2024-01-21. – ISSN 1476-5594
- [Carr u. a. 2005] CARR, Russell T. ; GEDDES, John B. ; WU, Fan: Oscillations in a Simple Microvascular Network. In: *Annals of Biomedical Engineering* 33 (2005), Juni, Nr. 6, S. 764–771. – URL <https://doi.org/10.1007/s10439-005-2345-2>. – Zugriffsdatum: 2024-08-23. – ISSN 1573-9686
- [Carter 1965] CARTER, S. B.: Principles of cell motility: the direction of cell movement and cancer invasion. In: *Nature* 208 (1965), Dezember, Nr. 5016, S. 1183–1187. – ISSN 0028-0836
- [Chaplain 2000] CHAPLAIN, M.: Mathematical Modelling of Angiogenesis. In: *Journal of Neuro-Oncology* 50 (2000), S. 37–51. – URL <https://consensus.app/papers/modelling-angiogenesis-chaplain/6d427094e8205125a43fe573afe3612c/>. – Zugriffsdatum: 2024-03-02
- [Chaplain 1995] CHAPLAIN, M. A.: The mathematical modelling of tumour angiogenesis and invasion. In: *Acta Biotheoretica* 43 (1995), Dezember, Nr. 4, S. 387–402. – ISSN 0001-5342
- [Chaplain und Stuart 1993] CHAPLAIN, M. A. ; STUART, A. M.: A model mechanism for the chemotactic response of endothelial cells to tumour angiogenesis factor. In: *IMA journal of mathematics applied in medicine and biology* 10 (1993), Nr. 3, S. 149–168. – ISSN 0265-0746
- [Chaplain 1996] CHAPLAIN, M. A. J.: Avascular growth, angiogenesis and vascular growth in solid tumours: The mathematical modelling of the stages of tumour development. In: *Mathematical and Computer Modelling* 23 (1996), März, Nr. 6, S. 47–87. – URL <https://www.sciencedirect.com/science/article/pii/0895717796000192>. – Zugriffsdatum: 2024-06-13. – ISSN 0895-7177
- [Chávez u. a. 2016] CHÁVEZ, Myra N. ; AEDO, Geraldine ; FIERRO, Fernando A. ; ALLENDE, Miguel L. ; EGAÑA, José T.: Zebrafish as an Emerging Model Organism to Study Angiogenesis in Development and Regeneration. In: *Frontiers in Physiology* 7 (2016), S. 56. – ISSN 1664-042X
- [Clark u. a. 1982] CLARK, R. A. ; DELLAPELLE, P. ; MANSEAU, E. ; LANIGAN, J. M. ; DVORAK, H. F. ; COLVIN, R. B.: Blood vessel fibronectin increases in conjunction with endothelial cell proliferation and capillary ingrowth during wound healing. In: *The Journal of Investigative Dermatology* 79 (1982), November, Nr. 5, S. 269–276. – ISSN 0022-202X

- [Clark u.a. 1981] CLARK, R. A. ; DVORAK, H. F. ; COLVIN, R. B.: Fibronectin in delayed-type hypersensitivity skin reactions: associations with vessel permeability and endothelial cell activation. In: *J. Immunol.* 126 (1981), Februar, Nr. 2, S. 787–793
- [Clark u.a. 1983] CLARK, R. A. ; WINN, H. J. ; DVORAK, H. F. ; COLVIN, R. B.: Fibronectin beneath reepithelializing epidermis in vivo: sources and significance. In: *The Journal of Investigative Dermatology* 80 (1983), Juni, Nr. 1 Suppl, S. 26s–30s. – ISSN 0022-202X
- [Cliff 1963] CLIFF, W. J.: Observations on Healing Tissue: A Combined Light and Electron Microscopic Investigation. In: *Philosophical Transactions of the Royal Society of London Series B* 246 (1963), Juli, S. 305–325. – URL <https://ui.adsabs.harvard.edu/abs/1963RSPTB.246..305C>. – Zugriffsdatum: 2024-06-12. – ADS Bibcode: 1963RSPTB.246..305C. – ISSN 1364-503X0962-84360080-4622
- [Collinet und Lecuit 2021] COLLINET, Claudio ; LECUIT, Thomas: Programmed and self-organized flow of information during morphogenesis. In: *Nature Reviews Molecular Cell Biology* 22 (2021), April, Nr. 4, S. 245–265. – URL <https://www.nature.com/articles/s41580-020-00318-6>. – Zugriffsdatum: 2024-08-26. – ISSN 1471-0080
- [Connor u.a. 2015] CONNOR, A. J. ; NOWAK, Radosław P. ; LORENZON, E. ; THOMAS, Markus ; HERTING, F. ; HOERT, Stefan ; QUAISER, Tom ; SHOCHAT, E. ; PITT-FRANCIS, J. ; COOPER, Jonathan ; MAINI, P. ; BYRNE, H.: An integrated approach to quantitative modelling in angiogenesis research. In: *Journal of The Royal Society Interface* 12 (2015). – URL <https://consensus.app/papers/integrated-approach-modelling-angiogenesis-research-connor/0d838b388d255567b36652e5a33a98b8/>. – Zugriffsdatum: 2024-03-03
- [Cooper u.a. 2010] COOPER, M. ; TANAKA, Martin L. ; PURI, I. K.: Coupled mathematical model of tumorigenesis and angiogenesis in vascular tumours. In: *Cell Proliferation* 43 (2010). – URL <https://consensus.app/papers/coupled-model-tumorigenesis-angiogenesis-vascular-cooper/8dd804e6a10c51e084bcb28451d1cc98/>. – Zugriffsdatum: 2024-03-02
- [Crawshaw u.a. 2023] CRAWSHAW, Jessica R. ; FLEGG, J. ; BERNABEU, M. ; OSBORNE, J.: Mathematical models of developmental vascular remodelling: A review. In: *PLOS Computational Biology* 19 (2023). – URL <https://consensus.app/papers/models-developmental-remodelling-review-crawshaw/15c1d1d3a7ef55dbbd5167b2a576258a/>. – Zugriffsdatum: 2024-03-02
- [Deno u.a. 1983] DENO, D. C. ; SABA, T. M. ; LEWIS, E. P.: Kinetics of endogenously labeled plasma fibronectin: incorporation into tissues. In: *The American Journal of Physiology* 245 (1983), Oktober, Nr. 4, S. R564–575. – ISSN 0002-9513
- [Duh u.a. 1997] DUH, E. J. ; KING, G. L. ; AIELLO, L. P.: Identification of a VEGF receptor (KDR/FLK) promoter element which binds an endothelial cell-specific protein conferring endothelial selective expression. In: *Investigative Ophthalmology and Visual Science* 38 (1997), Nr. 4, S. S242. – ISSN 0146-0404
- [Dumont u.a. 1994] DUMONT, D. J. ; GRADWOHL, G. ; FONG, G. H. ; PURI, M. C. ; GERTSENSTEIN, M. ; AUERBACH, A. ; BREITMAN, M. L.: Dominant-negative and targeted null mutations in the endothelial receptor tyrosine kinase, tek, reveal a critical role in vasculogenesis of the embryo. In: *Genes & Development* 8 (1994), August, Nr. 16, S. 1897–1909. – ISSN 0890-9369

- [Edelstein-Keshet 2005] EDELSTEIN-KESHET, Leah: *Mathematical models in biology*. SIAM, 2005
- [Edelstein-Keshet und Ermentrout 1989] EDELSTEIN-KESHET, Leah ; ERMENTROUT, Bard: Models for branching networks in two dimensions. In: *SIAM Journal on Applied Mathematics* 49 (1989), Nr. 4, S. 1136–1157
- [Edelstein-Keshet und Ermentrout 1990a] EDELSTEIN-KESHET, Leah ; ERMENTROUT, G B.: Contact response of cells can mediate morphogenetic pattern formation. In: *Differentiation* 45 (1990), Nr. 3, S. 147–159
- [Edelstein-Keshet und Ermentrout 1990b] EDELSTEIN-KESHET, Leah ; ERMENTROUT, G B.: Models for contact-mediated pattern formation: cells that form parallel arrays. In: *Journal of mathematical biology* 29 (1990), S. 33–58
- [Edelstein-Keshet und Ermentrout 2001] EDELSTEIN-KESHET, Leah ; ERMENTROUT, G B.: A model for actin-filament length distribution in a lamellipod. In: *Journal of mathematical biology* 43 (2001), Nr. 4, S. 325–355
- [Ermentrout und Edelstein-Keshet 1993] ERMENTROUT, G. B. ; EDELSTEIN-KESHET, L.: Cellular automata approaches to biological modeling. In: *Journal of Theoretical Biology* 160 (1993), Januar, Nr. 1, S. 97–133. – ISSN 0022-5193
- [Everitt u. a. 1996] EVERITT, E. A. ; MALIK, A. B. ; HENDEY, B.: Fibronectin enhances the migration rate of human neutrophils in vitro. In: *Journal of Leukocyte Biology* 60 (1996), August, Nr. 2, S. 199–206. – ISSN 0741-5400
- [Folarin u. a. 2010] FOLARIN, A. A. ; KONERDING, M. A. ; TIMONEN, J. ; NAGL, S. ; PEDLEY, R. B.: Three-dimensional analysis of tumour vascular corrosion casts using stereoinaging and micro-computed tomography. In: *Microvascular Research* 80 (2010), Juli, Nr. 1, S. 89–98. – URL <https://www.sciencedirect.com/science/article/pii/S002628621000052X>. – Zugriffsdatum: 2024-01-21. – ISSN 0026-2862
- [Folkman 1985] FOLKMAN, J.: Tumor angiogenesis. In: *Advances in Cancer Research* 43 (1985), S. 175–203. – ISSN 0065-230X
- [Folkman 1995] FOLKMAN, J.: Angiogenesis in cancer, vascular, rheumatoid and other disease. In: *Nature Medicine* 1 (1995), Januar, Nr. 1, S. 27–31. – ISSN 1078-8956
- [Folkman und Klagsbrun 1987] FOLKMAN, J. ; KLAGSBRUN, M.: Angiogenic factors. In: *Science (New York, N.Y.)* 235 (1987), Januar, Nr. 4787, S. 442–447. – ISSN 0036-8075
- [Folkman 1971] FOLKMAN, Judah: Tumor Angiogenesis: Therapeutic Implications. In: *New England Journal of Medicine* 285 (1971), November, Nr. 21, S. 1182–1186. – URL <https://doi.org/10.1056/NEJM197111182852108>. – Zugriffsdatum: 2024-01-21. – ISSN 0028-4793
- [Fong u. a. 1995] FONG, G. H. ; ROSSANT, J. ; GERTSENSTEIN, M. ; BREITMAN, M. L.: Role of the Flt-1 receptor tyrosine kinase in regulating the assembly of vascular endothelium. In: *Nature* 376 (1995), Juli, Nr. 6535, S. 66–70. – ISSN 0028-0836
- [Ghosh u. a. 2015] GHOSH, Samik ; KIM, Y. R. ; FLEGG, J. ; MENON, Shakti N. ; MAINI, P. ; MCELWAIN, D.: On the mathematical modeling of wound healing angiogenesis in skin as a reaction-transport process. In: *Frontiers in Physiology* 6 (2015). – URL

- <https://consensus.app/papers/modeling-wound-healing-angiogenesis-skin-ghosh/d1ad44d139c05acb9eec3082a14420b1/>. – Zugriffsdatum: 2024-03-02
- [Gimbrone u. a. 1974] GIMBRONE, Michael A. ; COTRAN, Ramzi S. ; LEAPMAN, Stephen B. ; FOLKMAN, Judah: Tumor Growth and Neovascularization: An Experimental Model Using the Rabbit Cornea2. In: *JNCI: Journal of the National Cancer Institute* 52 (1974), Februar, Nr. 2, S. 413–427. – URL <https://doi.org/10.1093/jnci/52.2.413>. – Zugriffsdatum: 2024-06-12. – ISSN 0027-8874
- [Graham und Lala 1992] GRAHAM, C. H. ; LALA, P. K.: Mechanisms of placental invasion of the uterus and their control. In: *Biochemistry and Cell Biology = Biochimie Et Biologie Cellulaire* 70 (1992), Nr. 10-11, S. 867–874. – ISSN 0829-8211
- [Grattan-Guinness 2008] GRATTAN-GUINNESS, Ivor: Solving wigner’s mystery: The reasonable (though perhaps limited) effectiveness of mathematics in the natural sciences. In: *The Mathematical Intelligencer* 30 (2008), Juni, Nr. 3, S. 7–17. – URL <https://doi.org/10.1007/BF02985373>. – Zugriffsdatum: 2024-03-23. – ISSN 0343-6993
- [Grogan u. a. 2017] GROGAN, James A. ; CONNOR, Anthony J. ; MARKELC, Bostjan ; MUSCHEL, Ruth J. ; MAINI, Philip K. ; BYRNE, Helen M. ; PITT-FRANCIS, Joe M.: Microvessel Chaste: An Open Library for Spatial Modeling of Vascularized Tissues. In: *Biophysical Journal* 112 (2017), Mai, Nr. 9, S. 1767–1772. – URL <https://www.sciencedirect.com/science/article/pii/S0006349517303843>. – Zugriffsdatum: 2024-01-21. – ISSN 0006-3495
- [Gupta und Qin 2003] GUPTA, Manoj K. ; QIN, Ren-Yi: Mechanism and its regulation of tumor-induced angiogenesis. In: *World Journal of Gastroenterology : WJG* 9 (2003), Juni, Nr. 6, S. 1144–1155. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4611774/>. – Zugriffsdatum: 2024-01-21. – ISSN 1007-9327
- [Hadjicharalambous u. a. 2021] HADJICHARALAMBOUS, Myrianthi ; WIJERATNE, Peter A. ; VAVOURAKIS, Vasileios: From tumour perfusion to drug delivery and clinical translation of in silico cancer models. In: *Methods* 185 (2021), Januar, S. 82–93. – URL <https://www.sciencedirect.com/science/article/pii/S1046202319302129>. – Zugriffsdatum: 2024-01-21. – ISSN 1046-2023
- [Hamming 1980] HAMMING, R. W.: The Unreasonable Effectiveness of Mathematics. In: *The American Mathematical Monthly* 87 (1980), Nr. 2, S. 81–90. – URL <https://www.jstor.org/stable/2321982>. – Zugriffsdatum: 2024-03-23. – ISSN 0002-9890
- [Hanahan 1997] HANAHAN, D.: Signaling vascular morphogenesis and maintenance. In: *Science (New York, N.Y.)* 277 (1997), Juli, Nr. 5322, S. 48–50. – ISSN 0036-8075
- [Hannezo u. a. 2017] HANNEZO, Edouard ; SCHEELE, Colinda L. G. J. ; MOAD, Mohammad ; DROGO, Nicholas ; HEER, Rakesh ; SAMPOGNA, Rosemary V. ; RHEENEN, Jacco van ; SIMONS, Benjamin D.: A Unifying Theory of Branching Morphogenesis. In: *Cell* 171 (2017), September, Nr. 1, S. 242–255.e27. – URL <https://www.sciencedirect.com/science/article/pii/S0092867417309510>. – Zugriffsdatum: 2024-08-21. – ISSN 0092-8674
- [Hasan u. a. 2004] HASAN, J. ; SHNYDER, S. ; BIBBY, M. ; DOUBLE, J. ; BICKNEL, R. ; JAYSON, G.: Quantitative Angiogenesis Assays in vivo – A Review. In: *Angiogenesis* 7 (2004), S. 1–16. – URL <https://consensus.app/papers/angiogenesis-assays-vivo-review-hasan/a633e139bbc55f17bfb6d5ce86ee244a/>. – Zugriffsdatum: 2024-03-02

- [Hatva u.a. 1995] HATVA, E. ; KAIPAINEN, A. ; MENTULA, P. ; JÄÄSKELÄINEN, J. ; PAETAU, A. ; HALTIA, M. ; ALITALO, K.: Expression of endothelial cell-specific receptor tyrosine kinases and growth factors in human brain tumors. In: *The American Journal of Pathology* 146 (1995), Februar, Nr. 2, S. 368–378. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1869858/>. – Zugriffsdatum: 2024-06-12. – ISSN 0002-9440
- [Hewett und Murray 1996] HEWETT, P. W. ; MURRAY, J. C.: Coexpression of flt-1, flt-4 and KDR in freshly isolated and cultured human endothelial cells. In: *Biochemical and Biophysical Research Communications* 221 (1996), April, Nr. 3, S. 697–702. – ISSN 0006-291X
- [Hu und Cai 2013] HU, Dan ; CAI, David: Adaptation and Optimization of Biological Transport Networks. In: *Physical Review Letters* 111 (2013), September, Nr. 13, S. 138701. – URL <https://link.aps.org/doi/10.1103/PhysRevLett.111.138701>. – Zugriffsdatum: 2024-08-27
- [Hynes 1989] HYNES, Richard O.: *Fibronectins*. 1990. New York, NY : Springer, Dezember 1989 (Springer Series in Molecular and Cell Biology)
- [Jafarnejad u.a. 2019] JAFARNEJAD, Mohammad ; ISMAIL, A. ; DUARTE, Delfim ; VYAS, Cian ; GHAHRAMANI, A. ; ZAWIEJA, David ; CELSO, Cristina ; POOLOGASUNDARAMPILLAI, Gowsihan ; JR, Moore: Quantification of the Whole Lymph Node Vasculature Based on Tomography of the Vessel Corrosion Casts. In: *Scientific Reports* 9 (2019), September
- [Jaffee 1978] JAFFEE: Synthesis of fibronectin by cultured human endothelial cells. In: *The Journal of Experimental Medicine* 147 (1978), Juni, Nr. 6, S. 1779–1791. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2184307/>. – Zugriffsdatum: 2024-06-12. – ISSN 0022-1007
- [Johansson u.a. 1987] JOHANSSON, S. ; GUSTAFSON, S. ; PERTOFT, H.: Identification of a fibronectin receptor specific for rat liver endothelial cells. In: *Experimental Cell Research* 172 (1987), Oktober, Nr. 2, S. 425–431. – ISSN 0014-4827
- [Jones und Sleeman 2006] JONES, Pamela F. ; SLEEMAN, Brian D.: Angiogenesis - understanding the mathematical challenge. In: *Angiogenesis* 9 (2006), Nr. 3, S. 127–138. – ISSN 0969-6970
- [Kannan u.a. 2018] KANNAN, Pavitra ; KRETZSCHMAR, Warren W. ; WINTER, Helen ; WARREN, Daniel ; BATES, Russell ; ALLEN, Philip D. ; SYED, Nigar ; IRVING, Benjamin ; PAPIEZ, Bartlomiej W. ; KAEPLER, Jakob ; MARKELC, Bosjtan ; KINCESH, Paul ; GILCHRIST, Stuart ; SMART, Sean ; SCHNABEL, Julia A. ; MAUGHAN, Tim ; HARRIS, Adrian L. ; MUSCHEL, Ruth J. ; PARTRIDGE, Mike ; SHARMA, Ricky A. ; KERSEMANS, Veerle: Functional Parameters Derived from Magnetic Resonance Imaging Reflect Vascular Morphology in Preclinical Tumors and in Human Liver Metastases. In: *Clinical Cancer Research* 24 (2018), Oktober, Nr. 19, S. 4694–4704. – URL <https://doi.org/10.1158/1078-0432.CCR-18-0033>. – Zugriffsdatum: 2024-01-21. – ISSN 1078-0432
- [Kappel u.a. 1999] KAPPEL, A. ; RÖNICKE, V. ; DAMERT, A. ; FLAMME, I. ; RISAU, W. ; BREIER, G.: Identification of vascular endothelial growth factor (VEGF) receptor-2 (Flk-1) promoter/enhancer sequences sufficient for angioblast and endothelial cell-specific transcription in transgenic mice. In: *Blood* 93 (1999), Juni, Nr. 12, S. 4284–4292. – ISSN 0006-4971
- [Khan u.a. 2014] KHAN, G. J. ; SHAKIR, Lubna ; KHAN, Sara ; NAEEM, H. S. ; OMER, M.: Assessment Methods of Angiogenesis and Present Approaches for Its Quantification. In: *Cancer Research* 2 (2014). – URL <https://doi.org/10.1155/2014/123456>. – Zugriffsdatum: 2024-01-21. – ISSN 2161-3304

- [//consensus.app/papers/assessment-methods-angiogenesis-present-approaches-khan/f73789f2ecf0541595b7c59887fdf599/](https://consensus.app/papers/assessment-methods-angiogenesis-present-approaches-khan/f73789f2ecf0541595b7c59887fdf599/). – Zugriffsdatum: 2024-03-02
- [Kidoya u. a. 2008] KIDOYA, Hiroyasu ; UENO, Masaya ; YAMADA, Yoshihiro ; MOCHIZUKI, Naoki ; NAKATA, Mitsugu ; YANO, Takashi ; FUJII, Ryo ; TAKAKURA, Nobuyuki: Spatial and temporal role of the apelin/APJ system in the caliber size regulation of blood vessels during angiogenesis. In: *The EMBO Journal* 27 (2008), Februar, Nr. 3, S. 522–534. – URL <https://www.embopress.org/doi/full/10.1038/sj.emboj.7601982>. – Zugriffsdatum: 2024-08-21. – ISSN 0261-4189
- [Kimura u. a. 1996] KIMURA, H ; BRAUN, R D. ; ONG, E T. ; HSU, R ; SECOMB, T W. ; PAPAHDJOPOULOS, D ; HONG, K ; DEWHIRST, M W.: Fluctuations in red cell flux in tumor microvessels can lead to transient hypoxia and reoxygenation in tumor parenchyma. In: *Cancer Res.* 56 (1996), Dezember, Nr. 23, S. 5522–5528
- [Konerding u. a. 2001] KONERDING, M. A. ; FAIT, E. ; GAUMANN, A.: 3D microvascular architecture of pre-cancerous lesions and invasive carcinomas of the colon. In: *British Journal of Cancer* 84 (2001), Mai, Nr. 10, S. 1354–1362. – URL <https://www.nature.com/articles/6691809>. – Zugriffsdatum: 2024-01-21. – ISSN 1532-1827
- [Konerding u. a. 1999] KONERDING, M. A. ; MALKUSCH, W. ; KLAPTHOR, B. ; ACKERN, C. v. ; FAIT, E. ; HILL, S. A. ; PARKINS, C. ; CHAPLIN, D. J. ; PRESTA, M. ; DENEKAMP, J.: Evidence for characteristic vascular patterns in solid tumours: quantitative studies using corrosion casts. In: *British Journal of Cancer* 80 (1999), Mai, Nr. 5, S. 724–732. – URL <https://www.nature.com/articles/6690416>. – Zugriffsdatum: 2024-01-21. – ISSN 1532-1827
- [Kopylova u. a. 2018] KOPYLOVA, V. ; BORONOVSKIY, S. ; NARTISSOV, Y.: Tree topology analysis of the arterial system model. In: *Journal of Physics: Conference Series* 1141 (2018). – URL <https://consensus.app/papers/tree-topology-analysis-system-model-kopylova/9915fb3edc1359f498296336de758dd4/>. – Zugriffsdatum: 2024-03-02
- [Köry u. a. 2024] KÖRY, Jakub ; NARAIN, Vedang ; STOLZ, Bernadette J. ; KAEPLER, Jakob ; MARKELC, Bostjan ; MUSCHEL, Ruth J. ; MAINI, Philip K. ; PITT-FRANCIS, Joe M. ; BYRNE, Helen M.: Enhanced perfusion following exposure to radiotherapy: A theoretical investigation. In: *PLOS Computational Biology* 20 (2024), Februar, Nr. 2, S. e1011252. – URL <https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1011252>. – Zugriffsdatum: 2024-03-09. – ISSN 1553-7358
- [Lapidus und Schiller 1976] LAPIDUS, I. R. ; SCHILLER, R.: Model for the chemotactic response of a bacterial population. In: *Biophysical Journal* 16 (1976), Juli, Nr. 7, S. 779–789. – ISSN 0006-3495
- [Lauffenburger u. a. 1984] LAUFFENBURGER, D. ; KENNEDY, C. R. ; ARIS, R.: Traveling bands of chemotactic bacteria in the context of population growth. In: *Bulletin of Mathematical Biology* 46 (1984), Januar, Nr. 1, S. 19–40. – URL <https://www.sciencedirect.com/science/article/pii/S0092824084800336>. – Zugriffsdatum: 2024-06-12. – ISSN 0092-8240
- [Lesk 2000] LESK, Arthur M.: The unreasonable effectiveness of mathematics in molecular biology. In: *The Mathematical Intelligencer* 22 (2000), März, Nr. 2, S. 28–37. – URL <https://doi.org/10.1007/BF03025372>. – Zugriffsdatum: 2024-03-23. – ISSN 0343-6993

- [Li und Harris 2005] LI, Ji-Liang ; HARRIS, Adrian L.: Notch signaling from tumor cells: A new mechanism of angiogenesis. In: *Cancer Cell* 8 (2005), Juli, Nr. 1, S. 1–3. – URL <https://www.sciencedirect.com/science/article/pii/S1535610805001996>. – Zugriffsdatum: 2024-01-21. – ISSN 1535-6108
- [Li u. a. 2002] LI, Song ; BUTLER, Peter ; WANG, Yingxiao ; HU, Yingli ; HAN, Dong C. ; USAMI, Shunichi ; GUAN, Jun-Lin ; CHIEN, Shu: The role of the dynamics of focal adhesion kinase in the mechanotaxis of endothelial cells. In: *Proceedings of the National Academy of Sciences* 99 (2002), März, Nr. 6, S. 3546–3551. – URL <https://www.pnas.org/doi/full/10.1073/pnas.052018099>. – Zugriffsdatum: 2024-01-21
- [Liotta u. a. 1983] LIOTTA, L. A. ; RAO, C. N. ; BARSKY, S. H.: Tumor invasion and the extracellular matrix. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 49 (1983), Dezember, Nr. 6, S. 636–649. – ISSN 0023-6837
- [Liotta u. a. 1977] LIOTTA, L. A. ; SAIDEL, G. M. ; KLEINERMAN, J.: Diffusion model of tumor vascularization and growth. In: *Bulletin of Mathematical Biology* 39 (1977), Nr. 1, S. 117–128. – ISSN 0092-8240
- [Lugano u. a. 2020] LUGANO, Roberta ; RAMACHANDRAN, Mohanraj ; DIMBERG, Anna: Tumor angiogenesis: causes, consequences, challenges and opportunities. In: *Cellular and Molecular Life Sciences* 77 (2020), Mai, Nr. 9, S. 1745–1770. – URL <https://doi.org/10.1007/s00018-019-03351-7>. – Zugriffsdatum: 2024-01-21. – ISSN 1420-9071
- [Macarak u. a. 1978] MACARAK, Edward J. ; KIRBY, Edward ; KIRK, Theresa ; KEFALIDES, Nicholas A.: Synthesis of Cold-Insoluble Globulin by Cultured Calf Endothelial Cells. In: *Proceedings of the National Academy of Sciences of the United States of America* 75 (1978), Nr. 6, S. 2621–2625. – URL <https://www.jstor.org/stable/68293>. – Zugriffsdatum: 2024-06-12. – ISSN 0027-8424
- [Mandriota u. a. 1995] MANDRIOTA, S. J. ; SEGHEZZI, G. ; VASSALLI, J. D. ; FERRARA, N. ; WASI, S. ; MAZZIERI, R. ; MIGNATTI, P. ; PEPPER, M. S.: Vascular endothelial growth factor increases urokinase receptor expression in vascular endothelial cells. In: *The Journal of Biological Chemistry* 270 (1995), April, Nr. 17, S. 9709–9716. – ISSN 0021-9258
- [Maringanti u. a. 2021] MARINGANTI, Ranganath ; MEIJER, Elana ; BRANDT, Maarten M. ; DUNCKER, Dirk J. ; CHENG, Caroline: Contributions of Wall Stretch and Shear Stress to Vascular Regulation: Molecular Mechanisms of Homeostasis and Expansion. Cham : Springer International Publishing, 2021, S. 21–46. – URL https://doi.org/10.1007/978-3-030-63164-2_2. – Zugriffsdatum: 2024-08-21. – ISBN 9783030631642
- [McCarthy und Furcht 1984] MCCARTHY, J. B. ; FURCHT, L. T.: Laminin and fibronectin promote the haptotactic migration of B16 mouse melanoma cells in vitro. In: *The Journal of Cell Biology* 98 (1984), April, Nr. 4, S. 1474–1480. – ISSN 0021-9525
- [McDougall u. a. 2006] MCDUGALL, S. ; ANDERSON, A. ; CHAPLAIN, M.: Mathematical modelling of dynamic adaptive tumour-induced angiogenesis: clinical implications and therapeutic targeting strategies. In: *Journal of theoretical biology* 241 3 (2006), S. 564–89. – URL <https://consensus.app/papers/modelling-tumourinduced-angiogenesis-implications-mcdougall/d43a720d3c1659a68fb7b56dee0798ec/>. – Zugriffsdatum: 2024-03-02

- [Meinhardt 1976] MEINHARDT, H.: Morphogenesis of lines and nets. In: *Differentiation; Research in Biological Diversity* 6 (1976), August, Nr. 2, S. 117–123. – ISSN 0301-4681
- [Meinhardt 1982] MEINHARDT, Hans: *Models of Biological Pattern Formation* (Academic Press, London, 1982). Mai 1982
- [Metzcar u. a. 2019] METZCAR, John ; WANG, Yafei ; HEILAND, Randy ; MACKLIN, Paul: A Review of Cell-Based Computational Modeling in Cancer Biology. In: *JCO Clinical Cancer Informatics* (2019), Dezember, Nr. 3, S. 1–13. – URL <https://ascopubs.org/doi/10.1200/CCI.18.00069>. – Zugriffsdatum: 2024-01-21
- [Millauer u. a. 1993] MILLAUER, B. ; WIZIGMANN-VOOS, S. ; SCHNÜRCH, H. ; MARTINEZ, R. ; MØLLER, N. P. ; RISAU, W. ; ULLRICH, A.: High affinity VEGF binding and developmental expression suggest Flk-1 as a major regulator of vasculogenesis and angiogenesis. In: *Cell* 72 (1993), März, Nr. 6, S. 835–846. – ISSN 0092-8674
- [Mogilner und Edelstein-Keshet 1995] MOGILNER, Alex ; EDELSTEIN-KESHET, Leah: Selecting a common direction: I. How orientational order can arise from simple contact responses between interacting cells. In: *Journal of mathematical biology* 33 (1995), S. 619–660
- [Mogilner 1995] MOGILNER, Alexander: *Modelling spatio-angular patterns in cell biology*, University of British Columbia, Dissertation, 1995
- [Mogilner und Edelstein-Keshet 1999] MOGILNER, Alexander ; EDELSTEIN-KESHET, Leah: A non-local model for a swarm. In: *Journal of mathematical biology* 38 (1999), S. 534–570
- [Muthukkaruppan u. a. 1982] MUTHUKKARUPPAN, V. R. ; KUBAI, L. ; AUERBACH, R.: Tumor-induced neovascularization in the mouse eye. In: *Journal of the National Cancer Institute* 69 (1982), September, Nr. 3, S. 699–708. – ISSN 0027-8874
- [Nerlich und Schleicher 1991] NERLICH, A. ; SCHLEICHER, E.: Immunohistochemical localization of extracellular matrix components in human diabetic glomerular lesions. In: *The American Journal of Pathology* 139 (1991), Oktober, Nr. 4, S. 889–899. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1886324/>. – Zugriffsdatum: 2024-06-12. – ISSN 0002-9440
- [Nickoloff 2000] NICKOLOFF, B.: Characterization of lymphocyte-dependent angiogenesis using a SCID mouse: human skin model of psoriasis. In: *The journal of investigative dermatology. Symposium proceedings* 5 1 (2000), S. 67–73. – URL <https://consensus.app/papers/characterization-lymphocytedependent-angiogenesis-nickoloff/4cf8d8e3578d59afb8c1e9d6043e9fde/>. – Zugriffsdatum: 2024-03-02
- [Nowak-Sliwinska u. a. 2018] NOWAK-SLIWINSKA, Patrycja ; ALITALO, Kari ; ALLEN, Elizabeth ; ANISIMOV, Andrey ; APLIN, Alfred C. ; AUERBACH, Robert ; AUGUSTIN, Hellmut G. ; BATES, David O. ; BEIJNUM, Judy R. van ; BENDER, R. Hugh F. ; BERGERS, Gabriele ; BIKFALVI, Andreas ; BISCHOFF, Joyce ; BÖCK, Barbara C. ; BROOKS, Peter C. ; BUSSOLINO, Federico ; CAKIR, Bertan ; CARMELIET, Peter ; CASTRANOVA, Daniel ; CIMPEAN, Anca M. ; CLEAVER, Ondine ; COUKOS, George ; DAVIS, George E. ; DE PALMA, Michele ; DIMBERG, Anna ; DINGS, Ruud P. M. ; DJONOV, Valentin ; DUDLEY, Andrew C. ; DUFTON, Neil P. ; FENDT, Sarah-Maria ; FERRARA, Napoleone ; FRUTTIGER, Marcus ; FUKUMURA, Dai ; GHESQUIÈRE, Bart ; GONG, Yan ; GRIFFIN, Robert J. ; HARRIS, Adrian L. ; HUGHES, Christopher C. W. ; HULTGREN, Nan W. ; IRUELA-ARISPE, M. L. ; IRVING, Melita ; JAIN, Rakesh K. ; KALLURI, Raghu ;

- KALUCKA, Joanna ; KERBEL, Robert S. ; KITAJEWSKI, Jan ; KLAASSEN, Ingeborg ; KLEINMANN, Hynda K. ; KOOLWIJK, Pieter ; KUCZYNSKI, Elisabeth ; KWAK, Brenda R. ; MARIEN, Koen ; MELERO-MARTIN, Juan M. ; MUNN, Lance L. ; NICOSIA, Roberto F. ; NOEL, Agnes ; NURRO, Jussi ; OLSSON, Anna-Karin ; PETROVA, Tatiana V. ; PIETRAS, Kristian ; PILI, Roberto ; POLLARD, Jeffrey W. ; POST, Mark J. ; QUAX, Paul H. A. ; RABINOVICH, Gabriel A. ; RAICA, Marius ; RANDI, Anna M. ; RIBATTI, Domenico ; RUEGG, Curzio ; SCHLINGEMANN, Reinier O. ; SCHULTE-MERKER, Stefan ; SMITH, Lois E. H. ; SONG, Jonathan W. ; STACKER, Steven A. ; STALIN, Jimmy ; STRATMAN, Amber N. ; VELDE, Maureen Van de ; HINSBERGH, Victor W. M. van ; VERMEULEN, Peter B. ; WALTENBERGER, Johannes ; WEINSTEIN, Brant M. ; XIN, Hong ; YETKIN-ARIK, Bahar ; YLA-HERTTUALA, Seppo ; YODER, Mervin C. ; GRIFFIOEN, Arjan W.: Consensus guidelines for the use and interpretation of angiogenesis assays. In: *Angiogenesis* 21 (2018), August, Nr. 3, S. 425–532. – ISSN 1573-7209
- [Nyberg u. a. 2005] NYBERG, P. ; XIE, Liang ; KALLURI, R.: Endogenous inhibitors of angiogenesis. In: *Cancer research* 65 10 (2005), S. 3967–79. – URL <https://consensus.app/papers/inhibitors-angiogenesis-nyberg/c8d04e4d75375d60a58dcc8bb36bc544/>. – Zugriffsdatum: 2024-03-02
- [Oh u. a. 1981] OH, E ; PIERSCHBACHER, M ; RUOSLAHTI, E: Deposition of plasma fibronectin in tissues. In: *Proceedings of the National Academy of Sciences of the United States of America* 78 (1981), Mai, Nr. 5, S. 3218–3221. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC319532/>. – Zugriffsdatum: 2024-06-13. – ISSN 0027-8424
- [Olsen u. a. 1997] OLSEN, L. ; SHERRATT, J. A. ; MAINI, P. K. ; ARNOLD, F.: A mathematical model for the capillary endothelial cell-extracellular matrix interactions in wound-healing angiogenesis. In: *IMA journal of mathematics applied in medicine and biology* 14 (1997), Dezember, Nr. 4, S. 261–281. – ISSN 0265-0746
- [Olsen und Siegelmann 2013] OLSEN, Megan M. ; SIEGELMANN, H.: Multiscale Agent-based Model of Tumor Angiogenesis. (2013), S. 1016–1025. – URL <https://consensus.app/papers/multiscale-agentbased-model-tumor-angiogenesis-olsen/4a2e14c0a7275b40a99f8401168c65d8/>. – Zugriffsdatum: 2024-03-02
- [Orme und Chaplain 1996] ORME, M. E. ; CHAPLAIN, M. A.: A mathematical model of the first steps of tumour-related angiogenesis: capillary sprout formation and secondary branching. In: *IMA journal of mathematics applied in medicine and biology* 13 (1996), Juni, Nr. 2, S. 73–98. – ISSN 0265-0746
- [Orme und Chaplain 1997] ORME, M. E. ; CHAPLAIN, M. A.: Two-dimensional models of tumour angiogenesis and anti-angiogenesis strategies. In: *IMA journal of mathematics applied in medicine and biology* 14 (1997), September, Nr. 3, S. 189–205. – ISSN 0265-0746
- [Paku und Paweletz 1991] PAKU, S. ; PAWELETZ, N.: First steps of tumor-related angiogenesis. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 65 (1991), September, Nr. 3, S. 334–346. – ISSN 0023-6837
- [Patterson u. a. 1996] PATTERSON, C. ; PERRELLA, M. A. ; ENDEGE, W. O. ; YOSHIKUMI, M. ; LEE, M. E. ; HABER, E.: Downregulation of vascular endothelial growth factor receptors by tumor necrosis factor-alpha in cultured human vascular endothelial cells. In: *The Journal of Clinical Investigation* 98 (1996), Juli, Nr. 2, S. 490–496. – ISSN 0021-9738

- [Paweletz und Knierim 1989] PAWELETZ, N. ; KNIERIM, M.: Tumor-related angiogenesis. In: *Critical Reviews in Oncology/Hematology* 9 (1989), Nr. 3, S. 197–242. – ISSN 1040-8428
- [Pegon u. a. 2019] PEGON, Paul ; SANTAMBROGIO, Filippo ; XIA, Qinglan: A fractal shape optimization problem in branched transport. In: *J. Math. Pures Appl.* 123 (2019), März, S. 244–269
- [Peirce 2008] PEIRCE, S.: Computational and Mathematical Modeling of Angiogenesis. In: *Microcirculation* 15 (2008). – URL <https://consensus.app/papers/computational-mathematical-modeling-angiogenesis-peirce/b868cc1948fc5b53a1ff58df257bffe2/>. – Zugriffsdatum: 2024-03-02
- [Peirce u. a. 2012] PEIRCE, S. ; GABHANN, F. M. ; BAUTCH, V.: Integration of experimental and computational approaches to sprouting angiogenesis. In: *Current Opinion in Hematology* 19 (2012). – URL <https://consensus.app/papers/integration-approaches-sprouting-angiogenesis-peirce/01b4a50a54bf5dcbb096cb1a7667e60f/>. – Zugriffsdatum: 2024-03-02
- [Perfahl u. a. 2017] PERFAHL, Holger ; HUGHES, Barry D. ; ALARCÓN, Tomás ; MAINI, Philip K. ; LLOYD, Mark C. ; REUSS, Matthias ; BYRNE, Helen M.: 3D hybrid modelling of vascular network formation. In: *Journal of Theoretical Biology* 414 (2017), Februar, S. 254–268. – URL <https://www.sciencedirect.com/science/article/pii/S0022519316303782>. – Zugriffsdatum: 2024-01-21. – ISSN 0022-5193
- [Pettet u. a. 1996] PETTET, G. ; CHAPLAIN, M. A. ; McELWAIN, D. L. ; BYRNE, H. M.: On the rôle of angiogenesis in wound healing. In: *Proceedings. Biological Sciences* 263 (1996), November, Nr. 1376, S. 1487–1493. – ISSN 0962-8452
- [Pries und Secomb 2014] PRIES, Axel R. ; SECOMB, Timothy W.: Making Microvascular Networks Work: Angiogenesis, Remodeling, and Pruning. In: *Physiology* 29 (2014), November, Nr. 6, S. 446–455. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4280154/>. – Zugriffsdatum: 2024-08-21. – ISSN 1548-9213
- [Relf u. a. 1997] RELF, M. ; LEJEUNE, S. ; SCOTT, P. A. ; FOX, S. ; SMITH, K. ; LEEK, R. ; MOGHADDAM, A. ; WHITEHOUSE, R. ; BICKNELL, R. ; HARRIS, A. L.: Expression of the angiogenic factors vascular endothelial cell growth factor, acidic and basic fibroblast growth factor, tumor growth factor beta-1, platelet-derived endothelial cell growth factor, placenta growth factor, and pleiotrophin in human primary breast cancer and its relation to angiogenesis. In: *Cancer Research* 57 (1997), März, Nr. 5, S. 963–969. – ISSN 0008-5472
- [Ribatti 2008] RIBATTI, Domenico: Judah Folkman, a pioneer in the study of angiogenesis. In: *Angiogenesis* 11 (2008), März, Nr. 1, S. 3–10. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2268723/>. – Zugriffsdatum: 2024-06-12. – ISSN 0969-6970
- [Rocco u. a. 1987] ROCCO, M. ; INFUSINI, E. ; DAGA, M. G. ; GOGIOSO, L. ; CUNIBERTI, C.: Models of fibronectin. In: *The EMBO journal* 6 (1987), August, Nr. 8, S. 2343–2349. – ISSN 0261-4189
- [Rodgers u. a. 1984] RODGERS, Griffin P. ; SCHECHTER, Alan N. ; NOGUCHI, Constance T. ; KLEIN, Harvey G. ; NIENHUIS, Arthur W. ; BONNER, Robert F.: Periodic Microcirculatory Flow in Patients with Sick-Cell Disease. In: *New England Journal of Medicine* 311

- (1984), Dezember, Nr. 24, S. 1534–1538. – URL <https://www.nejm.org/doi/full/10.1056/NEJM198412133112403>. – Zugriffsdatum: 2024-08-23. – ISSN 0028-4793
- [Ronellenfitch und Katifori 2016] RONELLENFITSCH, Henrik ; KATIFORI, Eleni: Global Optimization, Local Adaptation, and the Role of Growth in Distribution Networks. In: *Physical Review Letters* 117 (2016), September, Nr. 13, S. 138301. – URL <https://link.aps.org/doi/10.1103/PhysRevLett.117.138301>. – Zugriffsdatum: 2024-08-27
- [Roose u. a. 2007] ROOSE, T. ; CHAPMAN, S. ; MAINI, P.: Mathematical Models of Avascular Tumor Growth. In: *SIAM Rev.* 49 (2007), S. 179–208. – URL <https://consensus.app/papers/models-avascular-tumor-growth-roose/a77e9bfd612b51a2b233feb7b5b0aa0d/>. – Zugriffsdatum: 2024-03-02
- [Rupnick u. a. 1988] RUPNICK, M. A. ; STOKES, C. L. ; WILLIAMS, S. K. ; LAUFFENBURGER, D. A.: Quantitative analysis of random motility of human microvessel endothelial cells using a linear under-agarose assay. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 59 (1988), September, Nr. 3, S. 363–372. – ISSN 0023-6837
- [Saman u. a. 2020] SAMAN, Harman ; RAZA, Syed S. ; UDDIN, Shahab ; RASUL, Kakil: Inducing Angiogenesis, a Key Step in Cancer Vascularization, and Treatment Approaches. In: *Cancers* 12 (2020), Mai, Nr. 5, S. 1172. – URL <https://www.mdpi.com/2072-6694/12/5/1172>. – Zugriffsdatum: 2024-01-21. – ISSN 2072-6694
- [Sato u. a. 1995] SATO, T. N. ; TOZAWA, Y. ; DEUTSCH, U. ; WOLBURG-BUCHHOLZ, K. ; FUJIWARA, Y. ; GENDRON-MAGUIRE, M. ; GRIDLEY, T. ; WOLBURG, H. ; RISAU, W. ; QIN, Y.: Distinct roles of the receptor tyrosine kinases Tie-1 and Tie-2 in blood vessel formation. In: *Nature* 376 (1995), Juli, Nr. 6535, S. 70–74. – ISSN 0028-0836
- [Scianna u. a. 2013] SCIANNA, M. ; BELL, C. G. ; PREZIOSI, L.: A review of mathematical models for the formation of vascular networks. In: *Journal of Theoretical Biology* 333 (2013), September, S. 174–209. – URL <https://www.sciencedirect.com/science/article/pii/S0022519313002117>. – Zugriffsdatum: 2024-01-21. – ISSN 0022-5193
- [Secomb 2021] SECOMB, Timothy W.: Hemodynamics and Vascular Remodeling. Cham : Springer International Publishing, 2021, S. 1–20. – URL https://doi.org/10.1007/978-3-030-63164-2_1. – Zugriffsdatum: 2024-08-21. – ISBN 9783030631642
- [Secomb u. a. 2012] SECOMB, Timothy W. ; DEWHIRST, Mark W. ; PRIES, Axel R.: Structural Adaptation of Normal and Tumour Vascular Networks. In: *Basic & Clinical Pharmacology & Toxicology* 110 (2012), Nr. 1, S. 63–69. – URL <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1742-7843.2011.00815.x>. – Zugriffsdatum: 2024-08-25. – ISSN 1742-7843
- [Sefidgar u. a. 2015] SEFIDGAR, M. ; SOLTANI, M. ; RAAHEMIFAR, K. ; SADEGHI, M. ; BAZMARA, H. ; BAZARGAN, M. ; MOUSAVI NAEENIAN, M.: Numerical modeling of drug delivery in a dynamic solid tumor microvasculature. In: *Microvascular Research* 99 (2015), Mai, S. 43–56. – URL <https://www.sciencedirect.com/science/article/pii/S0026286215000187>. – Zugriffsdatum: 2024-01-21. – ISSN 0026-2862
- [Sherratt und Murray 1990] SHERRATT, J. A. ; MURRAY, J. D.: Models of epidermal wound healing. In: *Proceedings. Biological Sciences* 241 (1990), Juli, Nr. 1300, S. 29–36. – ISSN 0962-8452

- [Sherratt 1994] SHERRATT, Jonathan A.: Chemotaxis and chemokinesis in eukaryotic cells: The keller-segel equations as an approximation to a detailed model. In: *Bulletin of Mathematical Biology* 56 (1994), Januar, Nr. 1, S. 129–146. – URL <https://www.sciencedirect.com/science/article/pii/S0092824005802083>. – Zugriffsdatum: 2024-06-12. – ISSN 0092-8240
- [Sholley u. a. 1984] SHOLLEY, M. M. ; FERGUSON, G. P. ; SEIBEL, H. R. ; MONTOR, J. L. ; WILSON, J. D.: Mechanisms of neovascularization. Vascular sprouting can occur without proliferation of endothelial cells. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 51 (1984), Dezember, Nr. 6, S. 624–634. – ISSN 0023-6837
- [Stepanova u. a. 2021] STEPANOVA, Daria ; BYRNE, Helen M. ; MAINI, Philip K. ; ALARCÓN, Tomás: A multiscale model of complex endothelial cell dynamics in early angiogenesis. In: *PLOS Computational Biology* 17 (2021), Januar, Nr. 1, S. e1008055. – URL <https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1008055>. – Zugriffsdatum: 2024-01-21. – ISSN 1553-7358
- [Stokes u. a. 1990] STOKES, C. L. ; RUPNICK, M. A. ; WILLIAMS, S. K. ; LAUFFENBURGER, D. A.: Chemotaxis of human microvessel endothelial cells in response to acidic fibroblast growth factor. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 63 (1990), November, Nr. 5, S. 657–668. – ISSN 0023-6837
- [Stokes und Lauffenburger 1991] STOKES, Cynthia L. ; LAUFFENBURGER, Douglas A.: Analysis of the roles of microvessel endothelial cell random motility and chemotaxis in angiogenesis. In: *Journal of Theoretical Biology* 152 (1991), Oktober, Nr. 3, S. 377–403. – URL <https://www.sciencedirect.com/science/article/pii/S0022519305802012>. – Zugriffsdatum: 2024-01-21. – ISSN 0022-5193
- [Tegmark 2008] TEGMARK, Max: The Mathematical Universe. In: *Foundations of Physics* 38 (2008), Februar, Nr. 2, S. 101–150. – URL <https://doi.org/10.1007/s10701-007-9186-9>. – Zugriffsdatum: 2024-03-23. – ISSN 1572-9516
- [Terranova u. a. 1985] TERRANOVA, V. P. ; DI FLORIO, R. ; LYALL, R. M. ; HIC, S. ; FRIESEL, R. ; MACIAG, T.: Human endothelial cells are chemotactic to endothelial cell growth factor and heparin. In: *The Journal of Cell Biology* 101 (1985), Dezember, Nr. 6, S. 2330–2334. – ISSN 0021-9525
- [Uçar u. a. 2023] UÇAR, Mehmet C. ; HANNEZO, Edouard ; TIILIKAINEN, Emmi ; LIAQAT, Inam ; JAKOBSSON, Emma ; NURMI, Harri ; VAAHTOMERI, Kari: Self-organized and directed branching results in optimal coverage in developing dermal lymphatic networks. In: *Nature Communications* 14 (2023), September, Nr. 1, S. 5878. – ISSN 2041-1723
- [Vavourakis u. a. 2017] VAVOURAKIS, Vasileios ; WIJERATNE, Peter A. ; SHIPLEY, Rebecca ; LOIZIDOU, Marilena ; STYLIANOPOULOS, Triantafyllos ; HAWKES, David J.: A Validated Multi-scale In-Silico Model for Mechano-sensitive Tumour Angiogenesis and Growth. In: *PLOS Computational Biology* 13 (2017), Januar, Nr. 1, S. e1005259. – URL <https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1005259>. – Zugriffsdatum: 2024-01-21. – ISSN 1553-7358
- [Vilanova u. a. 2017] VILANOVA, Guillermo ; COLOMINAS, Ignasi ; GOMEZ, Hector: A mathematical model of tumour angiogenesis: growth, regression and regrowth. In: *Journal of The Royal Society Interface* 14 (2017), Januar, Nr. 126, S. 20160918. – URL <https://royalsocietypublishing.org/doi/10.1098/rsif.2016.0918>. – Zugriffsdatum: 2024-01-21

- [Vlodavsky u.a. 1979] VLODAVSKY, I. ; JOHNSON, L. K. ; GREENBURG, G. ; GOSPODAROWICZ, D.: Vascular endothelial cells maintained in the absence of fibroblast growth factor undergo structural and functional alterations that are incompatible with their in vivo differentiated properties. In: *The Journal of Cell Biology* 83 (1979), November, Nr. 2 Pt 1, S. 468–486. – ISSN 0021-9525
- [Walpole u.a. 2015] WALPOLE, Joseph ; CHAPPELL, J. ; CLUCERU, J. ; GABHANN, F. M. ; BAUTCH, V. ; PEIRCE, S.: Agent-based model of angiogenesis simulates capillary sprout initiation in multicellular networks. In: *Integrative biology : quantitative biosciences from nano to macro* 7 9 (2015), S. 987–97. – URL <https://consensus.app/papers/model-angiogenesis-simulates-sprout-initiation-walpole/af7809aa98fe5514bea86ecf7293a57d/>. – Zugriffsdatum: 2024-03-02
- [Wang u.a. 2015] WANG, Zhihui ; BUTNER, J. D. ; KERKETTA, Romica ; CRISTINI, V. ; DEISBOECK, T.: Simulating cancer growth with multiscale agent-based modeling. In: *Seminars in cancer biology* 30 (2015), S. 70–8. – URL <https://consensus.app/papers/simulating-cancer-growth-multiscale-agentbased-modeling-wang/3280bbb99ff457bca49eba3af9928a3a/>. – Zugriffsdatum: 2024-03-02
- [Warren und Shubik 1966] WARREN, B. A. ; SHUBIK, P.: The growth of the blood supply to melanoma transplants in the hamster cheek pouch. In: *Laboratory Investigation; a Journal of Technical Methods and Pathology* 15 (1966), Februar, Nr. 2, S. 464–478. – ISSN 0023-6837
- [Watanabe u.a. 2013] WATANABE, Sansuke M. ; BLANCO, P. ; FEIJÓO, R.: Mathematical Model of Blood Flow in an Anatomically Detailed Arterial Network of the Arm. In: *Mathematical Modelling and Numerical Analysis* 47 (2013), S. 961–985. – URL <https://consensus.app/papers/model-blood-flow-anatomically-detailed-arterial-network-watanabe/c1484228598b50c7899870e3ee72c8b2/>. – Zugriffsdatum: 2024-03-02
- [Wigner 1995] WIGNER, E. P.: The Unreasonable Effectiveness of Mathematics in the Natural Sciences. Berlin, Heidelberg : Springer, 1995, S. 534–549. – URL https://doi.org/10.1007/978-3-642-78374-6_41. – Zugriffsdatum: 2024-03-23. – ISBN 9783642783746
- [Williams u.a. 1982] WILLIAMS, E. C. ; JANMEY, P. A. ; FERRY, J. D. ; MOSHER, D. F.: Conformational states of fibronectin. Effects of pH, ionic strength, and collagen binding. In: *The Journal of Biological Chemistry* 257 (1982), Dezember, Nr. 24, S. 14973–14978. – ISSN 0021-9258
- [Woodward u.a. 1995] WOODWARD, D E. ; TYSON, R ; MYERSCOUGH, M R. ; MURRAY, J D. ; BUDRENE, E O. ; BERG, H C.: Spatio-temporal patterns generated by Salmonella typhimurium. In: *Biophysical Journal* 68 (1995), Mai, Nr. 5, S. 2181–2189. – URL <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1282123/>. – Zugriffsdatum: 2024-06-12. – ISSN 0006-3495
- [Zawicki u.a. 1981] ZAWICKI, D. F. ; JAIN, R. K. ; SCHMID-SCHOENBEIN, G. W. ; CHIEN, S.: Dynamics of neovascularization in normal tissue. In: *Microvascular Research* 21 (1981), Januar, Nr. 1, S. 27–47. – ISSN 0026-2862
- [Zudaire u.a. 2011] ZUDAIRE, E. ; GAMBARDELLA, L. ; KURCZ, Christopher ; VERMEREN, S.: A Computational Tool for Quantitative Analysis of Vascular Networks. In: *PLoS ONE* 6 (2011). – URL <https://consensus.app/papers/tool-quantitative-analysis-vascular-networks-zudaire/0ce65598d2355889bc86740873cf20b7/>. – Zugriffsdatum: 2024-03-03