Regional Circulations
(pulmonary, skin, muscle, cerebral, splanchnic, renal, fetal, coronary)

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This presentation includes only the most important terms and facts. Its content by itself is not a sufficient source of information required to pass the Physiology exam.

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

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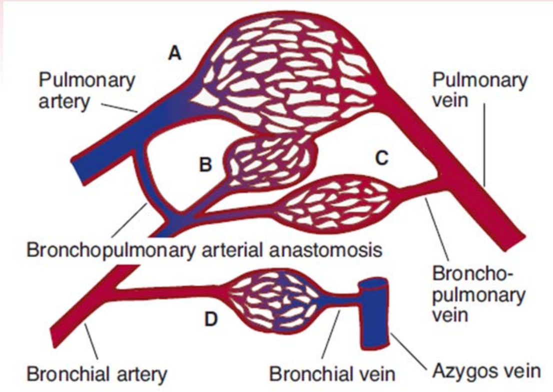
Pulmonary Circulation

- Arteries (differences compared to the arteries in the systemic circulation)
  - bigger total cross-section of all pulmonary arteries
  - smaller thickness of the vessel walls
  - high compliance
- Capillaries
  - wide, abundant anastomoses form a net surrounding alveoles
  - time of passage, area of perfused capillaries at rest and intensive exertion
- Veins
  - high compliance (blood reservoir, ortopnoe)

Blood pressure in pulmonary circulation

Pulmonary Circulation

- Nutrient circulation
  - physiological arteriovenous shunt



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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

No filtration in pulmonary capillaries physiologically!

1. pressures in intersticium and pulmonary capillaries
2. permeability of pulmonary capillaries

Pulmonary Circulation

- Regulation of blood flow in lungs

A. Systemic mechanisms

1) Neural regulation (sympathicus, parasympathicus)
2) Humoral regulation (circulating substances)

B. Local mechanisms

- chemical (metabolic) autoregulation

  opposite reaction compared to systemic circulation (vasoconstriction)

C. Passive factors

- cardiac output
- gravity (blood distribution in lungs)

Pulmonary Circulation

- Ratio of ventilation and perfusion
  - kept constant (local metabolic autoregulation)

    non-ventilated alveolus - vasoconstriction

    non-perfused alveolus - bronchoconstriction

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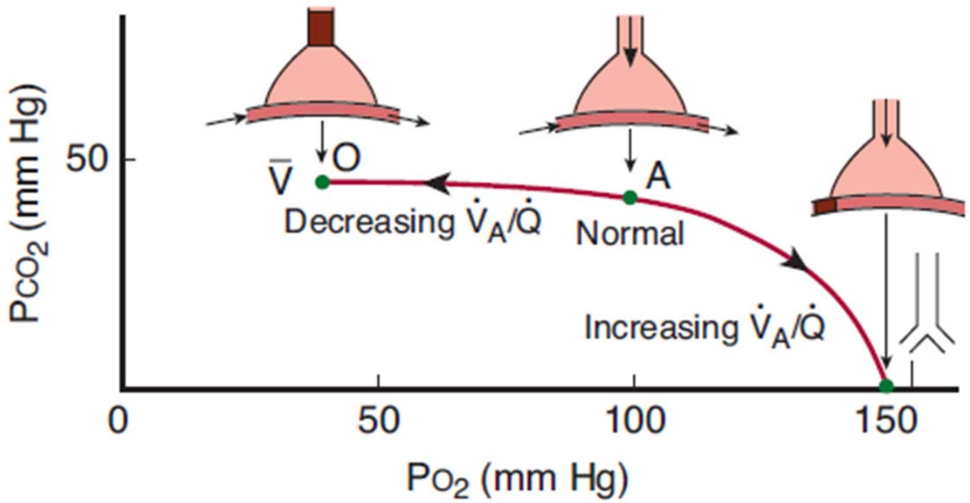
  - decreased ratio - most often cause of hypoxic hypoxia in clinical practise (right-left shunt) → ↓ arterial blood saturation with O_2



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

Skin Circulation

Skin Circulation

- Skin blood flow considerably varies (0.02-5 l/min).

Function:

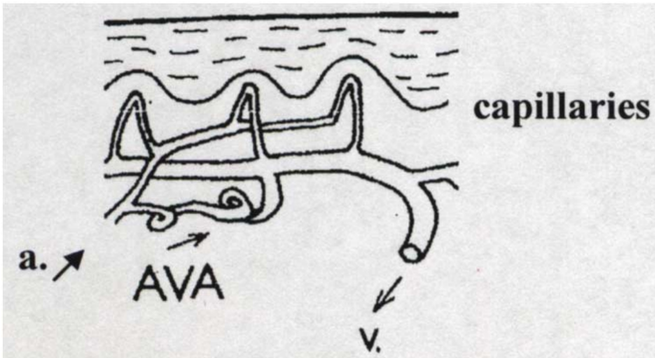
- Metabolic demands of skin – small (*decubitus*)
- **Maintenance of body temperature**

  poikilothermic tissue

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

Skin Circulation

- Arteriovenous anastomoses
  - 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

Skin Circulation

- Regulation of skin blood flow:
  - Sympathetic nerve fibers
  - Humoral – local factors

    (histamine, serotonine)

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

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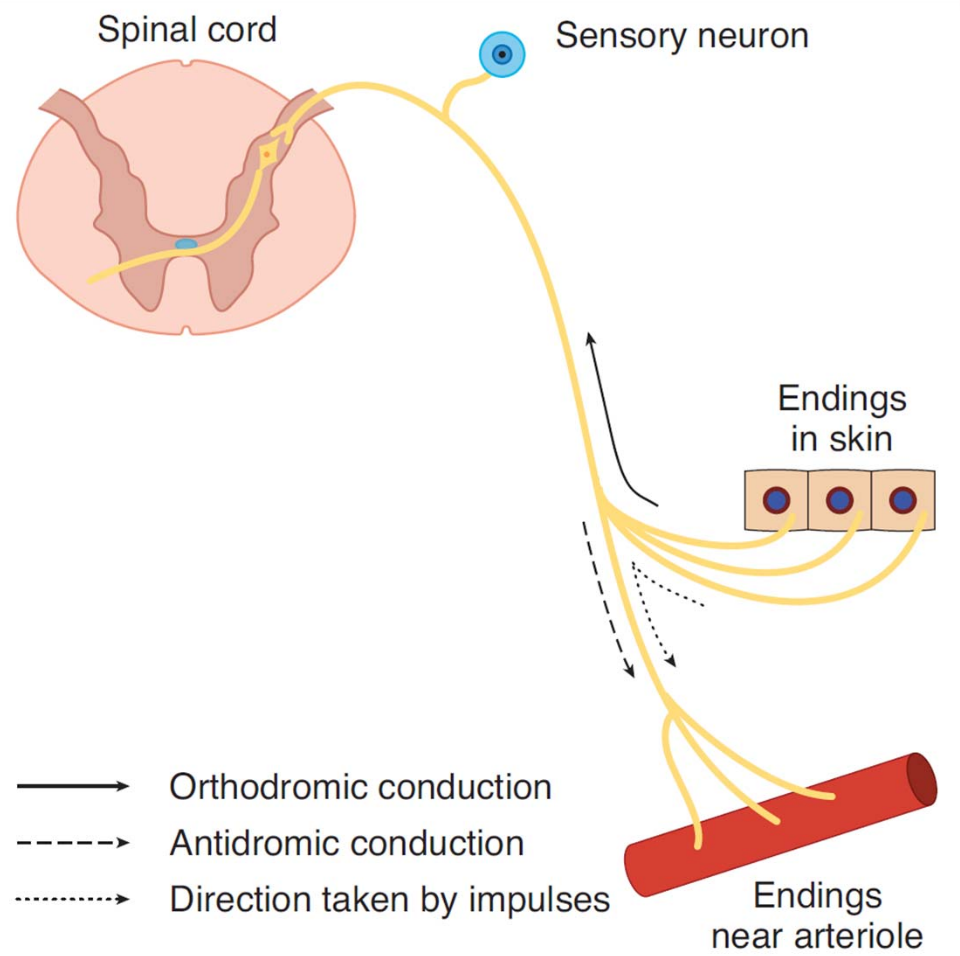
Skin Circulation

- Axon reflex



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Muscle Circulation

Muscle Circulation

- Function:
  1) Blood supply of muscles

     the resting blood flow – 18% of the cardiac output *vs.* even 90% at intensive exertion (the local blood flow ↑ even 20times)
  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
- The blood flow during muscle activity is intermittent, during the tetanic contraction even zero (oxygen debt).

Muscle Circulation

- Regulation of the muscle blood flow:

1) Neural regulation

dominates at rest (vasocontriction through sympathicus - big dilation reserve)

2) Local chemical regulation

dominates at physical exertion (metabolic vasodilation)

almost linear increase of the flow with increasing metabolic activity

increased blood flow + increased O_2 extraction

↑ capillary pressure + ↑ osmolarity → ↑ filtration → edema in active muscles

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

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

2) dynamic blood redistribution

   (metabolic hyperaemia)

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

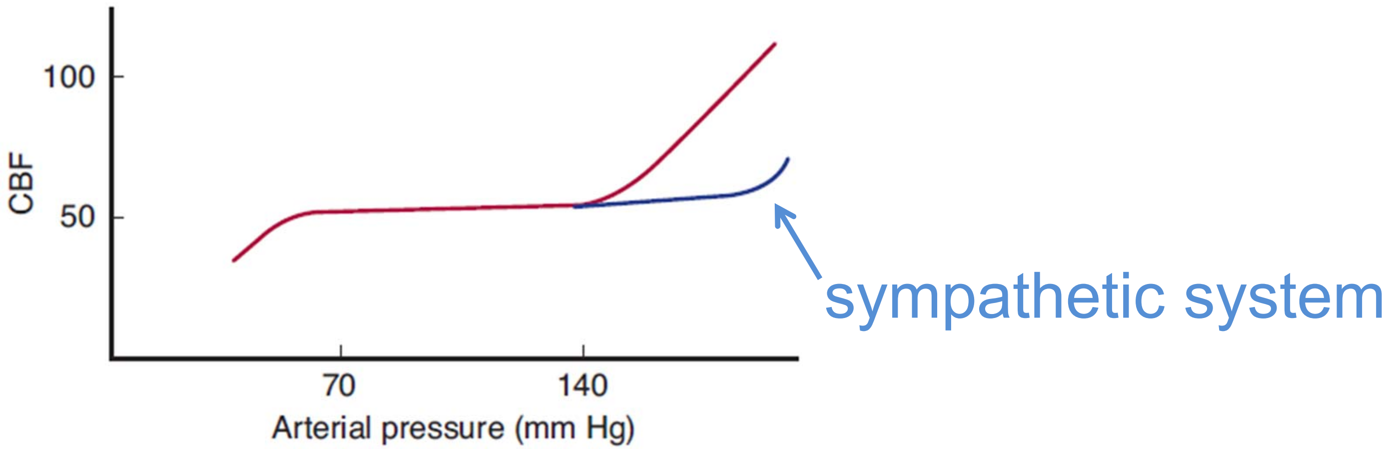
  3) very short arteriols

     (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
  2) high O_2 extraction
  3) well developed autoregulation (myogenic and metabolic)
  4) high reactivity on changes of CO_2 concentration
  5) local *vs.* total hypoxia
  6) innervation

Cerebral Circulation



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Cerebral Circulation

- Special physical conditions of cerebral circulation:

1) solid cover of brain by skull

   Monro-Kelli theory

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

   $\rightarrow$ Cushing reflex

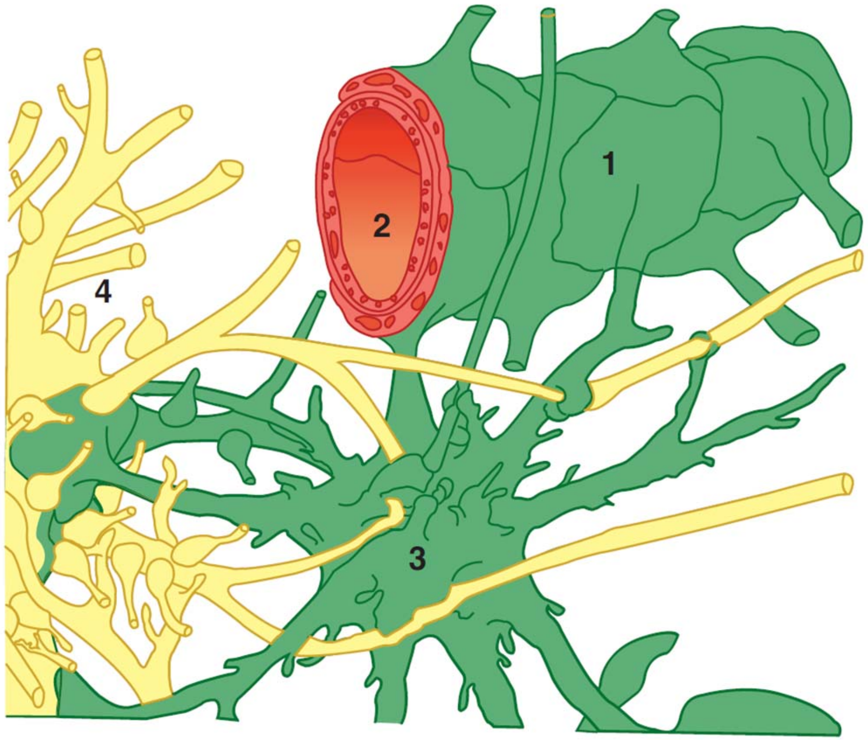
2) gravity

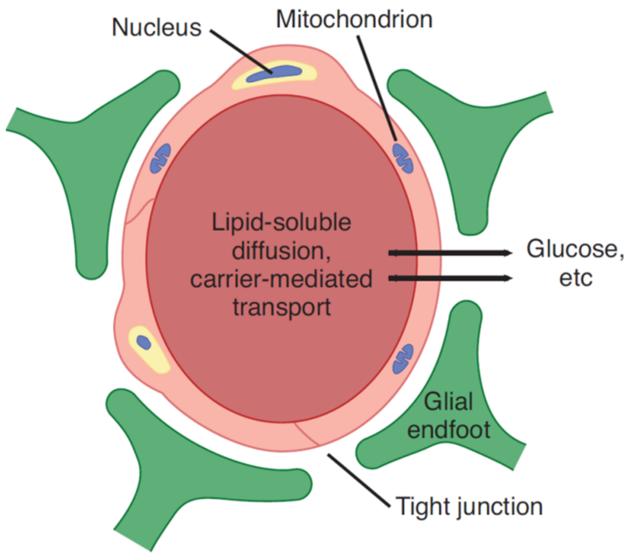
   orthostatic reaction (postural syncope)

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

- 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
  - localization
  - composition
  - volume ~150 ml,
    rate of production ~550 ml/d
    (exchange 3.7times/day)

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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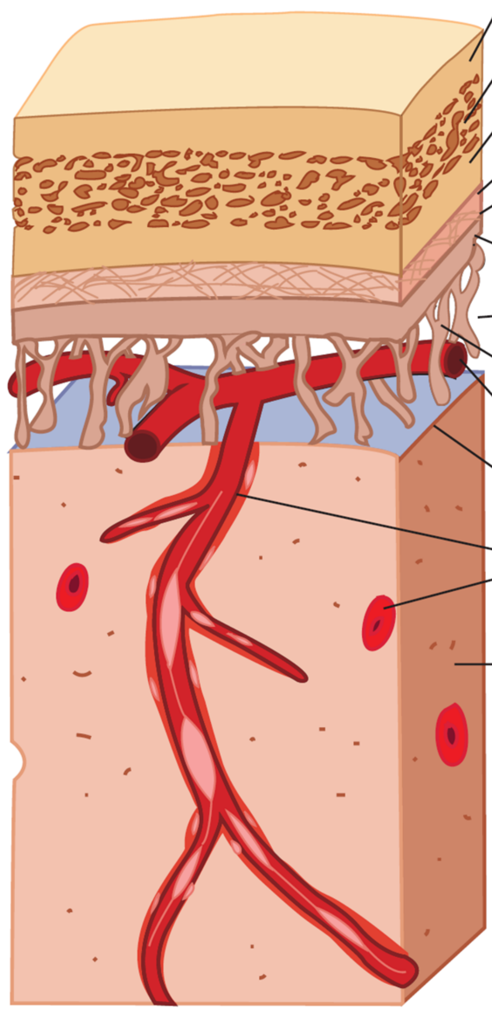
Cerebral Circulation

- Cerebrospinal fluid

  Function:

  - protection of brain
    (together with menanges)



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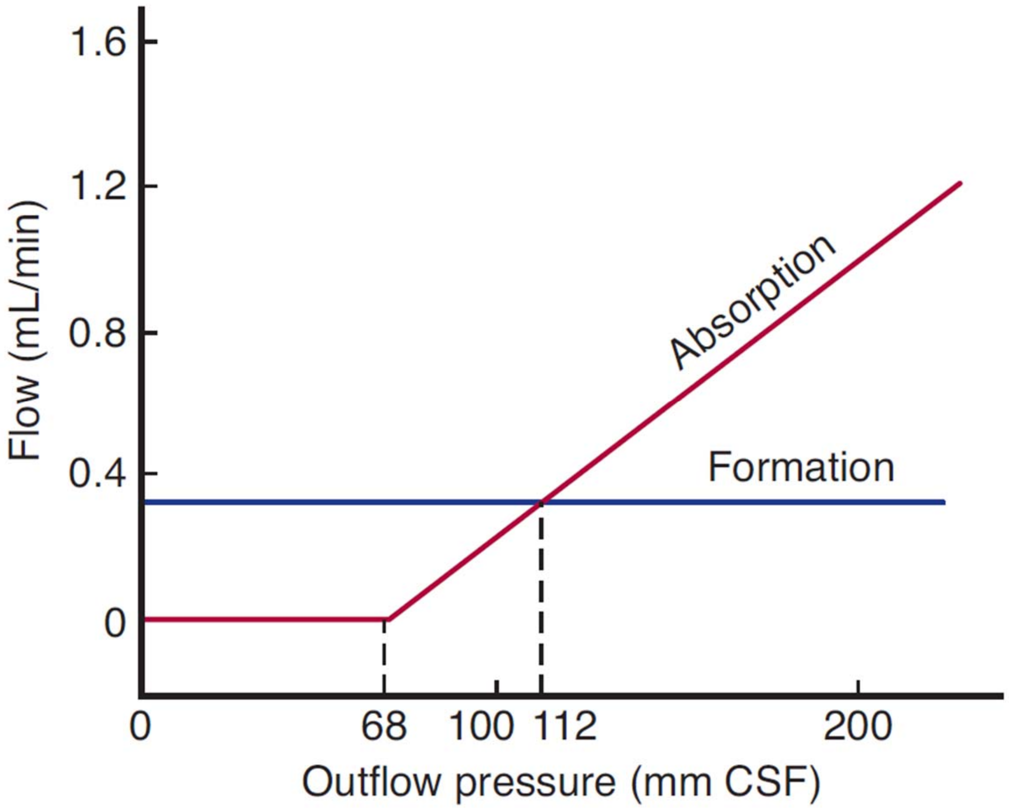
Cerebral Circulation

- Cerebrospinal fluid



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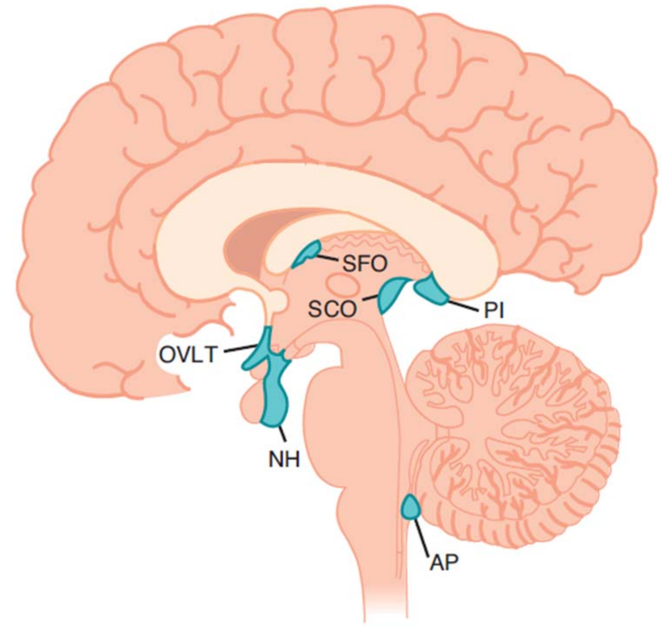
Cerebral Circulation

- Paraventricular organs

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

  - secretion of polypeptides (oxytocin, vasopressin, …),
  - chemoreceptive zones (AP)
  - osmoreceptive zones (OVLT)



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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)

fMRI (functional magnetic resonance)

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

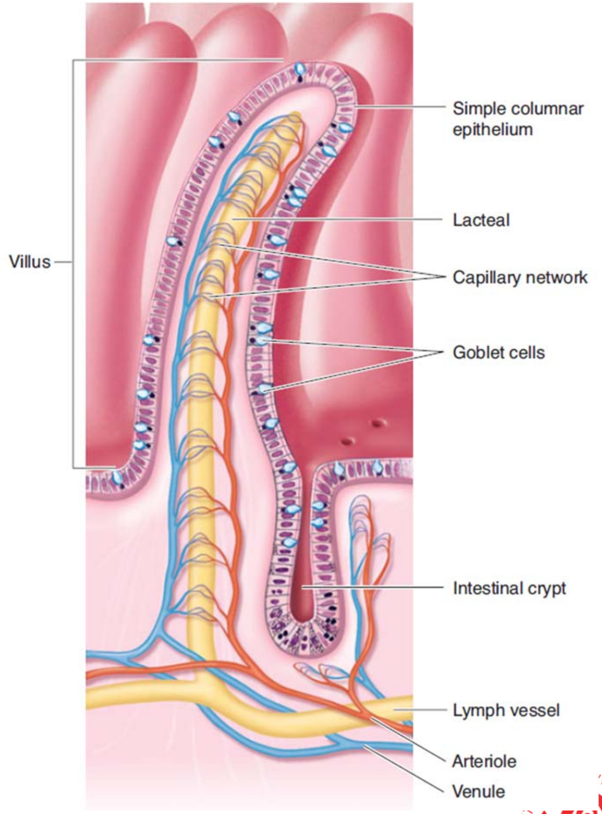
- Blood reservoir
- at rest ~20% of the total blood volume
- rich innervation with sympathetic vasoconstrictive fibers - α rec. (even 350 ml of the blood emptied into the systemic circulation during several minutes!)

Splanchnic Circulation

- **Intestinal circulation**
  (*a. coeliaca, a. mesenterica superior* and *inferior*)

- submucous plexus, branches enter musculature and intestinal villi

- countercurrent exchange of substances



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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)
  - neural regulation – almost exclusively sympathicus, $\alpha > \beta$ rec. → vasoconstriction

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 (intestinal villi, liver sinusoids)
  - ↓ O_2 content → *a. hepatica* represents the nutritive hepatic circulation

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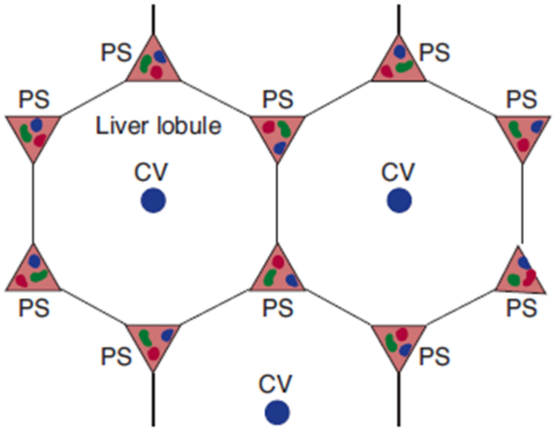
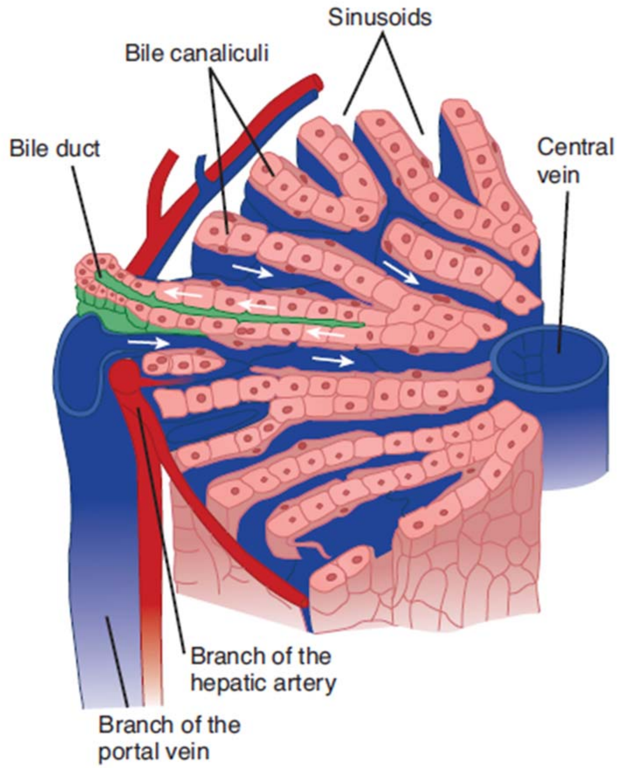
Splanchnic Circulation

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

- functional unit - acinus





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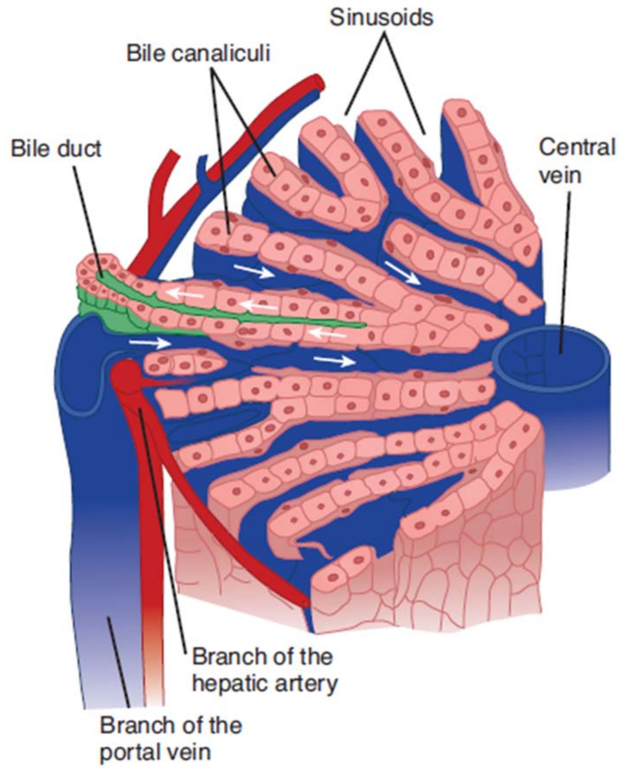
Splanchnic Circulation

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

- pressures:
  - *a. hepatica*: 90 mmHg
  - *v. hepatica*: 5 mmHg
  - *v. portae*: 10 mmHg
  - sinusoids: 2.25 mmHg



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Splanchnic Circulation

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

- inverse regulation of blood flow in *v. portae* and *a. hepatica*:
  - <u>between meals:</u> many sinusoids collapsed, flow in *v. portae* low, adenosine formed constantly and washed less → dilation of terminal hepatic arterioles
  - <u>after a meal:</u> flow in *v. portae* ↑, adenosine washed faster → constriction of hepatic arterioles, higher flow in *v. portae* opens so far collapsed sinusoids

- increased hepatic pressure (cirhosis) → ascites

Splanchnic Circulation

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

    congestive heart failure

    diffuse noradrenergic discharge due to ↓ BP
- sufficient O_2 supply is essential for liver function! - ↓ flow → ↑ O_2 extraction

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)

Renal Circulation

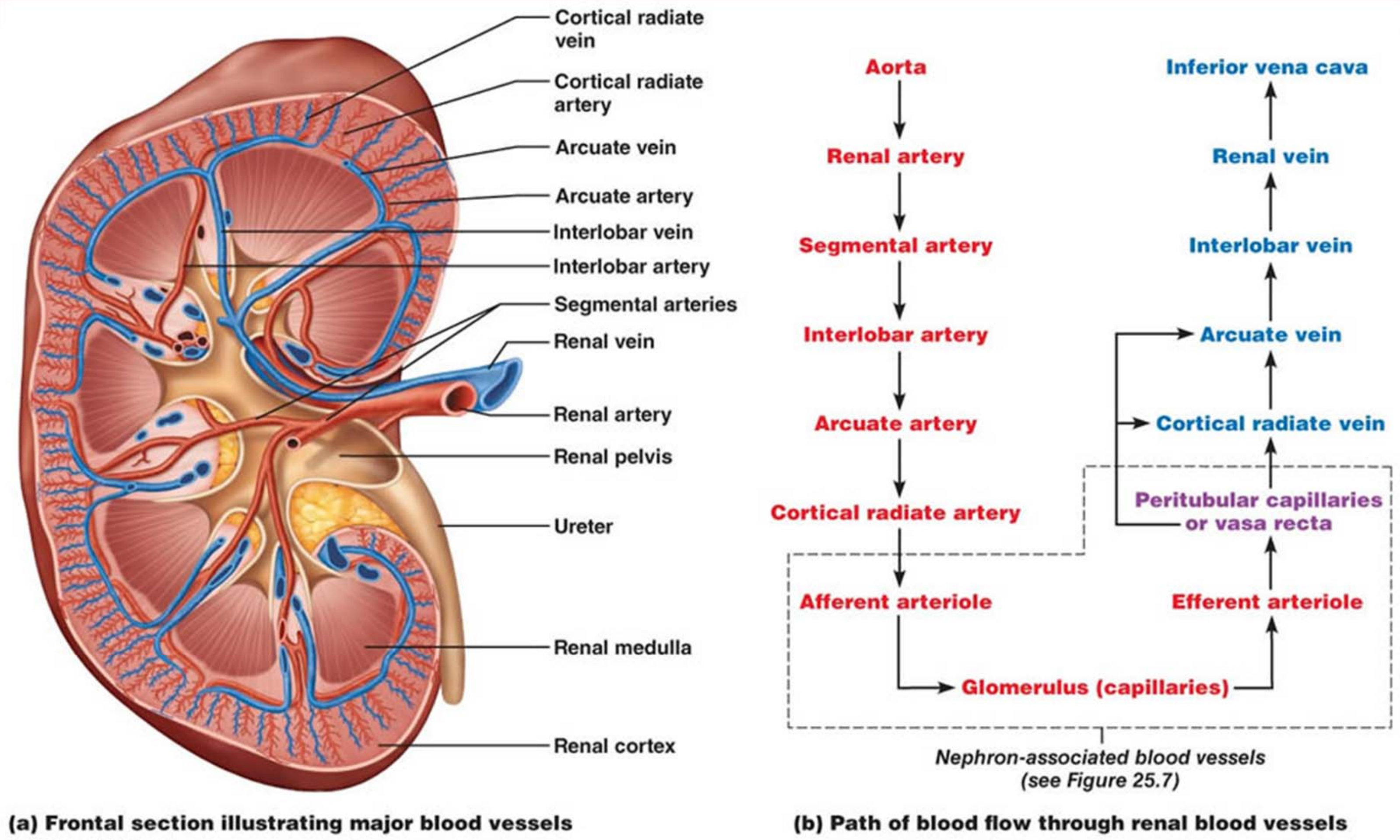
Renal Circulation

- main functions of kidneys

- High filtration rate requires an adequate blood supply!
  - kidneys form only ~0.4 % of the body weight
  - blood flow 1.2 l/min, ~25% of cardiac output

- distribution of blood flow is irregular, the most flows through cortex (glomeruli – filtration)

Renal Circulation



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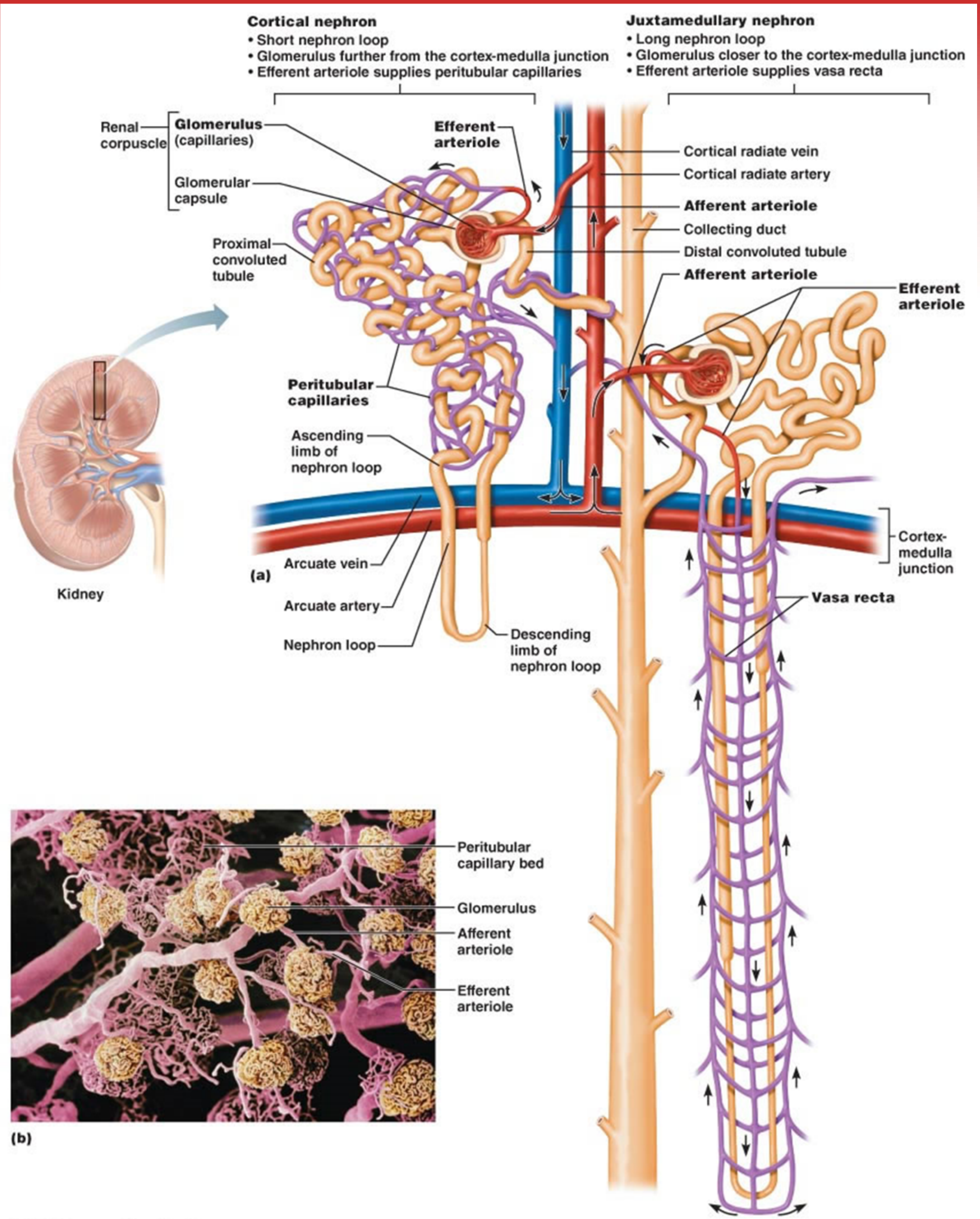

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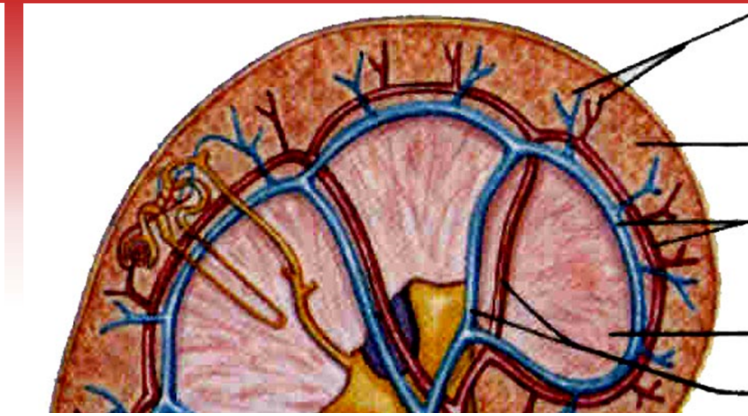

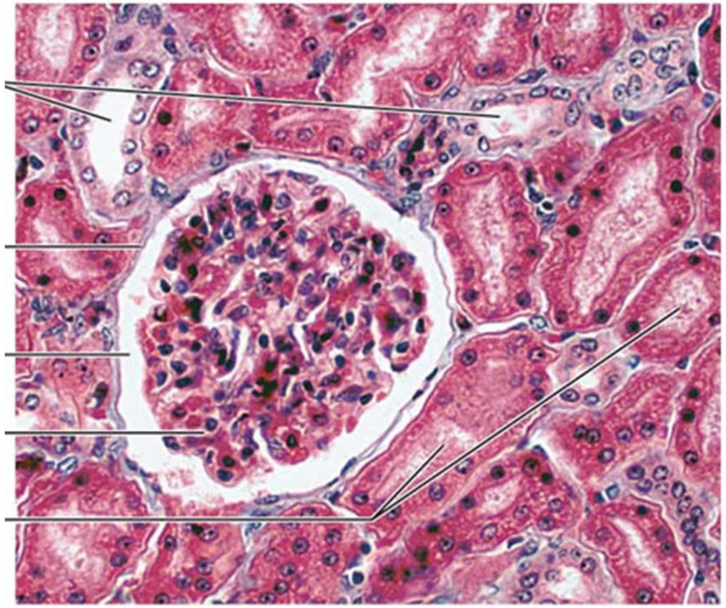

f renal cortical tissue (180×)

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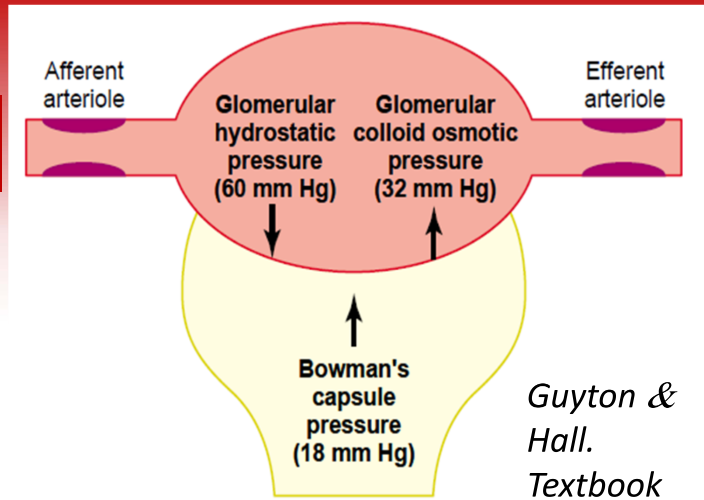
Renal Circul



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- *v. aff., v. eff.*
- glomerular blood flow $= \dfrac{P_{v.a.} - P_{v.e.}}{R_{v.a.} + R_{v.e.} + \cancel{R_{g.k.}}}$
- ↑ resistance in *vas aff.* or *vas eff.* → ↓ the renal blood flow (if the arterial pressure is stable)
- regulate the glomerular filtration pressure:

constriction of *vas aff.* → ↓ glomerular pressure → ↓ filtration

constriction of *vas eff.* → ↑ glomerular pressure → ↑ filtration

Renal Circulation

- **Regulation of renal blood flow:**

1) Myogenic autoregulation
2) Neural regulation
3) Humoral regulation

Renal Circulation

- **Regulation of renal blood flow:**

  1) Myogenic autoregulation

     - dominates
     - provides stable renal filtration activity by maintaining stable blood flow at varying systemic blood pressure

Renal Circulation

- **Regulation of renal blood flow:**

2) Neural regulation

- conformed to demands of systemic circulation
- **sympathetic system - norepinephrine**

light exertion/upright body posture → ↑ sympathetic tone → ↑ tone of *v. aff.* and *eff.* → ↓ renal blood flow but without ↓ GFR (↑ FF)

higher ↑ of sympathetic tone - during anesthesia and pain - GFR may already ↓

Renal Circulation

- **Regulation of renal blood flow:**

3) Humoral Regulation

   - contribute to regulation of systemic BP and regulation of body fluids

   - **NE, E** (from the adrenal medulla)

     constriction of aff. and eff. arterioles → ↓ renal blood flow and GFR

     (small impact with the exception of serious conditions, for example serious bleeding)

Renal Circulation

- **Regulation of renal blood flow:**

3) Humoral Regulation

- contribute to regulation of systemic BP and regulation of body fluids

- **endothelin**

constriction of aff. and eff. arterioles → ↓ renal blood flow and GFR

released locally from the impaired endothel (physiological impact - hemostasis; pathologically increased levels at the toxemia of pregnancy, acute renal failure, chronic uremia)

Renal Circulation

- **Regulation of renal blood flow:**

3) Humoral Regulation

- contribute to regulation of systemic BP and regulation of body fluids
- **NO**

  continual basal production → vasodilation → stable renal blood flow and GFR
- **prostanglandins (PGE_2, PGI_2), bradykinin**

  → vasodilation

  minor impact under physiological conditions

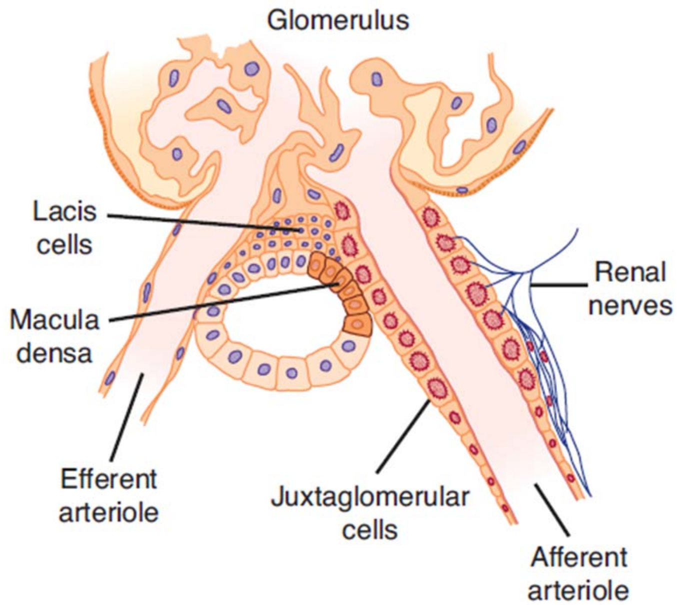
  non-steroidal anti-inflammatory agents during stress!

Renal Circulation

- **Regulation of renal blood flow:**

3) Humoral regulation

   - contribute to regulation of systemic BP and regulation of body fluids
   - **Renin-angiotensine system**



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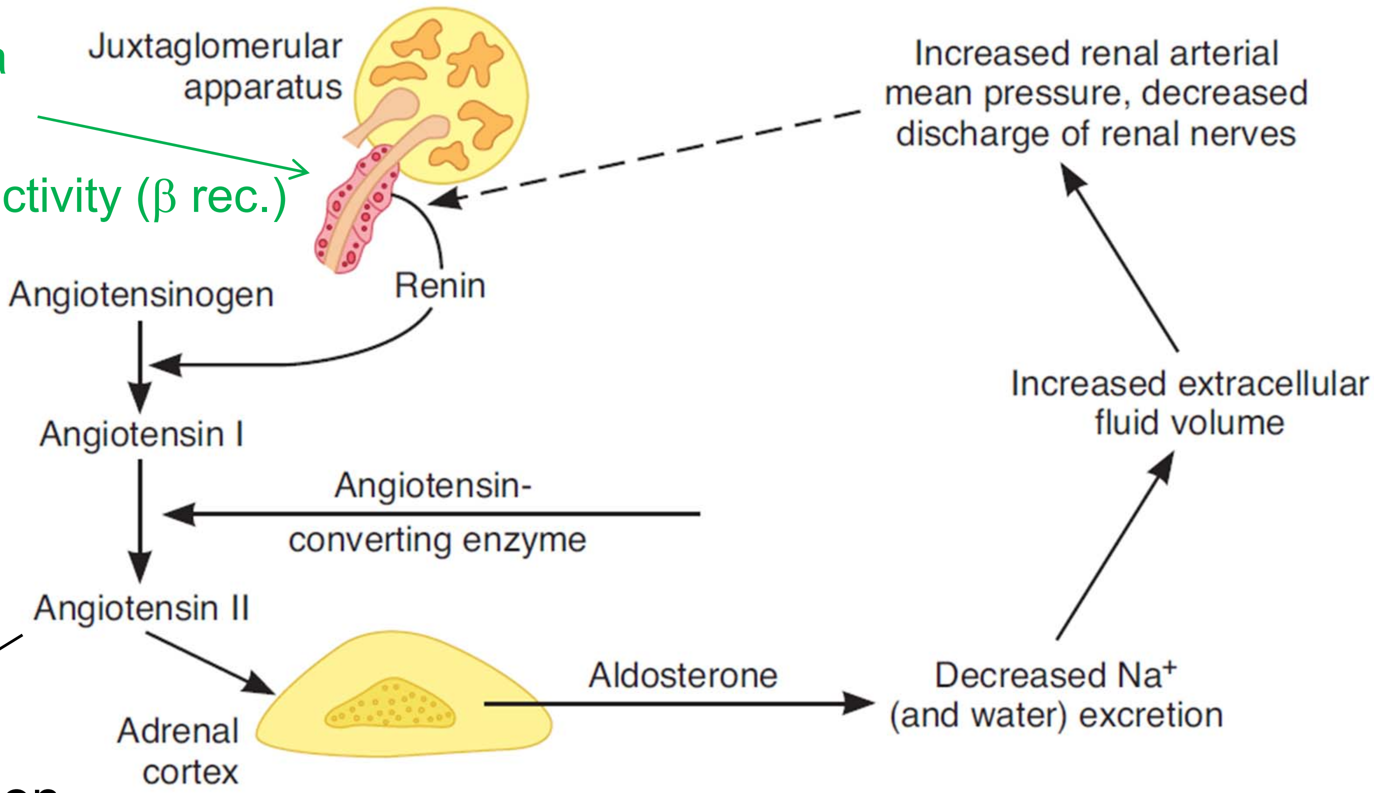
Renal Circulation

Renin-angiotensine system

↓ Na^+ in plasma

↓ BP

↑ sympathetic activity (β rec.)



vasoconstriction

thirst, ADH

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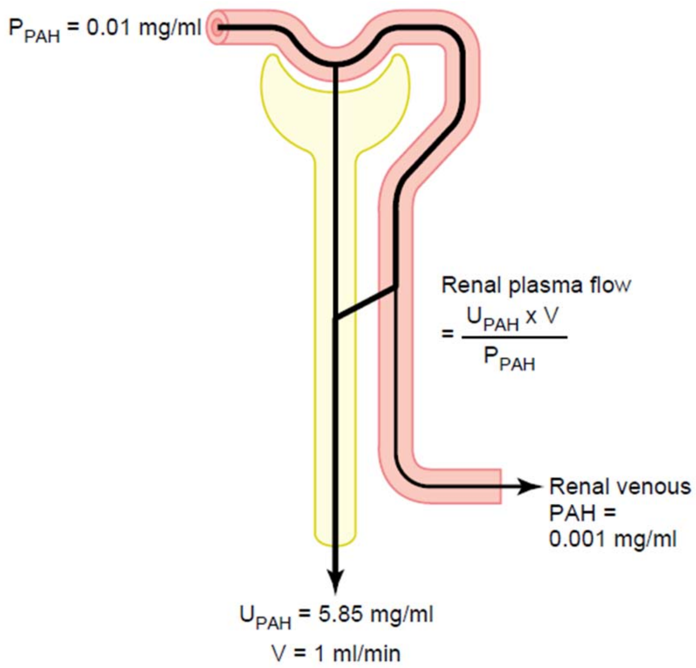
Renal Circulation

Determination of renal plasma flow velocity (RPF)

Clearance of a substance which is fully cleared from plasma in glomerulotubular apparatus.

PAH (paraaminohippuric acid) cleared by 90%

$$RPF = \frac{5.85 \times 1 \text{ mg/min}}{0.01 \text{ mg/ml}} = 585 \text{ ml/min}$$



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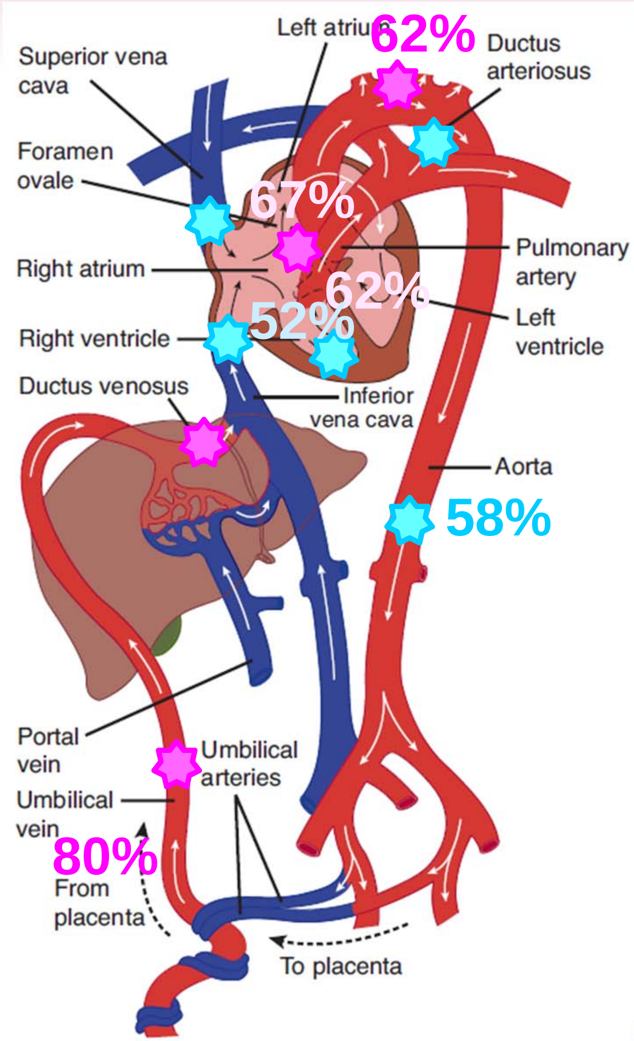
Correction to the extraction ratio of PAH (E_{PAH}):

$$E_{PAH} = \frac{P_{PAH} - V_{PAH}}{P_{PAH}} = 0.9 \longrightarrow RPF = \frac{585 \text{ ml/min}}{0.9} = 650 \text{ ml/min}$$

Fetal Circulation

Fetal Circulation

- placenta, umbilical vein
- liver, *ductus venosus*
- *crista dividens, foramen ovale*
- blood supply of the head and upper limbs
- *v. cava superior and inferior*
- the right ventricle
- *ductus arteriosus*
- aorta – the blood supply of the lower part of body + 60% of the cardiac output is directed to placenta



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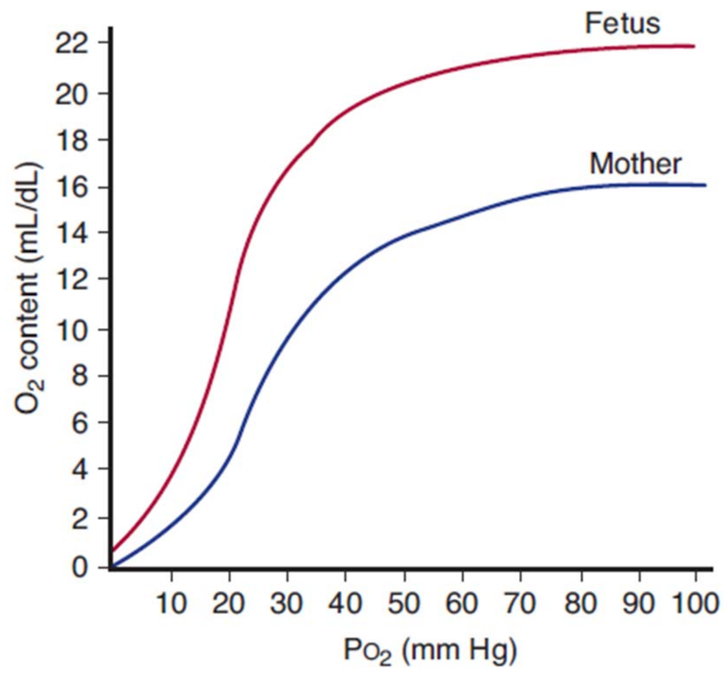
Fetal Circulation

- fetal haemoglobin

- short-period hypoxia
- longer hypoxia

- thick muscle wall of umbilical vessels



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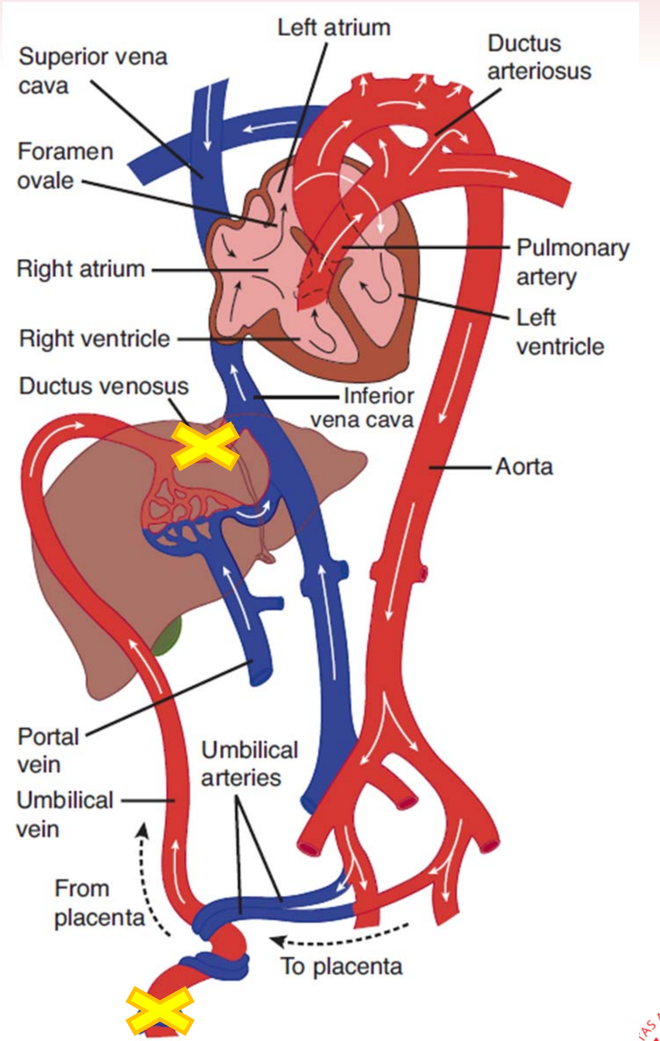
Fetal Circulation

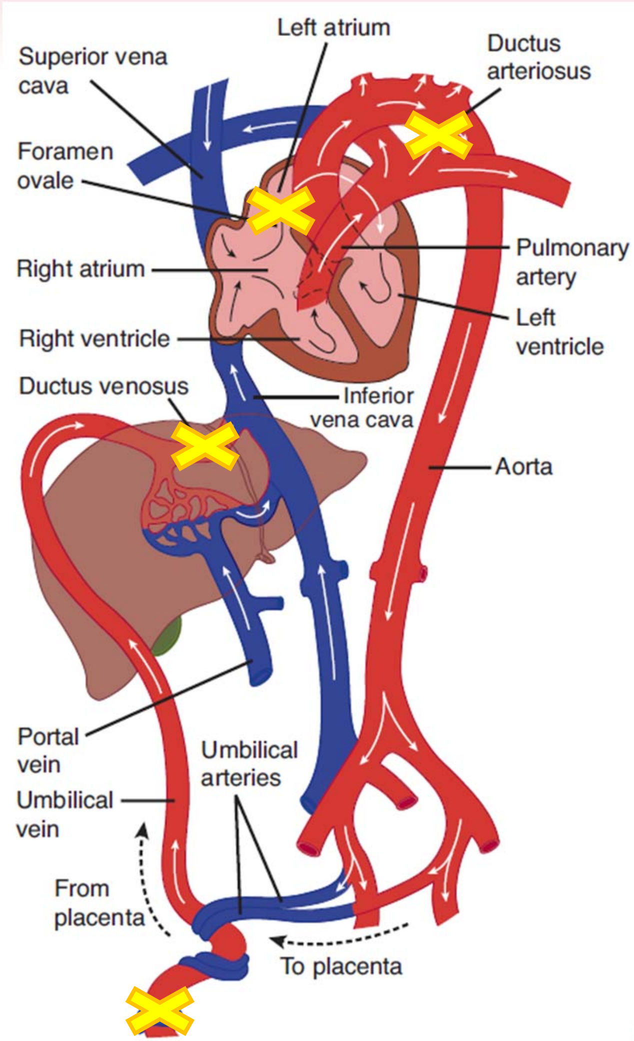
- **Changes after birth**
- **Closure of umbilical vein**
  - sudden ↑ of peripheral resistance and blood pressure
  - contraction of musculature of *ductus venosus* and its closure
- **The first inspiration** (due to asphyxia and cooling of the body)
  - ↓ resistance of the lung bloodstream
  - much more blood into lungs



Ganong´s Review of Medical Physiology, 23rd edition

Fetal Circulation

- **Changes after birth**
- **Decrease of pressure in right atrium and its increase in left atrium** due to:
  - ↑ filling of left atrium by the blood from lungs
  - ↓ venous return to right atrium due to closure of umbilical vein
  - left ventricle works against ↑ pressure in aorta
- **Closure of *formanen ovale***
- **Closure of *ductus arteriosus***



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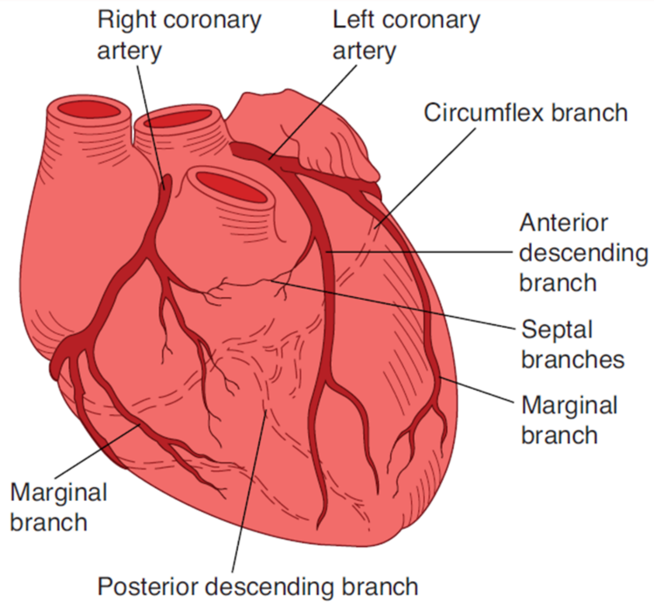
Coronary Circulation

Coronary Circulation

- *a. cor. sinistra*
- *a. cor. dextra*

- O_2 diffusion directly from the blood situated in the cardiac cavities
- placing of coronary arteries and capillaries in the cardiac walls; consequences!



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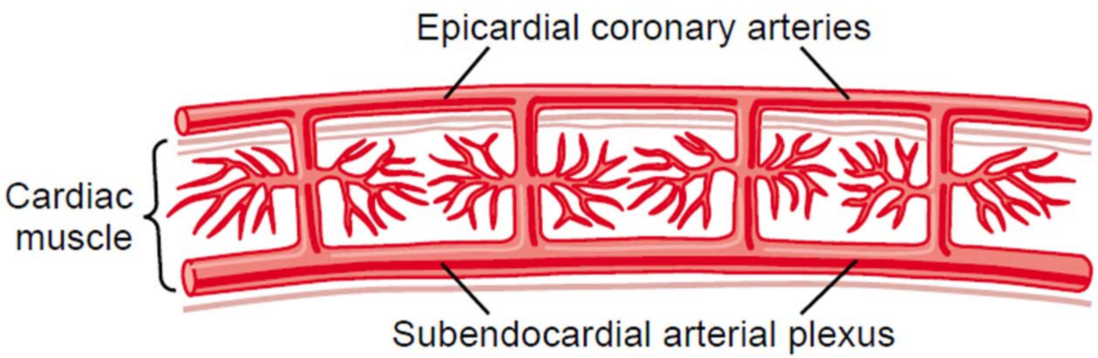
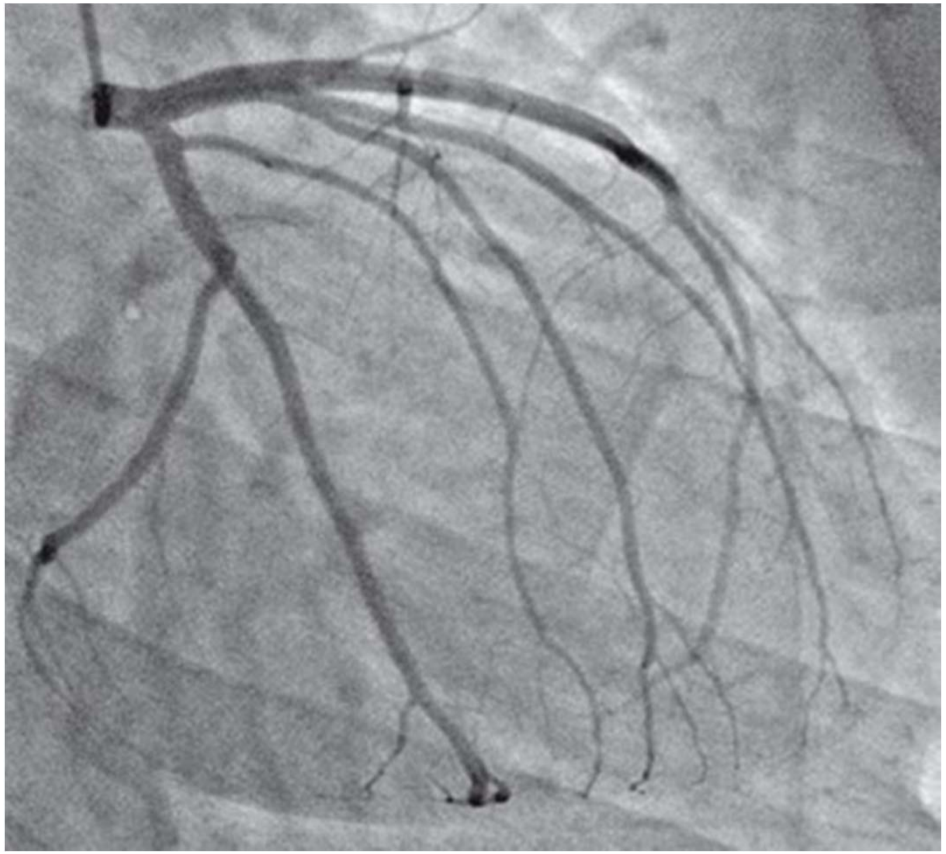


Guyton and Hall. Textbook of Medical Physiology, 11th edition

Coronary Circulation

Coronary angiography



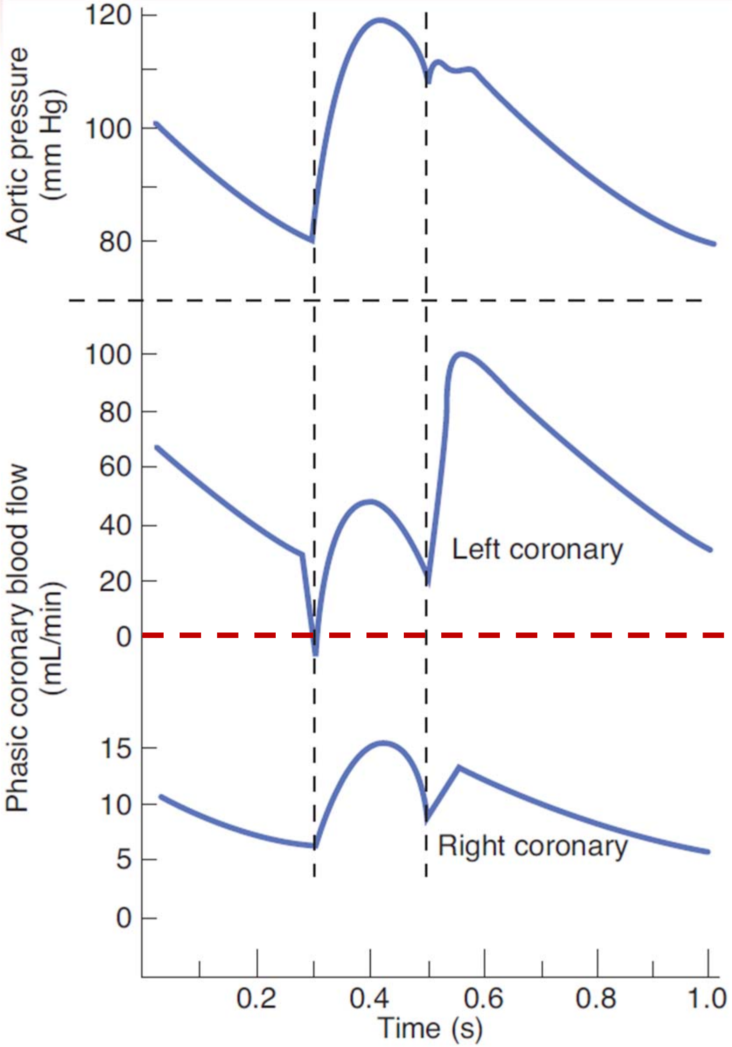
http://pochp.mp.pl/aktualnosci/show.html?id=55102

Coronary Circulation

TABLE 34–4 Pressure in aorta and left and right ventricles (vent) in systole and diastole.

	Pressure (mm Hg) in			Pressure Differential (mm Hg) between Aorta and	
	Aorta	Left Vent	Right Vent	Left Vent	Right Vent
Systole	120	121	25	–1	95
Diastole	80	0	0	80	80

- intramural vessels
- left *vs.* right ventricle
- high heart rate



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Coronary Circulation

- O_2 extraction is almost maximal already at rest, capillaries are open

↓

- The only possibility how to increase O_2 supply (for example during exercise) is the coronary vasodilation!

Coronary Circulation

Control of coronary blood flow

1) reduction/interruption of the blood flow or increased demands

↓

hyperaemia (reactive or active) based on the metabolic vasodilation

Coronary Circulation

Control of coronary blood flow

2) the neural regulation of the vessel diameter – secondary impact
   a) indirect effects
   b) direct effects

X (mostly opposite)

Coronary Circulation

Control of coronary blood flow

2) the neural regulation of the vessel diameter – secondary impact

   a) indirect effects

      sympathetic system (NE, E)

      ↑ HR + contractility → rate of cardiac metabolism → increased O_2 consumption → activation of local vasodilating mechanisms

      parasympathetic system (ACH)

      opposite changes → vasoconstriction

Coronary Circulation

Control of coronary blood flow

2) the neural regulation of the vessel diameter – secondary impact
   a) indirect effects
   b) direct effects

sympathetic system (NE, E)

vasospastic myocardial ischemia

epicardial vessels – mostly α-rec. → vasoconstriction
intramural vessels – mostly β-rec. → vasodilation

parasympathetic system (ACH)

vasodilation, but not significant (only few fibers)

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Coronary Circulation

Control of coronary blood flow

2) the neural regulation of the vessel diameter – secondary impact
    a) indirect effects
    b) direct effects

Whenever the direct effects alter the coronary blood flow in the wrong direction, the metabolic control overrides them within seconds!

Coronary Reserve

- ability of coronary vessels to adapt blood flow to the actual cardiac work (**ergometry**)
- **the maximal blood flow / the resting blood flow**
- reduction of the coronary reserve:
  - relative coronary insufficiency
  - absolute coronary insufficiency (~ coronary heart disease)

Reduced coronary reserve is a limiting factor of the cardiac output, thus, also of the effort of organism!