Regional Circulation (pulmonary, skin, muscle, cerebral, splanchnic)

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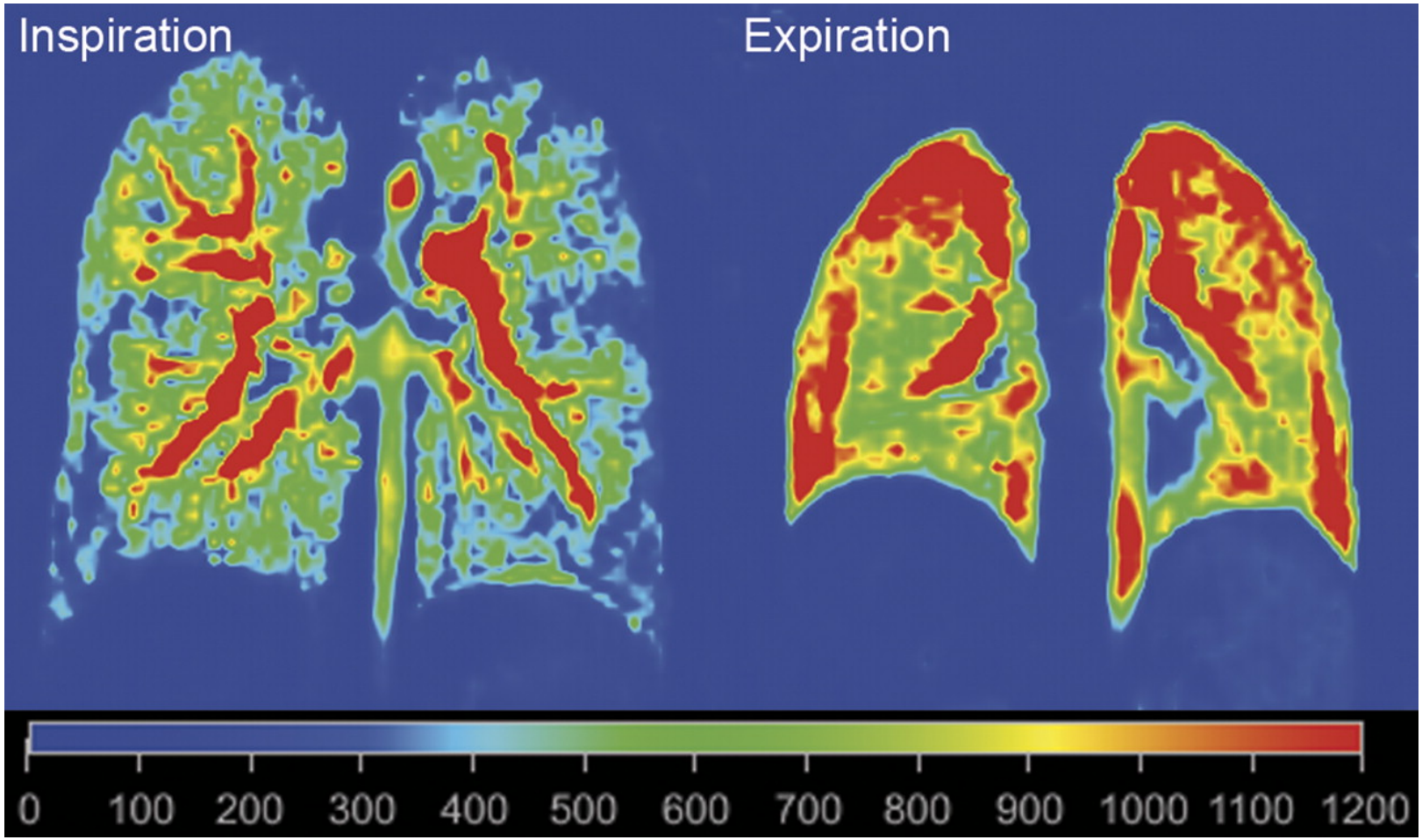
Regional Circulation

- an organ may be supplied by two blood inflows:
  - the nutrient circulation
  - the functional circulation
- various ways of anatomical and functional adaptation of an organ-specific circulation to provide the optimal function of the organ
- varying impact of particular ways of regulation of the blood flow (~ vasal tone) in various organs

Pulmonary Circulation



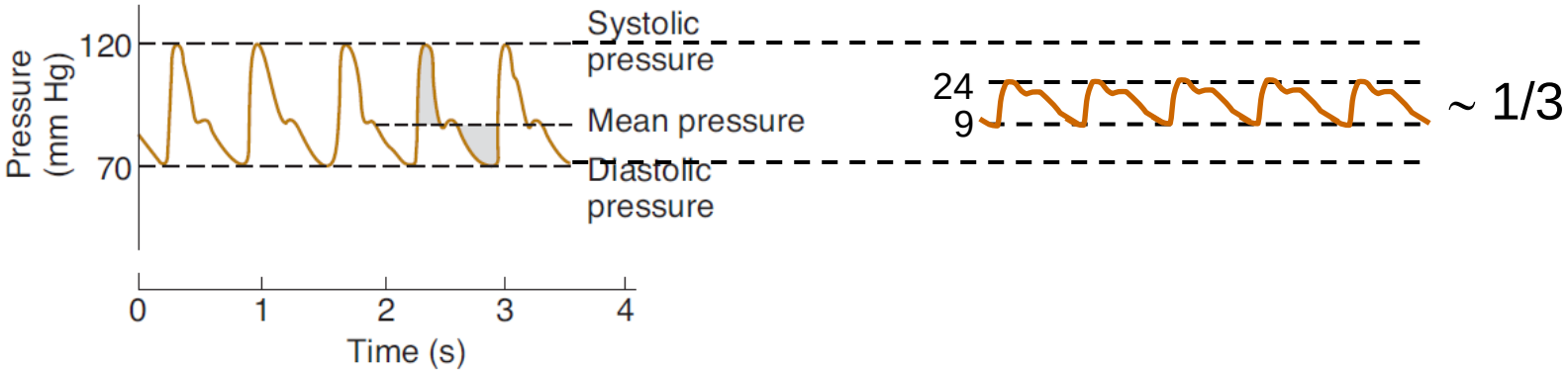
Pulmonary Circulation

- Blood flow through lungs is virtually equal to the blood flow through all other organs.

- Functions:
  - provide the gas exchange
  - blood reservoir
  - mechanical, chemical and immunological filter

Pulmonary Circulation

- Arteries (differences compared to the arteries in the systemic circulation)
  - bigger total cross-section of all pulmonary arteries
  - smaller thickness of the vessel walls
  - arterioles have a thin muscle layer → lower resistance (1/10 of the resistance in systemic circulation; the smallest during a mild inspiration), lower decrease of blood pressure in this part of bloodstream
  - high compliance



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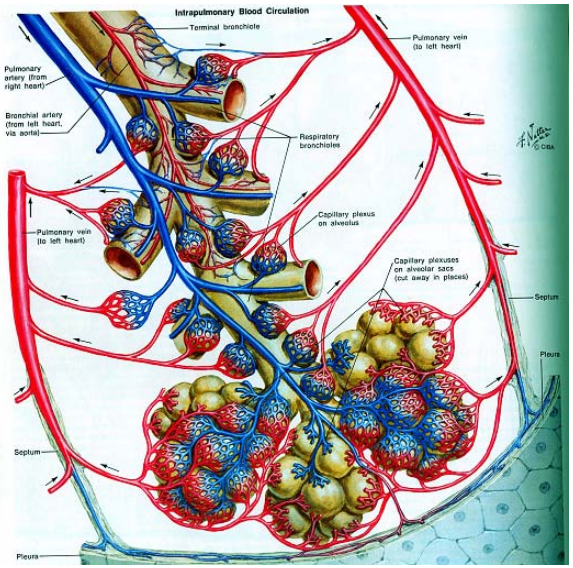
Pulmonary Circulation

- Capillaries
  - wide, abundant anastomoses form a net surrounding alveoles
  - time of passage ~0.75 s (gas exchange)
  - area of perfused capillaries: at rest ~60 m^2, at intensive exertion ~90 m^2



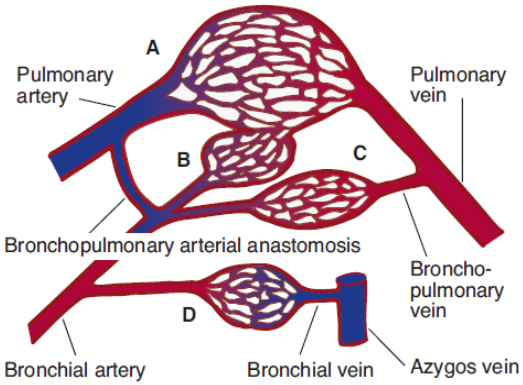
http://www.percussionaire.com/historyreview.asp

- Veins
  - high compliance
    (blood reservoir, autoregulatory mechanism at maintaining the blood pressure during orthostasis – in lying position, about 400 ml of blood moves to lungs → ↓ vital capacity)
  - failure of the left heart → *ortopnoe*

Pulmonary Circulation

- Nutrient circulation
  - *aa. bronchiales, vv. bronchiales , vv. pulmonales*

    (physiological arteriovenous shunt + part of blood from coronary capillaries → saturation of blood with oxygen in the systemic circulation 98%, the stroke volume in the left ventricle by 1-2% bigger than in the right ventricle)



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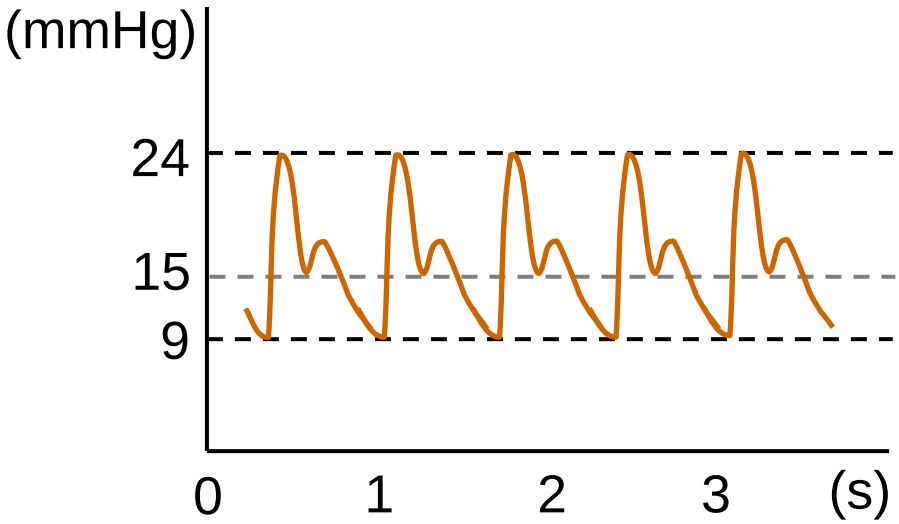
- Lymphatic vessels
  - fast transport of proteins and various particles from the peribronchial and perivascular tissue → ↓ formation of the tissue fluid ~ prevention of the pulmonary edema

Pulmonary Circulation

- Blood pressure in the pulmonary bloodstream
  - pressure in *a. pulmonalis*



  - pressure in pulmonary capillaries – measured as the pulmonary artery wedge pressure (~7.5 mmHg)
  - pressure in pulmonary veins pulsates between 1 and 6 mmHg (as the pressure in left atrium)

Pulmonary Circulation

- Factors affecting the fluid filtration into intersticium:

Minimal filtration in pulmonary capillaries physiologically!

1. pressures in intersticium and pulmonary capillaries

   capillary pressure about 10 mmHg, oncotic pressure 13 mmHg

2. permeability of pulmonary capillaries

- Pulmonary edema inhibits effective gas exchange.

Pulmonary Circulation

- Regulation of blood flow in lungs

  A. Systemic mechanisms

  B. Local mechanisms

Pulmonary Circulation

- Regulation of blood flow in lungs

A. Systemic mechanisms

1) Neural regulation

- sympathetic nerve fibers

through α_1 rec. – vasoconstriction
(small impact on resistance, *i.e.* pressure, but decrease capacity of the lung bloodstream, ~empty lung blood reservoir)

through α_2 and β_2 rec. – vasodilation - NO

- parasympathetic nerve fibers (M_3 rec. $\rightarrow$ relaxation - NO)

2) Humoral regulation (circulating substances)

vasoconstriction: adenosine (A_1), endothelin (ET_A), angiotensine II

vasodilation: adenosine (A_2), endothelin (ET_B), histamine (H_1,H_2),

Pulmonary Circulation

- Regulation of blood flow in lungs

B. Local mechanisms

- chemical (metabolic) autoregulation

  opposite reaction compared to systemic circulation ($\downarrow pO_2$ – also systemic hypoxia, $\uparrow pCO_2$, $\downarrow$ pH , histamine $\rightarrow$ vasoconstriction $\rightarrow$ deviation of perfusion from the non-ventilated alveoli within 5-10 min)

  unknown mechanism, key role likely playes surrounding lung tissue, maybe degranulation of basofile granulocytes releasing vasoactive substances (namely histamine)

  works also in opposite way: obstruction of perfusion in a part of lungs $\rightarrow \downarrow pCO_2 \rightarrow$ constriction of influent bronchus to provide optimal ratio of ventilation/perfusion)

Pulmonary Circulation

- Regulation of blood flow in lungs

  C. Passive factors

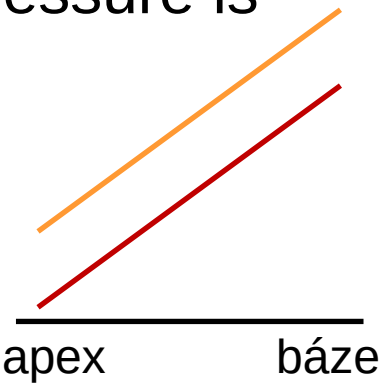
  - cardiac output

    physical exertion $\rightarrow \uparrow$ cardiac output $\rightarrow$ saturation of haemoglobin is stable, opening of so far non-perfused capillaries $\rightarrow \uparrow$ blood flow through lungs and total amount of O_2 delivered to body

  - gravity

Pulmonary Circulation

- Blood distribution in lungs - gravity
  - irregular due to action of the hydrostatic pressure
  - pulmonary apexes – about 15 cm above the orificium of *a. pulmonalis*, hydrostatic and arterial pressure is approx. equal → minimal blood flow
  - blood flow increases from apex to base in a linear way
  - ↑ total blood flow (*e.g.* physical exertion) ~ equivalent ↑ flow through individual regions



Pulmonary Circulation

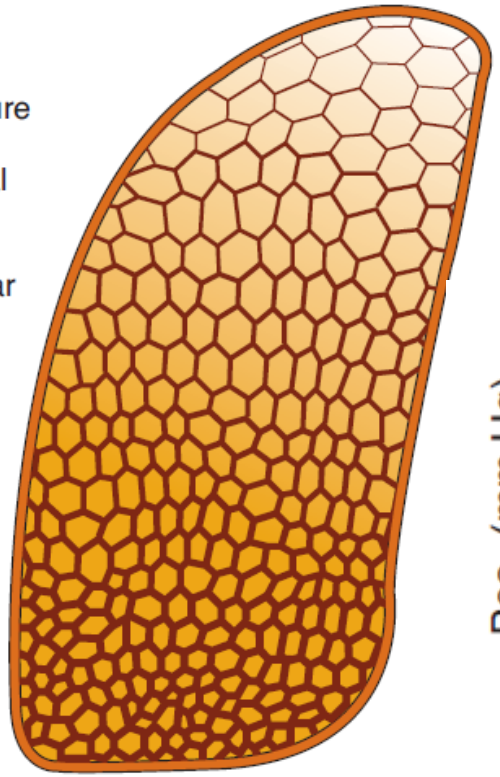
- Blood distribution in lungs - gravity
  - irregular due to action of the hydrostatic pressure
  - pulmonary apexes – about 15 cm above the orificium of *a. pulmonalis*, hydrostatic and arterial pressure is approx. equal → minimal blood flow
  - blood flow increases from apex to base in a linear way
  - intensive physical exertion → ↑ cardiac output even 6times → opening of so far unperfused capillaries → pressure in *a. pulmonalis* increased only slightly

    (decreased work of the right heart + prevention of formation of the pulmonary edema due to increased capillary pressure)

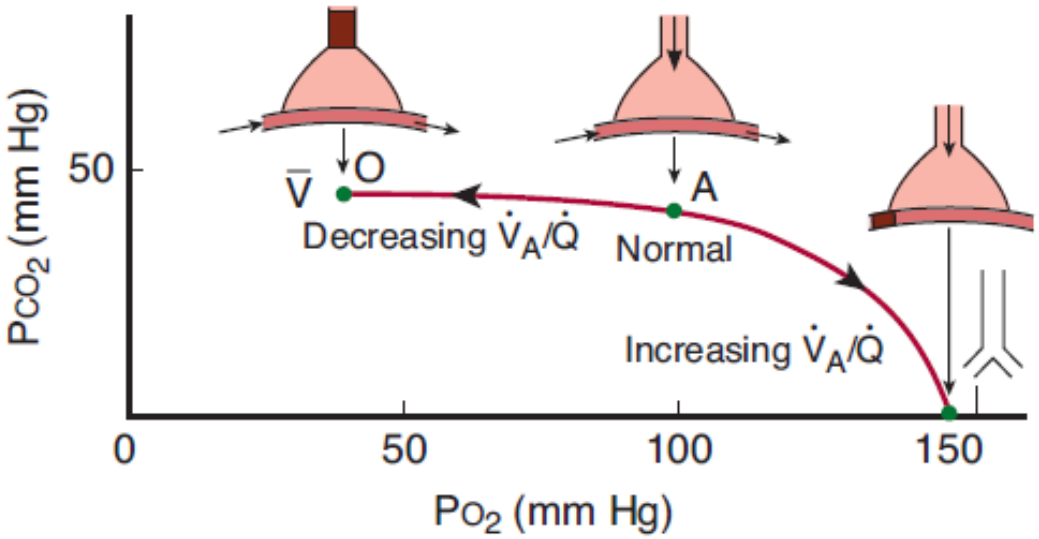
Pulmonary Circulation

At apex

Intrapleural pressure more negative
Greater transmural pressure
Large alveoli
Lower intravascular pressure
Less blood flow
So less ventilation and perfusion



Ventilation / perfusion



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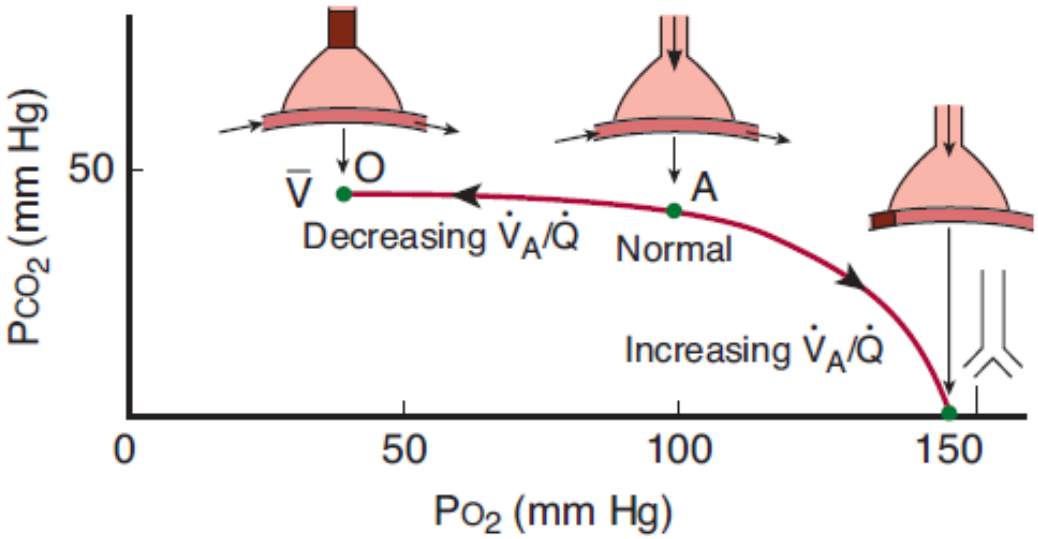
Pulmonary Circulation

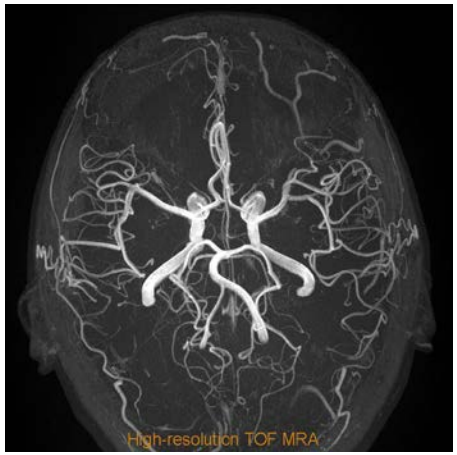
- Defective ratio of ventilation and perfusion
  - most often cause of hypoxic hypoxia in clinical practise
  - blood flow through non-ventilated alveoli → right-left shunt (deoxygenated blood directly to the left heart) → ↓ arterial blood saturation with O_2

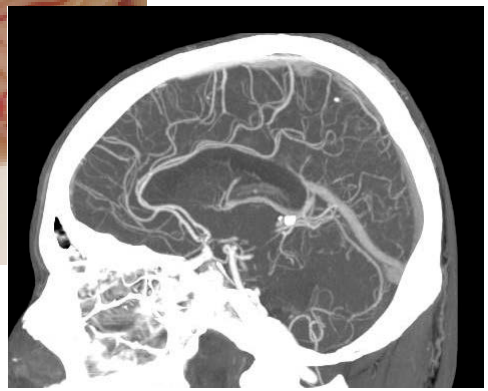
Ventilation / perfusion



  - content of CO_2 usually not changed (compensatory hyperventilation in other alveoles)

Cerebral Circulation





Cerebral Circulation

TABLE 34–1 Resting blood flow and O_2 consumption of various organs in a 63-kg adult man with a mean arterial blood pressure of 90 mm Hg and an O_2 consumption of 250 mL/min.

Region	Mass (kg)	Blood Flow		Arteriovenous Oxygen Difference (mL/L)	Oxygen Consumption		Resistance (R units)[a]		Percentage of Total	
		mL/min	mL/100 g/min		mL/min	mL/100 g/min	Absolute	per kg	Cardiac Output	Oxygen Consumption
Liver	2.6	1500	57.7	34	51	2.0	3.6	9.4	27.8	20.4
Kidneys	0.3	1260	420.0	14	18	6.0	4.3	1.3	23.3	7.2
Brain	1.4	750	54.0	62	46	3.3	7.2	10.1	13.9	18.4
Skin	3.6	462	12.8	25	12	0.3	11.7	42.1	8.6	4.8
Skeletal muscle	31.0	840	2.7	60	50	0.2	6.4	198.4	15.6	20.0
Heart muscle	0.3	250	84.0	114	29	9.7	21.4	6.4	4.7	11.6
Rest of body	23.8	336	1.4	129	44	0.2	16.1	383.2	6.2	17.6
Whole body	63.0	5400	8.6	46	250	0.4	1.0	63.0	100.0	100.0

[a]R units are pressure (mm Hg) divided by blood flow (mL/s).

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Cerebral Circulation

- provides:

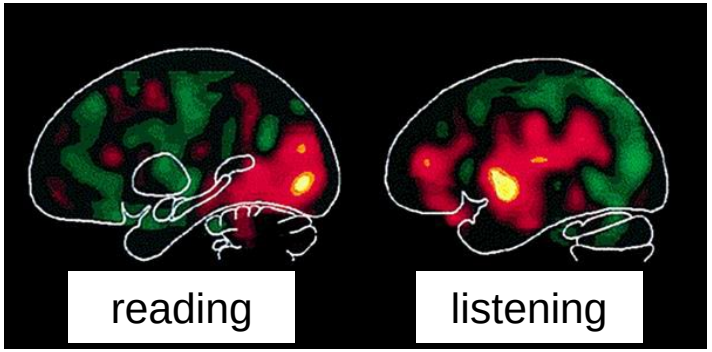
1) constant sufficient blood supply

   intensive oxidative metabolism of the grey matter (40% of the brain matter), is metabolically more active – the grey matter is very sensitive to hypoxia !

   (black-out during several seconds of the brain ischemia, irreversible damage during several minutes)

2) dynamic blood redistribution

   neuronal activity and, thus, the rate of metabolism of particular regions of the grey matter notably varies (metabolic hyperaemia)



http://observatory.cz/static/vystavy/castice/p2_PET-tomogram.jpg

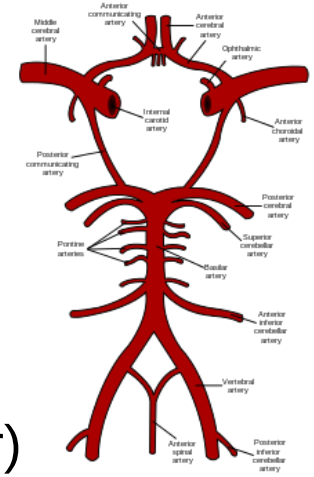
Cerebral Circulation

- provides:
  1) constant sufficient blood supply
  2) dynamic blood redistribution

Cover of these specific demands of brain, namely of its grey matter, requires both anatomical and functional adaptation of the cerebral circulation.

Cerebral Circulation

- Anatomical specialities of cerebral circulation:



1) *circulus arteriosus cerebri*

   (interconnection of main cerebral arteries by anastomoses)

2) very high density of capillaries

   (3000 – 4000 capillaries / mm^2 od the grey matter)

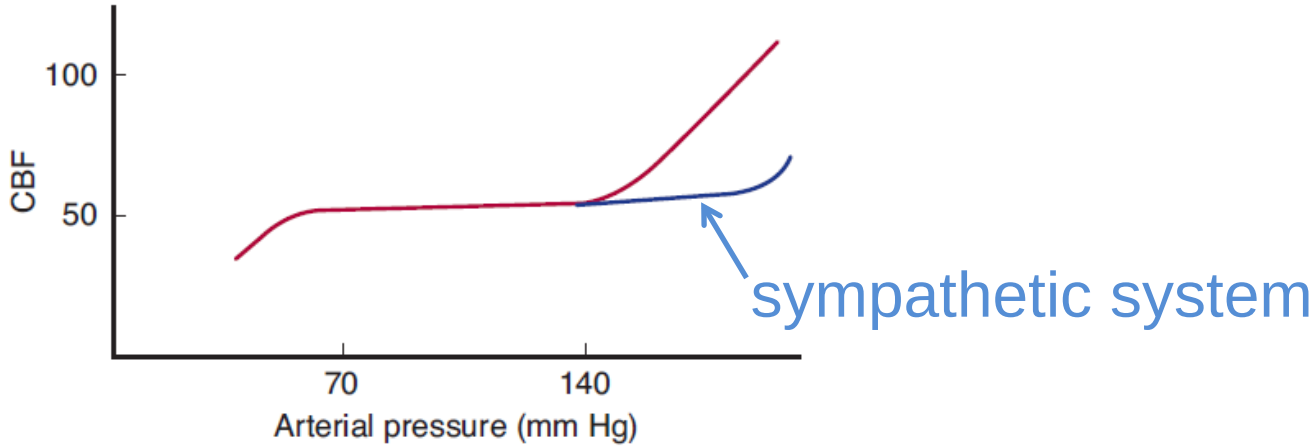
   ~ minimalization of diffuse distance for gases and other substances

3) very short arteriols

   (almost 1/2 of the vasal resistance falls on arteries which are abundantly innervated)

Cerebral Circulation

- Functional adaptation of cerebral circulation:
  1) high and stable blood flow (grey matter: 1 l/kg/min)
  2) high O_2 extraction (35%)
  3) well developed autoregulation (myogenic and metabolic)



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Cerebral Circulation

- Functional adaptation of cerebral circulation:
  1) high and stable blood flow (grey matter: 1 l/kg/min)
  2) high O_2 extraction (35%)
  3) well developed autoregulation (myogenic and metabolic)
  4) high reactivity on changes of CO_2 concentration
  5) local *vs.* total hypoxia
  6) innervation

     sympathetic vasoconstr. fibers (norepinephrine, neuropeptide Y)

     parasympathetic cholinergic fibers (acetylcholine, VIP)

     sensoric fibers (substance P, CGRP; migraine headache)

Cerebral Circulation

- Special physical conditions of cerebral circulation:

1) solid cover of brain by skull

   Ultimate value of actual blood volume in brain, of cerebral tissue and liquor is constant (Monro-Kelli theory).

   → flow may be increased only by acceleration of the blood flow, not by an increase of capacity of the bloodstream

   → Cushing reflex (tumour, bleeding)

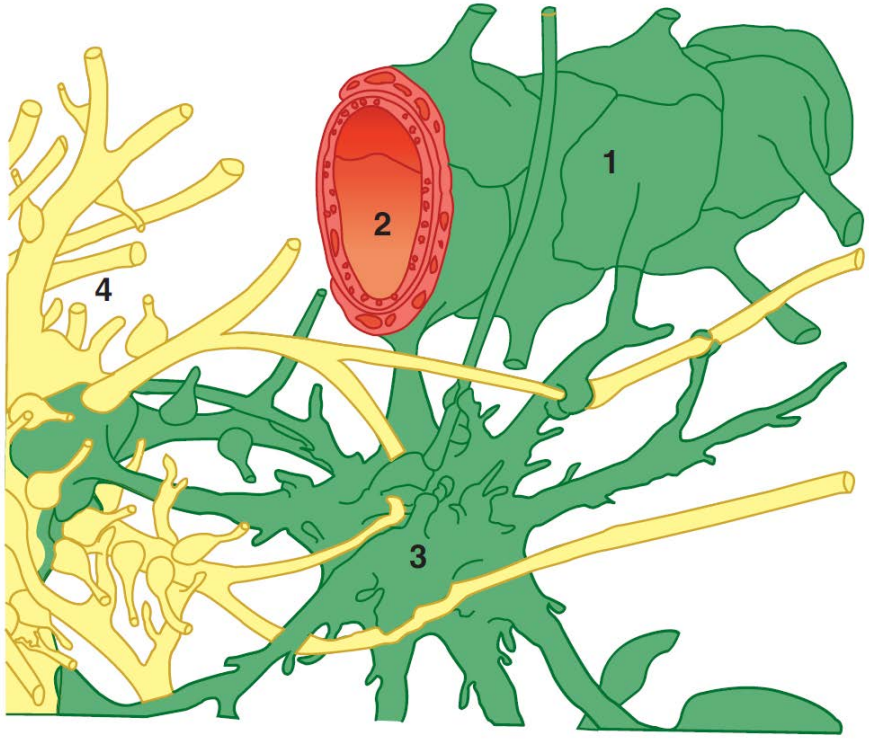
2) gravity

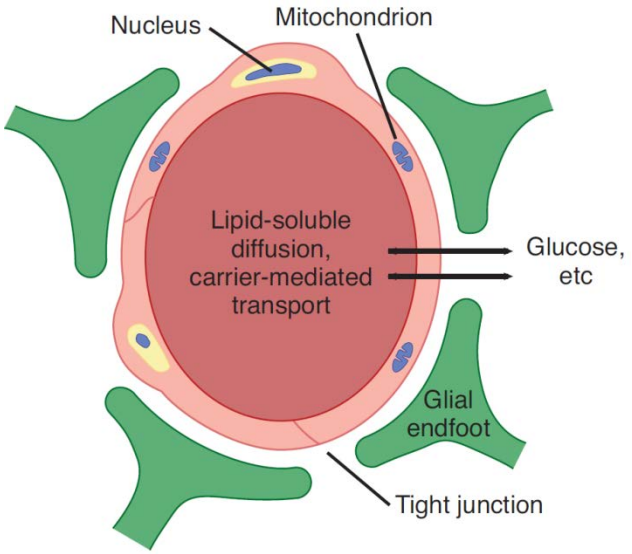
   orthostatic reaction (lower central venous pressure + decreased stroke volume → hypotension → postural syncope)

Cerebral Circulation

- Blood-brain barrier

  cerebral capillaries – tight inter-endothelial connections





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Cerebral Circulation

- Blood-brain barrier

By free diffusion:

→ lipophilic substances (O_2, CO_2, xenon; unbound forms of steroid hormones)

→ water (aquaporins; osmolality of blood and cerebrospinal fluid is identical!)

→ glucose – the main source of energy for neurons (free diffusion would be slow – accelerated by GLUT)

By transcellular transport (regulated):

→ ions (*e.g.* H^+, HCO^{3-} *vs.* CO_2 !)

→ transporters for thyroid hormones, some organic acids, choline, precursors of nucleic acids, aminoacids, …

Cerebral Circulation

- Blood-brain barrier

  Many drugs and peptides pass the capillary wall as well but they are immediately transported back to the blood by a nonspecific transporter - **glycoprotein P** – located in apical membranes of endothelial cells.

- Functions:
  - maintenance of constant composition of the neuron environment
  - protection of brain against endogenic and exogenic toxins
  - prevention of loss of neurotransmitters to the bloodstream

Cerebral Circulation

- Cerebrospinal fluid
  - fills the brain chambers and subarachnoidal space
  - volume ~150 ml, rate of production ~550 ml/d (exchange 3.7times/day)

Cerebrospinal fluid is constantly of a composition different from plasma.

Substance		CSF	Plasma	Ratio CSF/Plasma
Na^+	(meq/kg H_2O)	147.0	150.0	0.98
K^+	(meq/kg H_2O)	2.9	4.6	0.62
Mg^{2+}	(meq/kg H_2O)	2.2	1.6	1.39
Ca^{2+}	(meq/kg H_2O)	2.3	4.7	0.49
Cl^-	(meq/kg H_2O)	113.0	99.0	1.14
HCO_3^-	(meq/L)	25.1	24.8	1.01
P_{CO_2}	(mm Hg)	50.2	39.5	1.28
pH		7.33	7.40	. . .
Osmolality	(mosm/kg H_2O)	289.0	289.0	1.00
Protein	(mg/dL)	20.0	6000.0	0.003
Glucose	(mg/dL)	64.0	100.0	0.64
Inorganic P	(mg/dL)	3.4	4.7	0.73
Urea	(mg/dL)	12.0	15.0	0.80
Creatinine	(mg/dL)	1.5	1.2	1.25
Uric acid	(mg/dL)	1.5	5.0	0.30
Cholesterol	(mg/dL)	0.2	175.0	0.001

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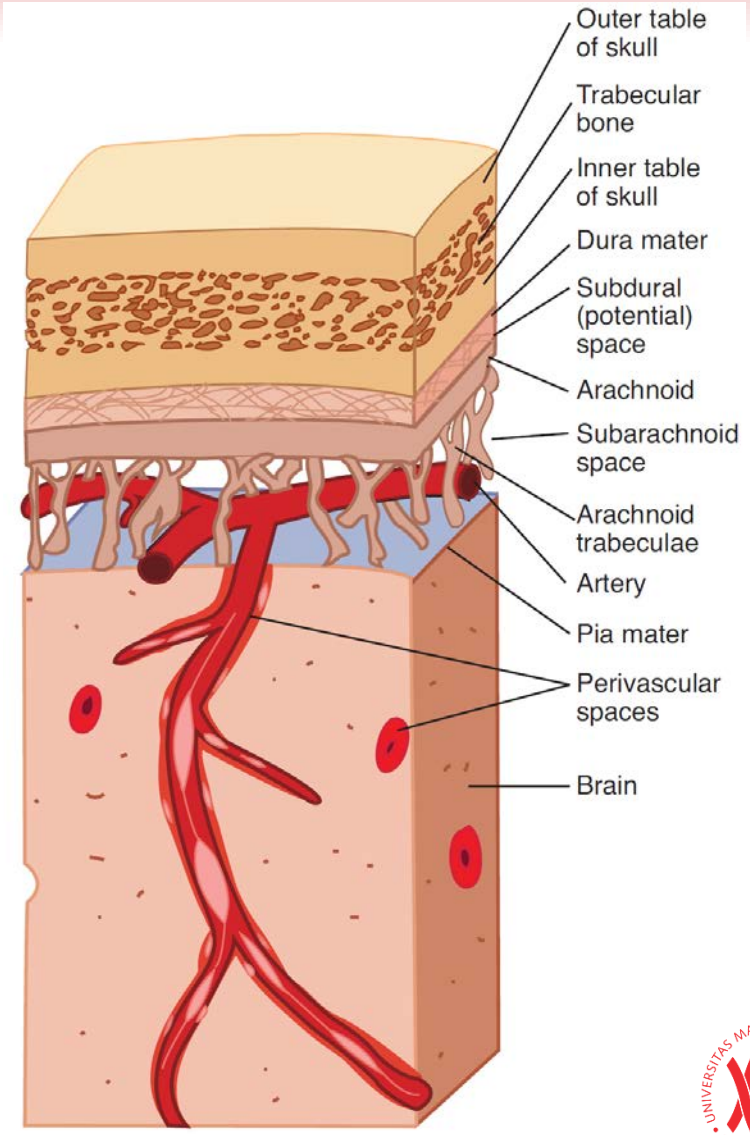
Cerebral Circulation

- Cerebrospinal fluid

  Function:

  - protection of brain
    (together with menanges)



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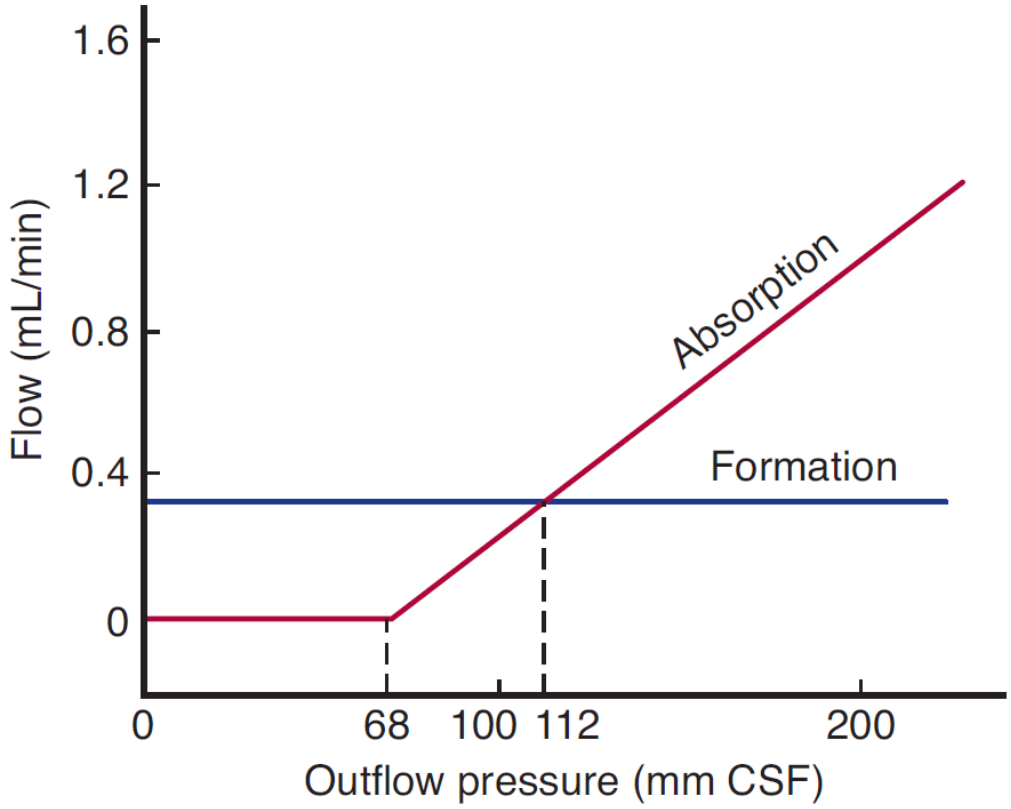
Cerebral Circulation

- Cerebrospinal fluid



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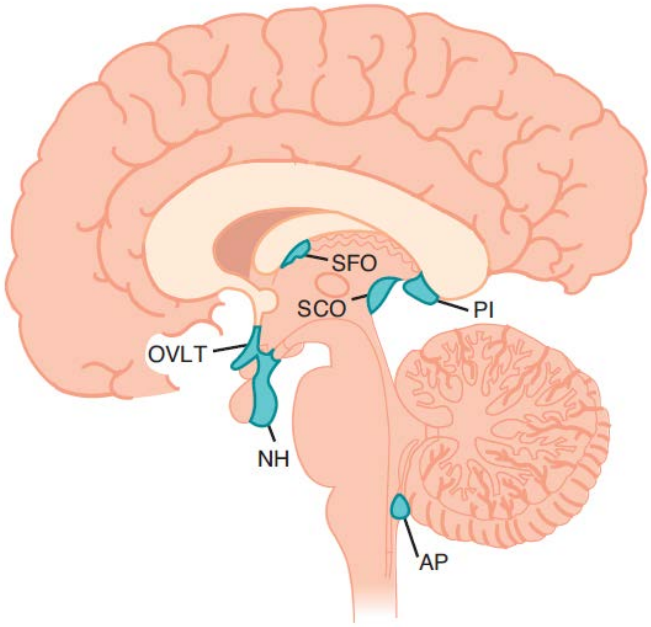
Cerebral Circulation

- Paraventricular organs

  ~ brain regions where the blood-brain barrier is missing (fenestrated capillaries)

  - neurohypophysis + neighbouring ventral part of *eminentia medialis*
  - *area postrema* (AP)
  - *organum vasculosum laminae terminalis* (OVLT)
  - subfornical organ (SFO)



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Regions secreting polypeptides into the bloodstream (oxytocin, vasopressin, hypothalamic hormones), chemoreceptive zones (AP), osmoreceptive zones (OVLT).

Cerebral Circulation

- Measurement of cerebral blood flow

  Kety method

  - Fick principle, method of indicatory gas
  - nitrous oxide N_2O

N_2O concentration in the venous blood

$$\text{cerebral blood flow} = \frac{N_2O \text{ removed from blood by brain / time}}{\text{average arteriovenous difference of } N_2O}$$

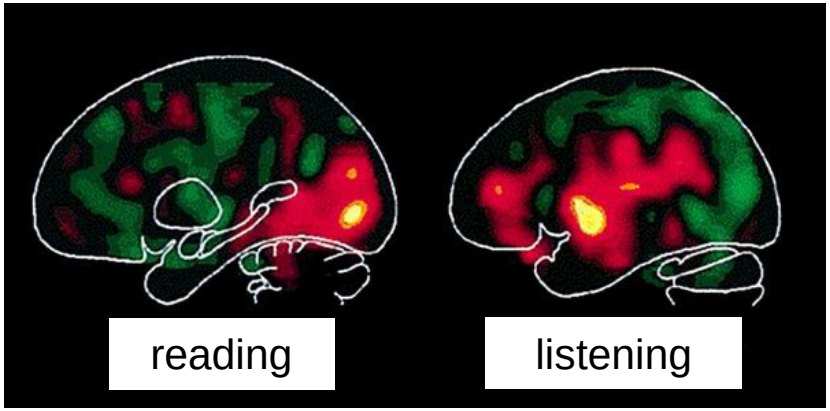
$\rightarrow$ average blood flow through all perfused regions!

Cerebral Circulation

- Measurement of cerebral blood flow - regional

  PET (positron emission tomography)

  - a substance labelled by radionuclides with a short half time
  - the substance is injected, the increase and following decrease of its concentration is evaluated by scintillation detectors placed around the head
  - *e.g.* labelled 2-deoxyglucose – its consumption is a good indicator of the flow



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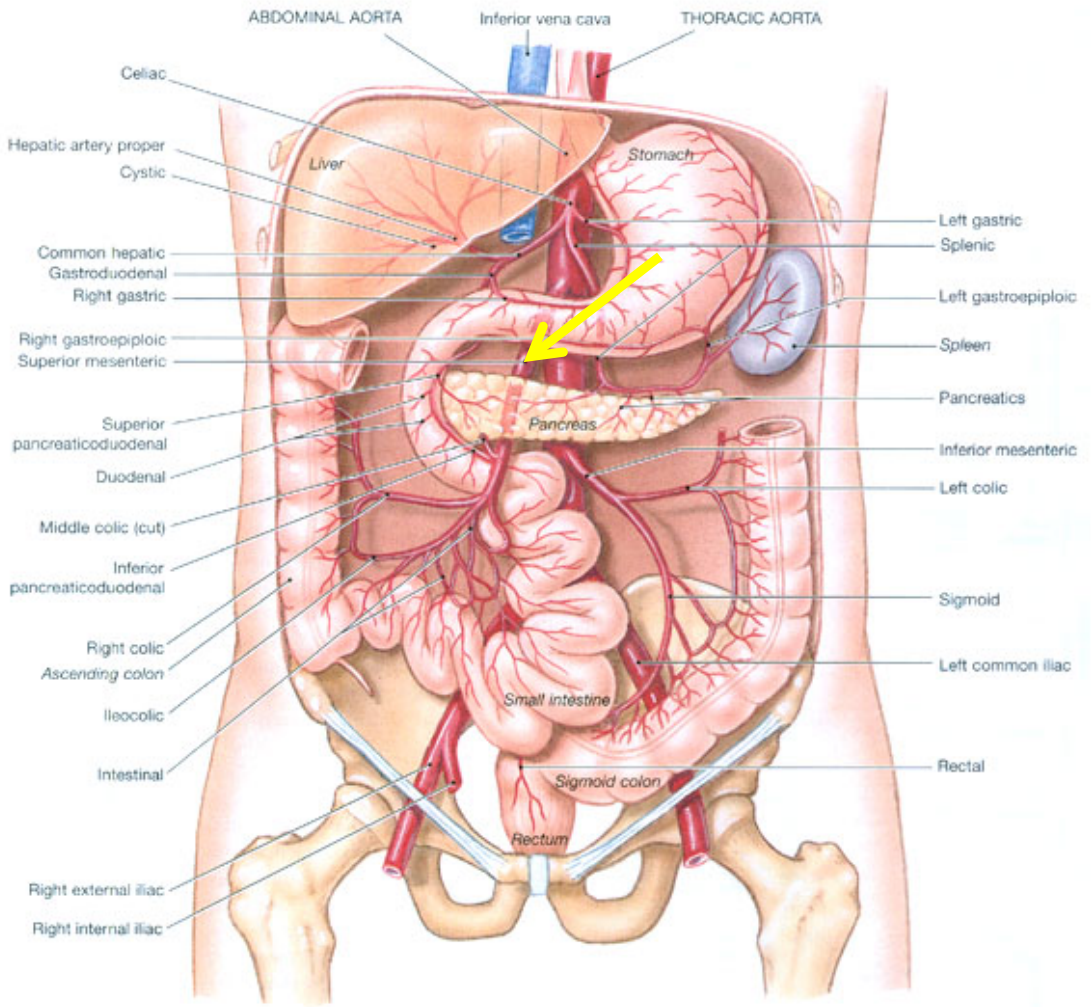
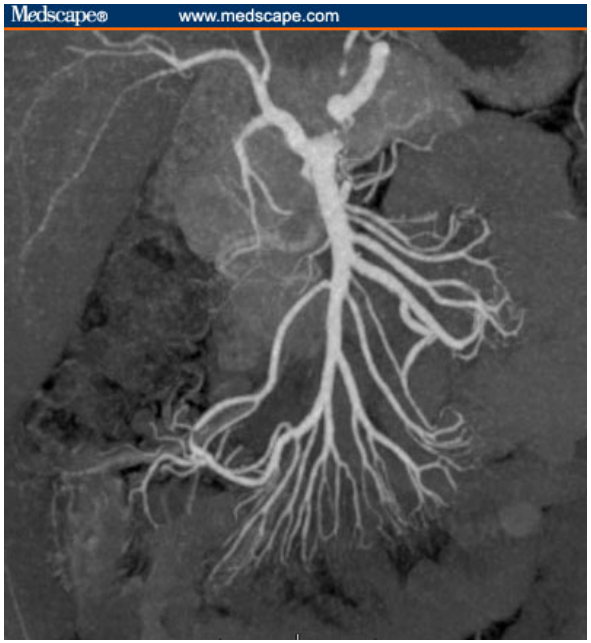
fMRI (functional magnetic resonance)

- better resolution
- reduced haemoglobin becomes paramagnetic, change the signal emitted by blood, we can measure the amount of oxy- and deoxyhaemoglobin as an indicator of the blood flow

Splanchnic Circulation





Splanchnic Circulation

- blood flow through GIT including liver and pancreas
- blood flow through spleen

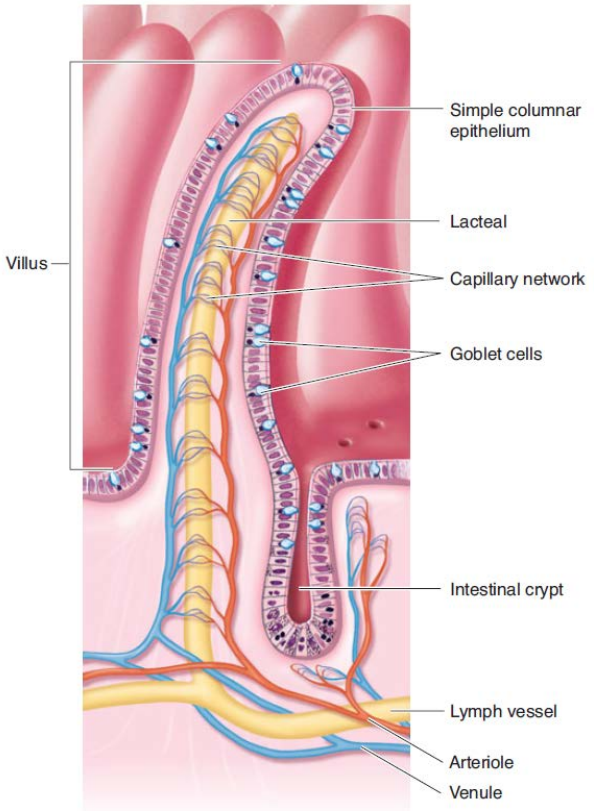
- Main functional roles:
  - metabolic function of GIT
  - blood reservoir
  - special (*e.g.* spleen – removal and degradation of old/altered erythrocytes)

Splanchnic Circulation

- Blood reservoir
- due to the high capacitive ability of splanchnic vessels – notable impact on the systemic regulation of circulation (BP)
- at rest ~20% of the total blood volume
- rich innervation with sympathetic vasoconstrictive fibers - α rec. → vasoconstriction at ↑ activity of sympathicus or ↑ concentration of circulating catecholamines → even 350 ml of the blood emptied into the systemic circulation during several minutes! → stabilization of stroke volume and BP (hypotension – bleeding, intensive physical exertion, …)

Splanchnic Circulation

- **Intestinal circulation**
  (*a. coeliaca, a. mesenterica superior* and *inferior*)
- small arterioles form a submucous plexus from which branches enter musculature and intestinal villi
- countercurrent exchange of substances between arteriole and venule in the villus (water, Na^+, O_2)



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Splanchnic Circulation

- **Intestinal circulation**
  (*a. coeliaca, a. mesenterica superior* and *inferior*)
- Regulation of blood flow:
  - metabolic vasodilation (mediators: adenosine, ↓ $[K^+]_e$ and ↑ osmolarity)
    (functional hyperaemia during digestion: induced by GIT hormones – gastrin and cholecystokinin – and by resorbed substances – glucose and fatty acids)
  - neural regulation – almost exclusively sympathicus, α > β rec. → vasoconstriction
    (during defense reaction, blood diverted from GIT to muscles and heart by vasoconstriction)

Splanchnic Circulation

- **Intestinal circulation**
  (*a. coeliaca, a. mesenterica superior* and *inferior*)
- Regulation of blood flow:
  - metabolic vasodilation (mediators: adenosine, ↓ $[K^+]_e$ and ↑ osmolarity)
  - neural regulation – almost exclusively sympathicus, α > β rec. → vasoconstriction

During ischemia, the metabolic vasodilation will be present regardless of vasoconstrictory action of sympathetic system
(the so called autoregulatory escape).

Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- 25% of the cardiac output (~1.5 l/min)
  - ¾ *v. portae*, ¼ *a. hepatica*

- portal circulation – 2 capillary bloodstreams in series:
  1) in intestinal villi – resorption of water-soluble substances from the intestine
  2) in liver sinusoids – high permeability (large gaps between endothelial cells), also for proteins synthesized in liver and released to circulation

Splanchnic Circulation

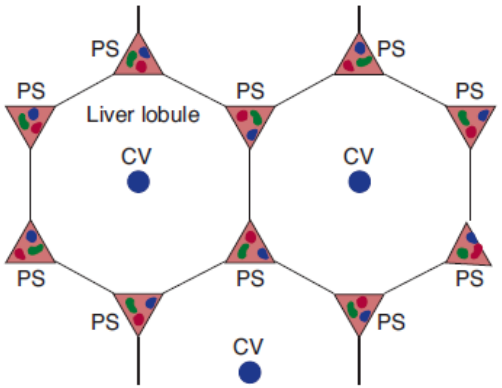
- **Hepatic circulation** (*v. portae, a. hepatica*)
- 25% of the cardiac output (~1.5 l/min)
  - ¾ *v. portae*, ¼ *a. hepatica*

Regarding O_2 supply, the ratio is opposite!

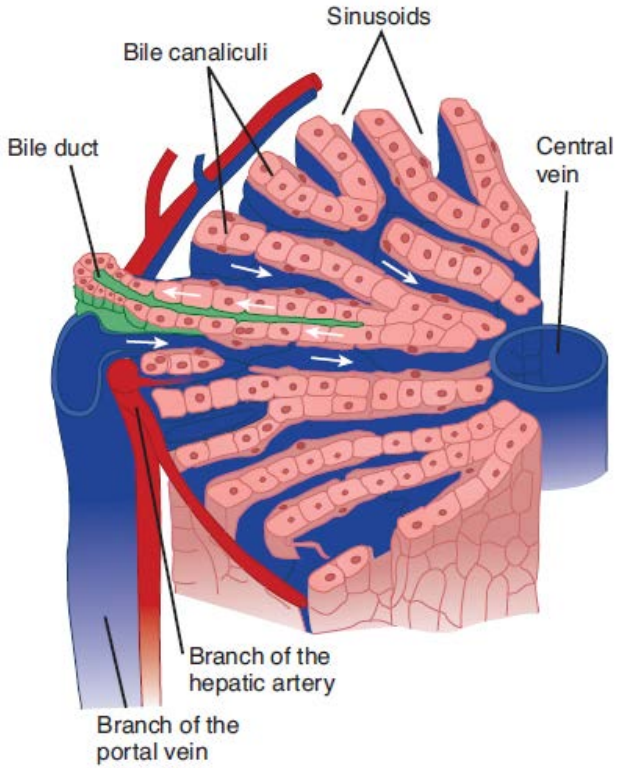
- portal circulation – 2 capillary bloodstreams in series:
- the portal blood which has already passed the first capillary bloodstream in the intestine has ↓ O_2 content → *a. hepatica* represents the nutrition hepatic circulation
  (interrupted blood flow → lethal liver necrosis)

Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- terminal portal venules and hepatic arteriols empty into a net of sinusoids in liver lobuli, the mixed blood leaves lobuli through the central vein



- functional unit - acinus



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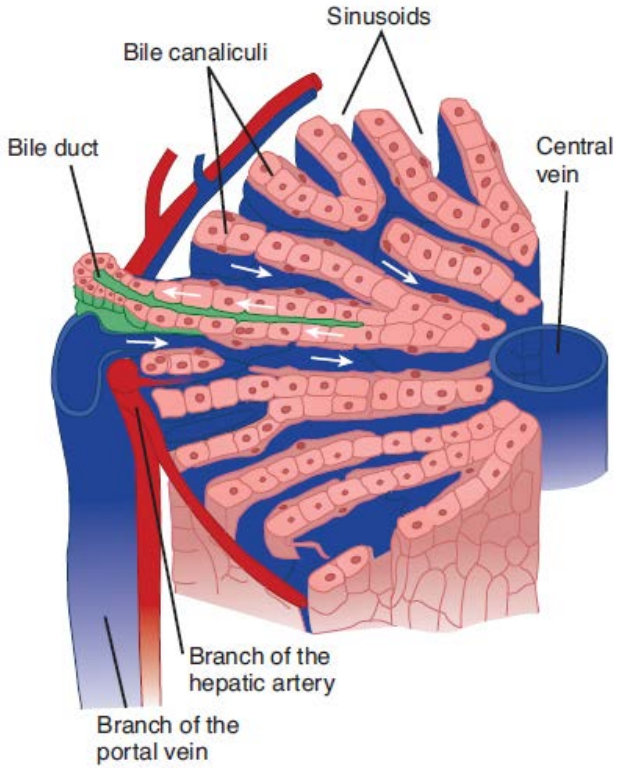
Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)

- pressures different from other tissues:
  - *a. hepatica*: 90 mmHg
  - *v. hepatica*: 5 mmHg
  - *v. portae*: 10 mmHg
  - sinusoids: 2.25 mmHg

  (big pressure reduction due to high resistance in branches of *a. hepatica*)

Pressure in sinusoids below pressure in *v. portae*!



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Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- due to sudden pressure ↓ in *a. hepatica* → inverse regulation of blood flow in *v. portae* and *a. hepatica*:
  - between meals: many sinusoids collapsed, flow in *v. portae* low, adenosine formed constantly and washed less → dilation of terminal hepatic arterioles
  - after a meal: flow in *v. portae* ↑, adenosine washed faster → constriction of hepatic arterioles, higher flow in *v. portae* also opens so far collapsed sinusoids → pressure in *v. portae* does not ↑ too much (protection against fluid loss in highly permeable liver tissue)
- increased hepatic pressure (cirhosis) → ascites

Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- Regulation of blood flow:
  - neural: sympathetic vasoconstrictive fibers – α rec. → vasoconstriction
  - metabolic: adenosine → vasodilation
  - passive: ↑ BP → passive dilation of portal vein radicles → ↑ liver blood amount

    congestive heart failure → extreme venous congestion

    diffuse noradrenergic discharge due to ↓ BP → constriction of portal vein radicles → ↑ portal pressure → blood flow bypasses most of liver and enters systemic circulation

Splanchnic Circulation

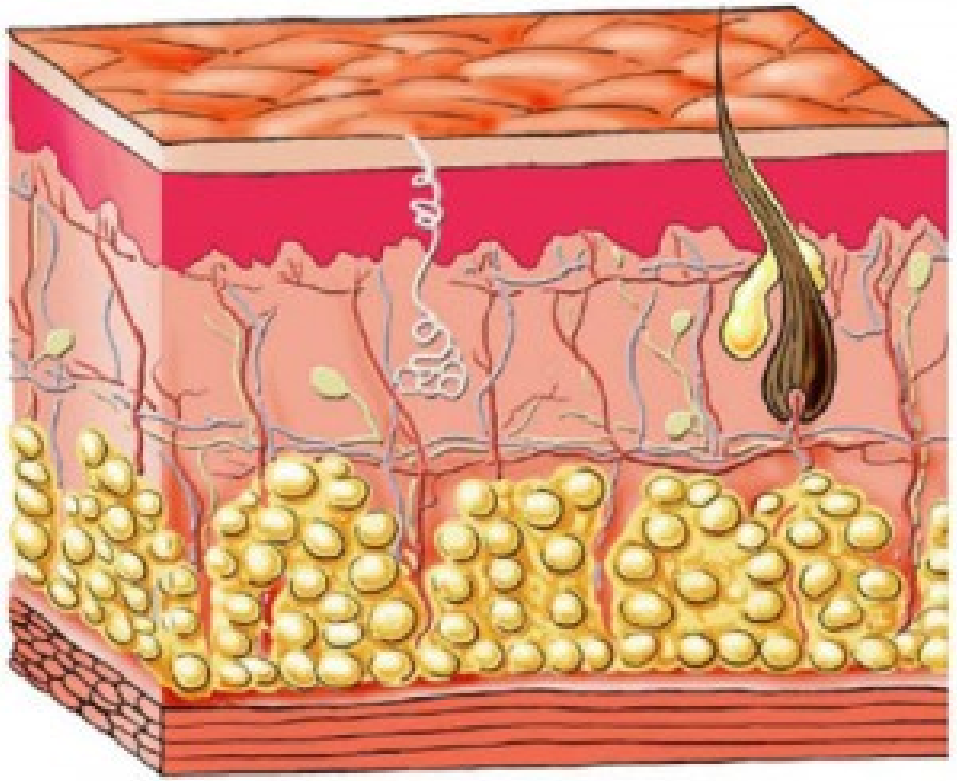
- **Hepatic circulation** (*v. portae, a. hepatica*)
- flow in *a. hepatica* and in *v. portae* are complementary - reciprocal compensation of changes but incomplete due to different way of autoregulation:
  - *a. hepatica* – ability of autoregulation
  - *v. portae* – not able to autoregulate
- sufficient O_2 supply is essential for liver function! - ↓ flow → ↑ O_2 extraction

  (reserve for ↑ O_2 extraction – anatomical setting of hepatic circulation, arteries and veins distant → no ↓ of arterial O_2 by countercurrent exchange)

Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- hepatic lymphatic circulation
  - formation of almost ¾ of the body lymph
  - lymph rich on proteins (many plasmatic proteins are formed in hepatocytes + proteins from plasma due to the high permeability of sinusoids)

Skin Circulation



Skin Circulation

- Skin blood flow considerably varies (0.02-5 l/min).
- Regulation of skin blood flow:
  - Sympathetic nerve fibers
  - Humoral – local factors

    (histamine → vasodilation, serotonine → vasoconstriction)

Skin Circulation

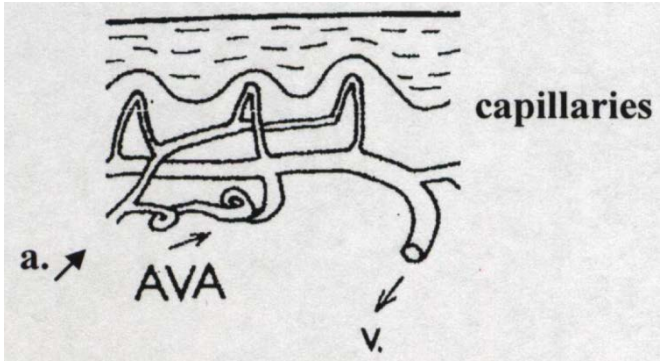
- Metabolic demands of skin – small (*decubitus*)
- **Maintenance of body temperature**
  - warm supply from the core (dependent on blood inflow)
  - warm loss (conduction, convection, radiation, evaporation)

  poikilothermic tissue (toleration of strong warm fluctuation, 0 - 45°C)

  Arteriovenous anastomoses
- **Protection against environment**
- **Maintenance of mean blood pressure**

Skin Circulation

- Arteriovenous anastomoses
  - specific structural adaptation
  - convoluted muscle vessels directly connecting arteriols and venules (low-resistance shunt)



Honzíková N - Poznámky k přednáškám z fysiologie (1992)

  - regulated by sympathetic vasoconstrictive nerve fibers (their activity regulated by the centre for thermoregulation located in hypothalamus)

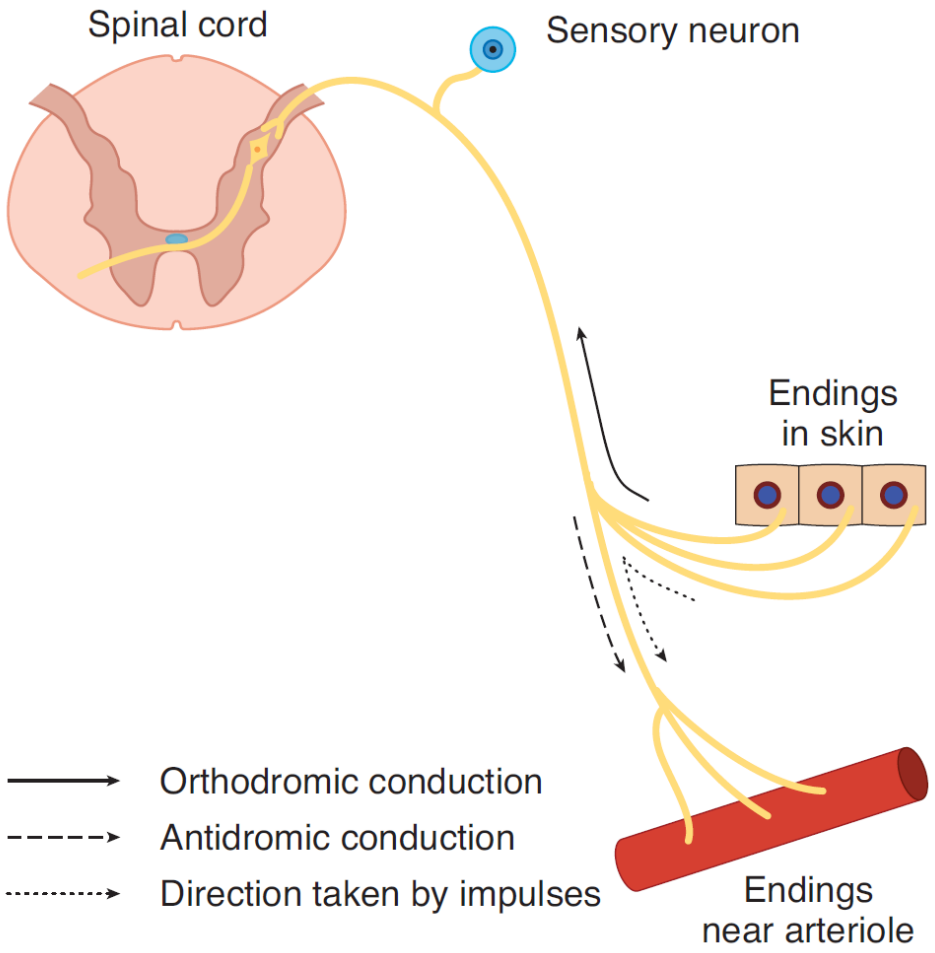
Skin Circulation

- Reaction on a temperature change:
  1) direct impact of a temperature change on the vessel tone
  2) excitation of skin thermoreceptors
  3) excitation of thermoreceptors in brain

reflex modulation of
sympathetic vasoconstrictive activity

Skin Circulation

- Axon reflex

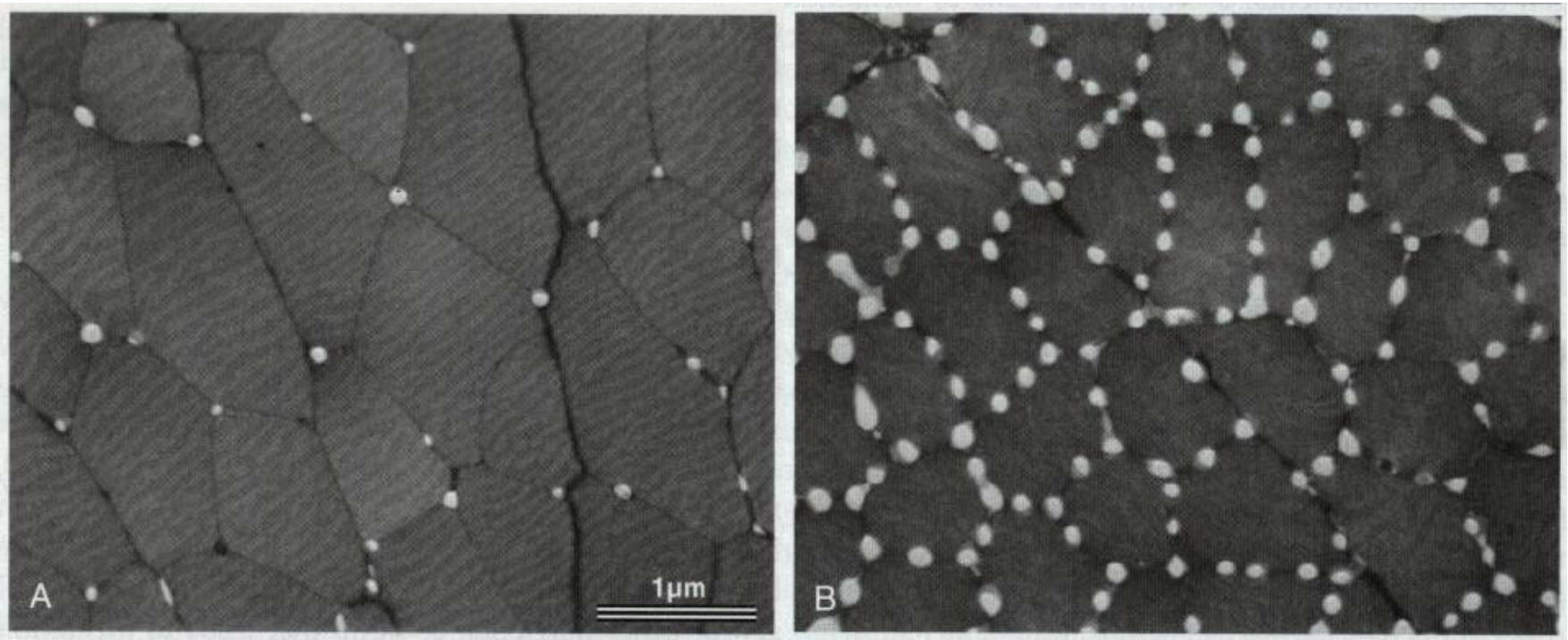


Ganong´s Review of Medical Physiology, 23rd edition.

Muscle Circulation

unstimulated muscle

regularly stimulated muscle



Guyton and Hall. Textbook of Medical Physiology, 12th edition

Muscle Circulation

- Function:

1) Blood supply of muscles

   O_2 and nutrients supply, namely glucose
   wash of metabolites (CO_2) and metabolic heat

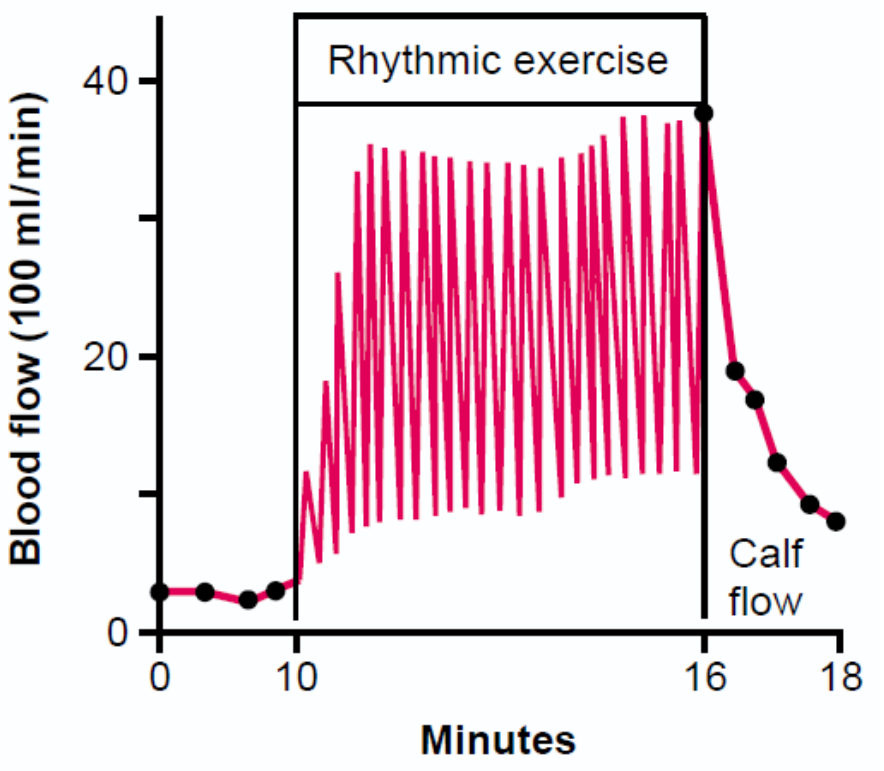
   the resting blood flow – 18% of the cardiac output *vs.*
   even 90% at intensive exertion (the local blood flow ↑
   even 20times; opening of capillaries closed at rest)

2) Regulation of blood pressure

   skeletal muscles – 40% of the body weight →
   resistance of the muscle bloodstream has a high
   impact on the total peripheral resistance

Muscle Circulation

- The blood flow during muscle activity is intermittent.



Guyton and Hall. Textbook of Medical Physiology, 11th edition

Muscle Circulation

- The blood flow during muscle activity is intermittent.
- During the tetanical contraction, the blood flow may be almost stopped.

  O_2 content in myoglobin is sufficient for about 5-s to 10-s lasting ischemia. Anaerobic glycolysis follows, lactate is formed and cumulates (fatique, pain).

- Muscle pump (massage of the deep veins during contractions, increase of the venous return)

Muscle Circulation

- Regulation of the muscle blood flow:

1) Neural regulation

   dominates at rest

2) Local chemical regulation

   dominates at physical exertion

Muscle Circulation

- Regulation of the muscle blood flow:

1) Neural regulation

dominates at rest

rich innervation by tonic active sympathetic vasoconstrictive fibers (norepinephrine) → high tone of arteriols at rest ~ big dilation reserve

activity regulated from baroreceptors (baroreflex) – noted impact on regulation of total peripheral resistance (orthostasis, hypovolaemia → ↓ flow even to only 1/5 of the resting flow)

norepinephrine – at low dose vasodilation (baroreceptors), at high doses vasoconstriction (α receptors)

epinephrine – vasodilation (more β receptors)

Muscle Circulation

- Regulation of the muscle blood flow:

1) Neural regulation

dominates at rest

sympathetic cholinergic vasodilatory fibers
(resistant vessels in muscles and skin) → ↑ flow even before the start of muscle activity ~ anticipation of the muscle activity during the stress reaction
(+ vasoconstriction in other locations – prevention of sudden drop of the blood pressure)

Muscle Circulation

- Regulation of the muscle blood flow:

  2) Local chemical regulation

     dominates at physical exertion

     release of K^+ from contracting muscles → ↑ concentration of K^+ in intersticium + ↑ osmolarity (also lactate)
     + ↓ pO_2 (and nutrients) + ↑ pCO_2 + ↓ pH (also lactate)
     → metabolic vasodilation

     almost linear increase of the flow with increasing metabolic activity

Muscle Circulation

- Sufficient release of energy for the muscle activity is dependent on:

  1) increased blood flow (~increased O_2 supply)
  2) increased O_2 extraction (from 25 to 80%)

Muscle Circulation

- Anaerobic glycolysis

  The amount of formed lactate is proportional to O_2 deficiency (oxygen debt).

  lactate → acidosis → metabolic vasodilation + pain (nociceptive C fibers) – the pain terminates the intensive muscle load

  hyperaemia persists after the end of muscle work→ lactate washed and mostly metabolized in liver to glycogen + primary source of energy for the heart

Muscle Circulation

- Local vasodilation in contracting muscles

  → ↑ blood flow

  → ↑ capillary pressure + ↑ osmolarity (K^+, lactate)

  → ↑ filtration → edema in contraction muscles