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

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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

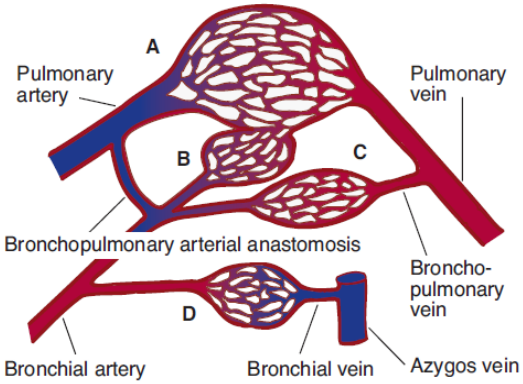
Pulmonary Circulation

- Arteries (differences compared to the arteries in the systemic circulation)
  - bigger total cross-section of all pulmonary arteries
  - smaller thickness of the vessel walls
  - 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

Minimal 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

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

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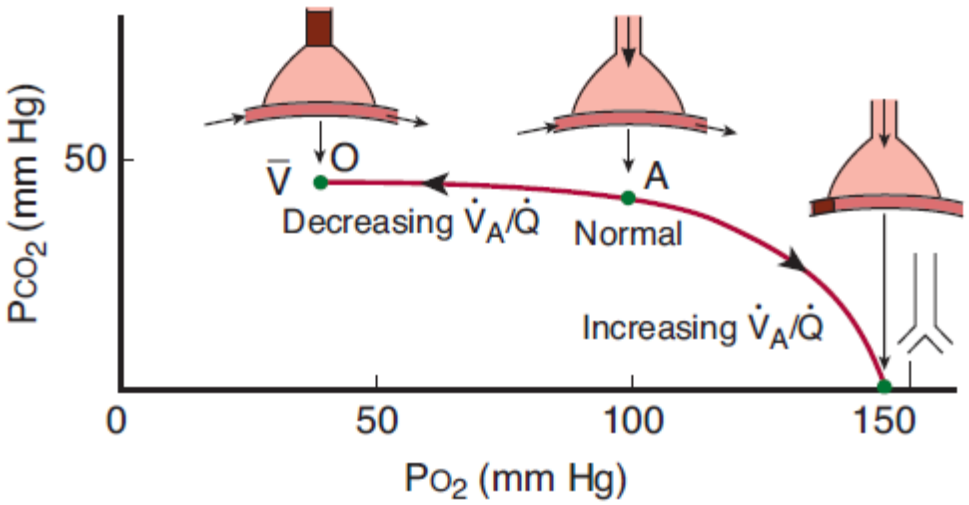


  - content of CO_2 usually not changed (compensatory hyperventilation in other alveoles)

Skin Circulation

Skin Circulation

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

Function:

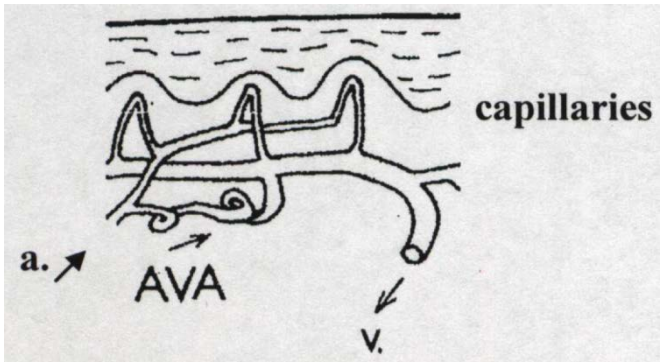
- Metabolic demands of skin – small (*decubitus*)
- **Maintenance of body temperature**

  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)

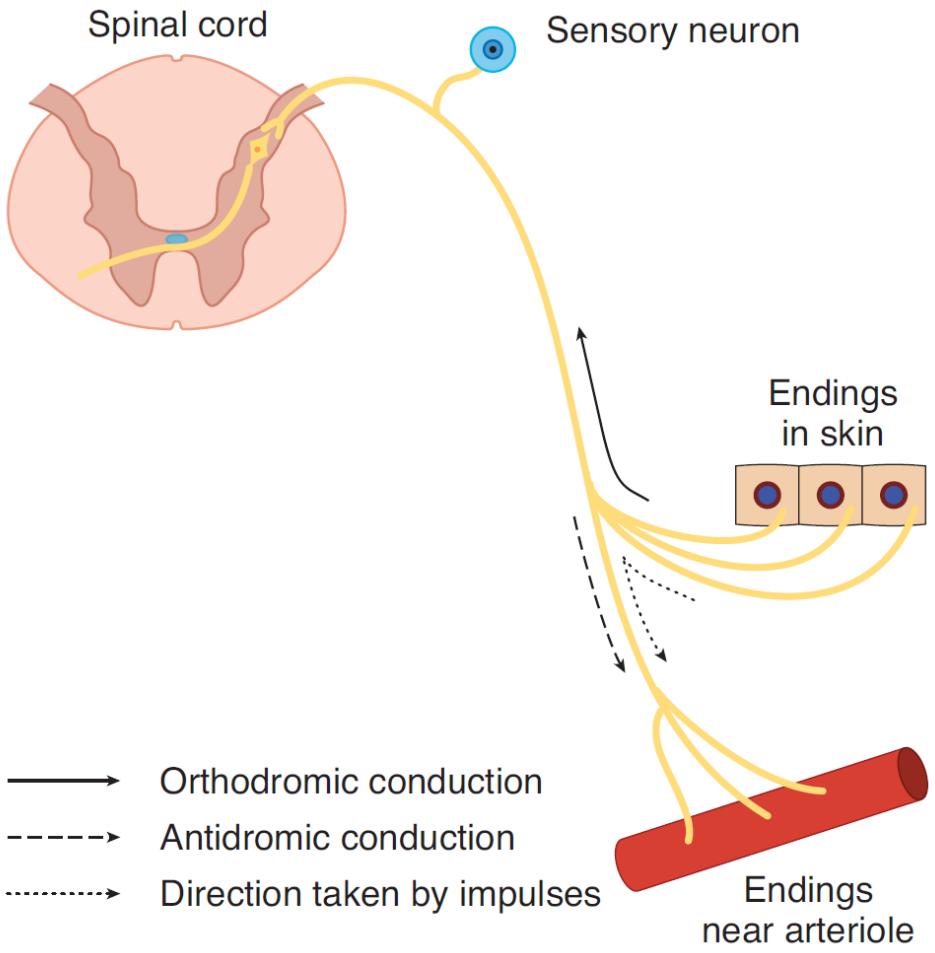
Skin Circulation

- 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

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

- 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

- Special physical conditions of cerebral circulation:

1) solid cover of brain by skull

   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

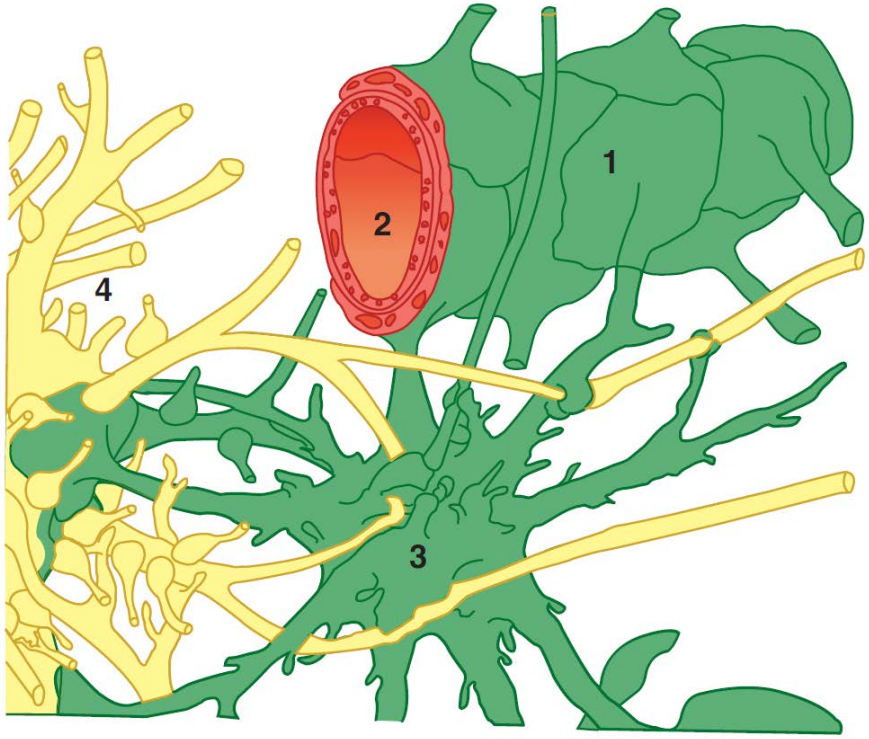
2) gravity

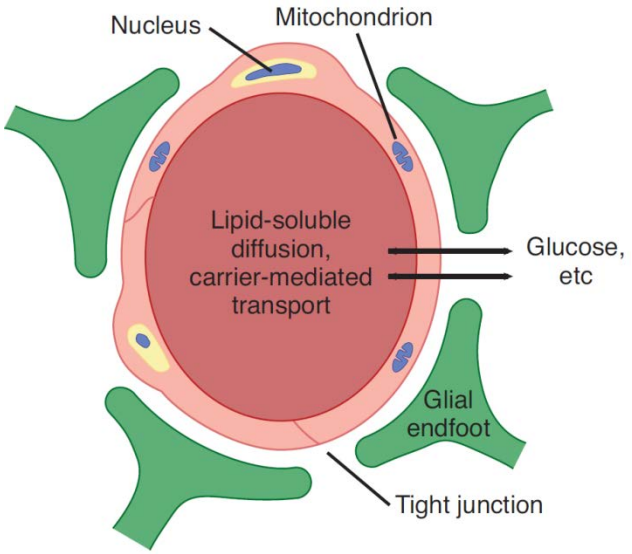
   orthostatic reaction (postural syncope)

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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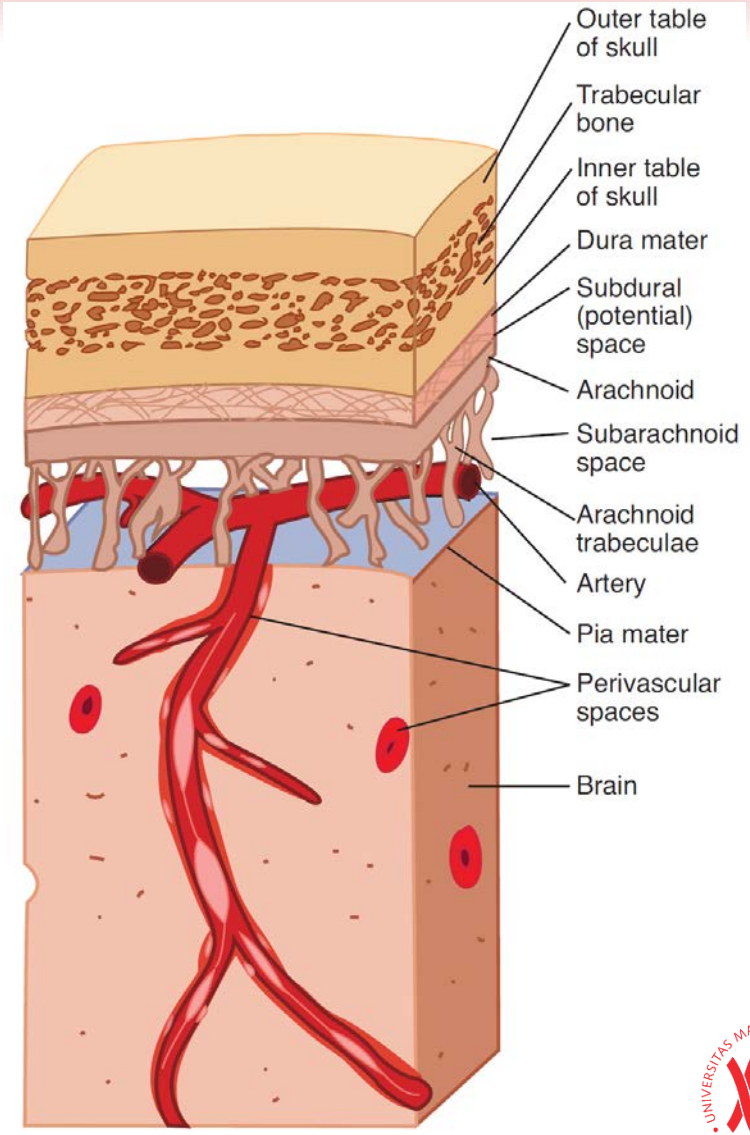
Cerebral Circulation

- Cerebrospinal fluid

  Function:

  - protection of brain
    (together with menanges)



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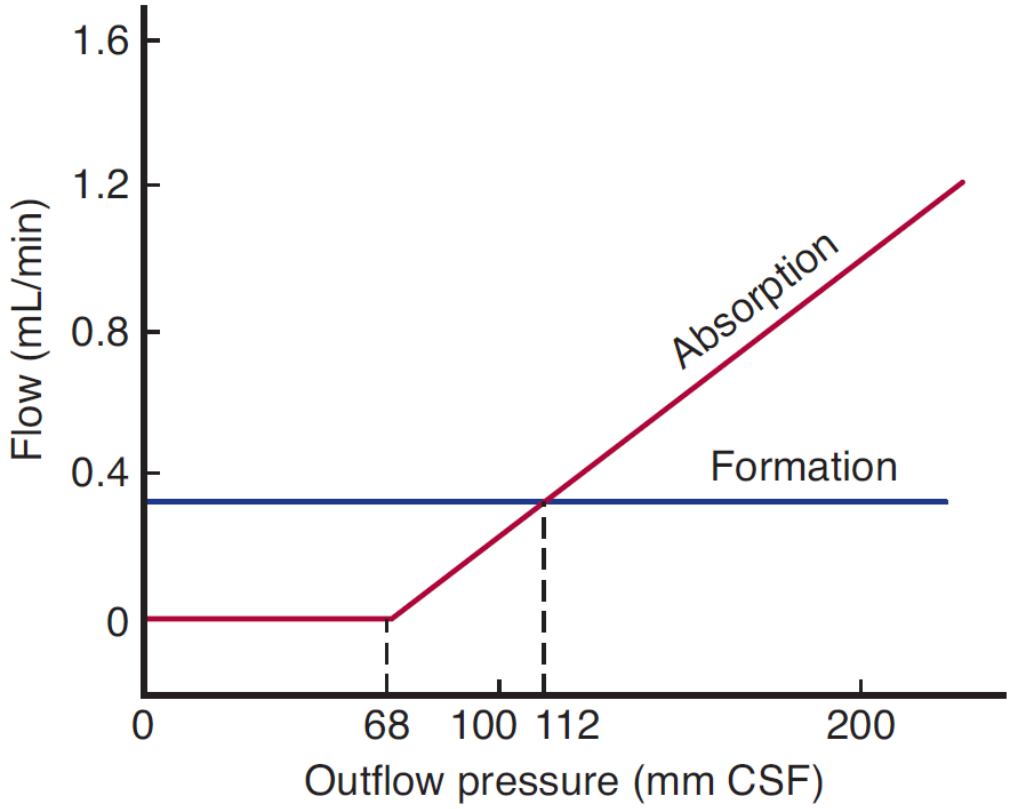
Cerebral Circulation

- Cerebrospinal fluid



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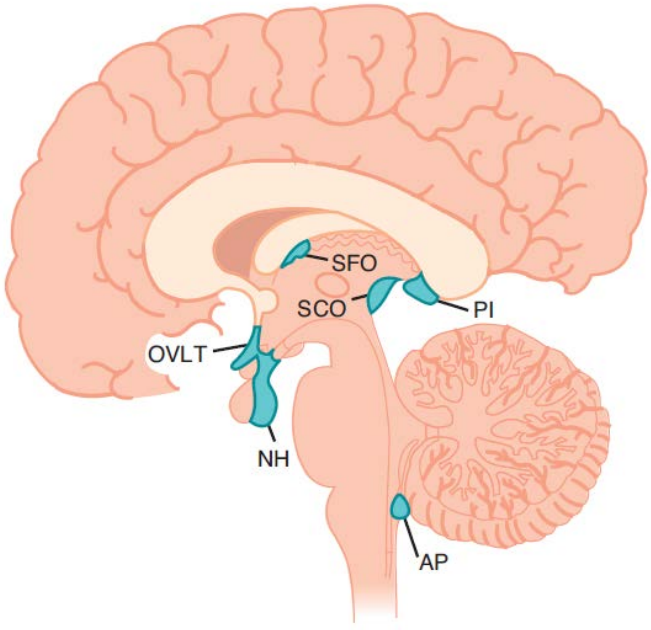
Cerebral Circulation

- 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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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

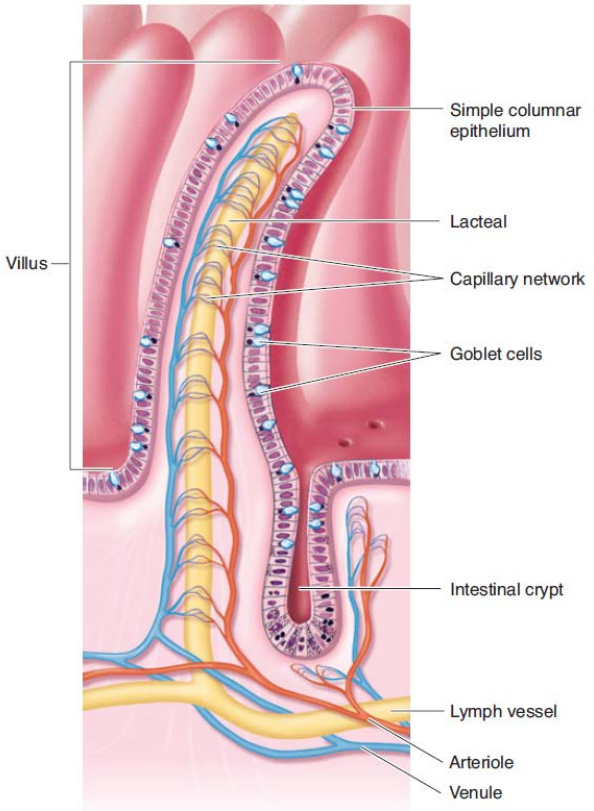
- Blood reservoir
- at rest ~20% of the total blood volume
- rich innervation with sympathetic vasoconstrictive fibers - α rec. (even 350 ml of the blood emptied into the systemic circulation during several minutes!)

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, α > β 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*

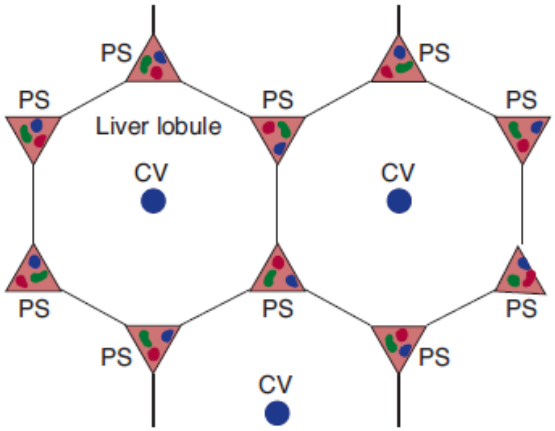
Regarding O_2 supply, the ratio is opposite!

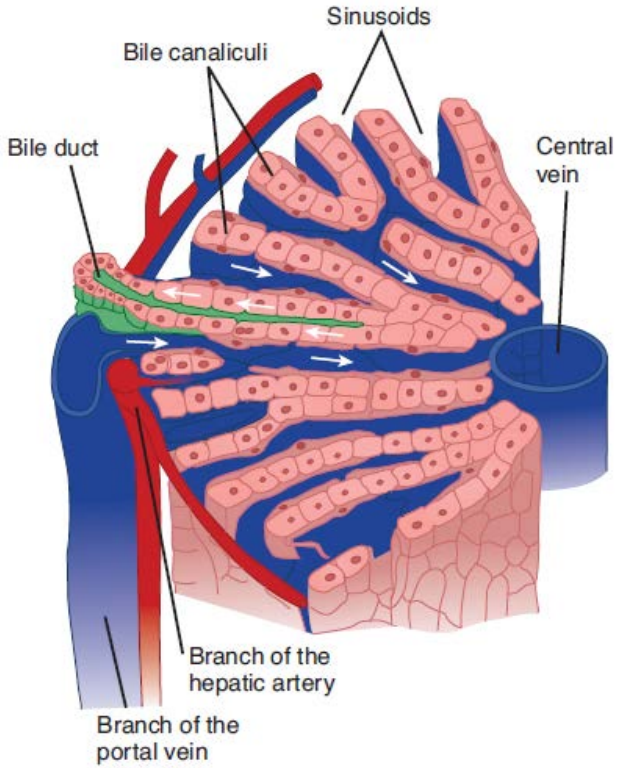
- portal circulation
  - 2 capillary bloodstreams in series (intestinal villi, liver sinusoids)
  - ↓ O_2 content → *a. hepatica* represents the nutritive hepatic circulation

Splanchnic Circulation

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

- functional unit - acinus





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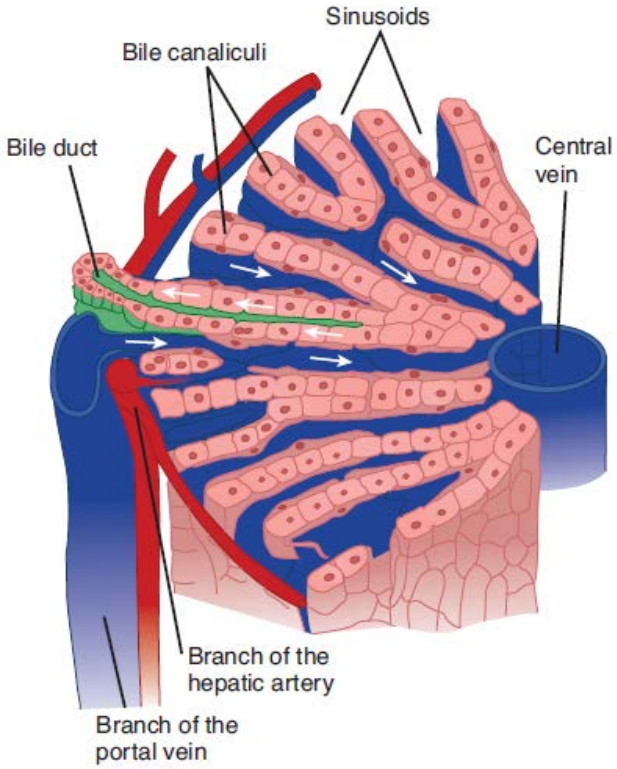
Splanchnic Circulation

- **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*:
  - 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* opens so far collapsed sinusoids
- increased hepatic pressure (cirhosis) → ascites

Splanchnic Circulation

- **Hepatic circulation** (*v. portae, a. hepatica*)
- Regulation of blood flow:
  - 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

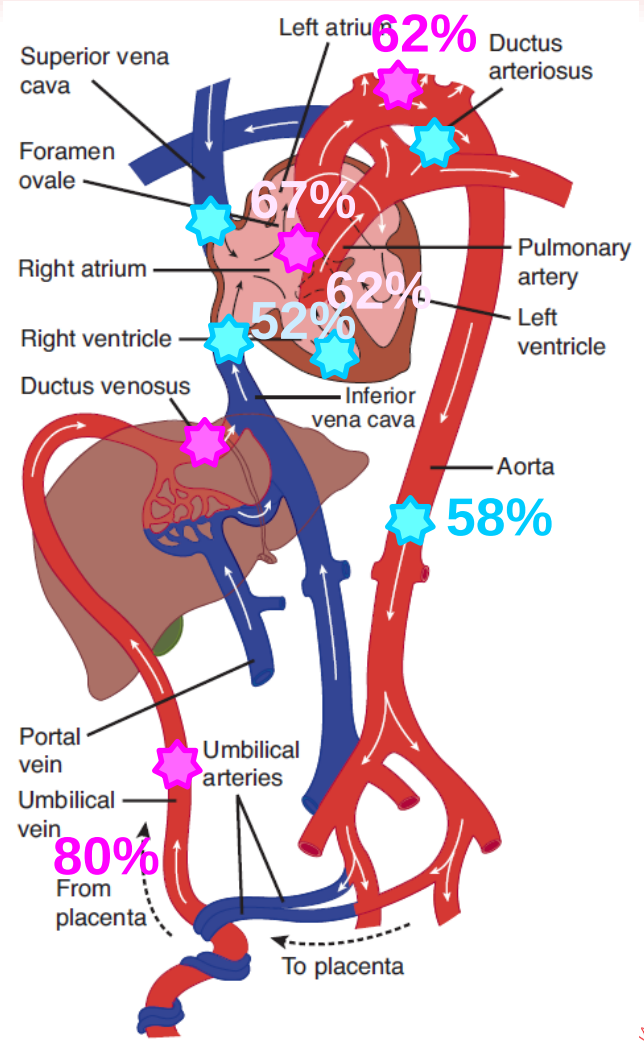
Splanchnic Circulation

- **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)

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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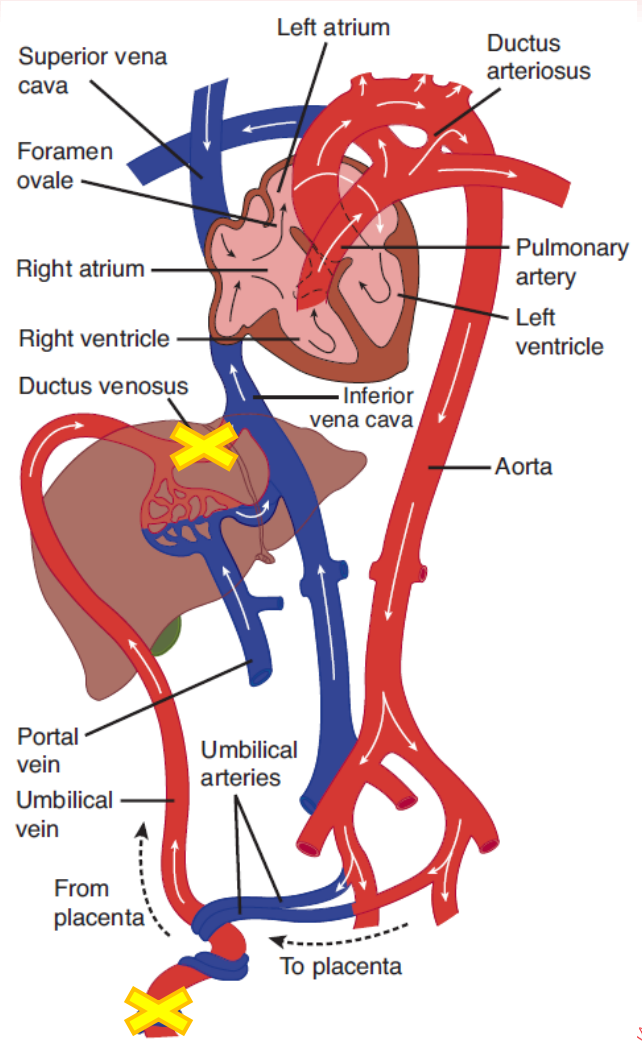
Fetal Circulation

- **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



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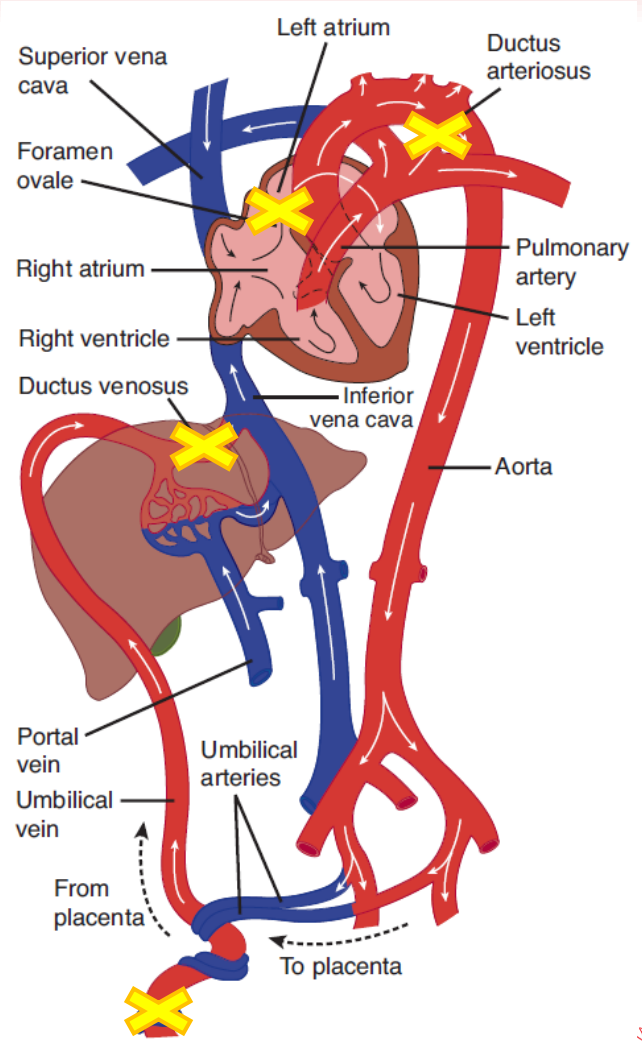
Fetal Circulation

- **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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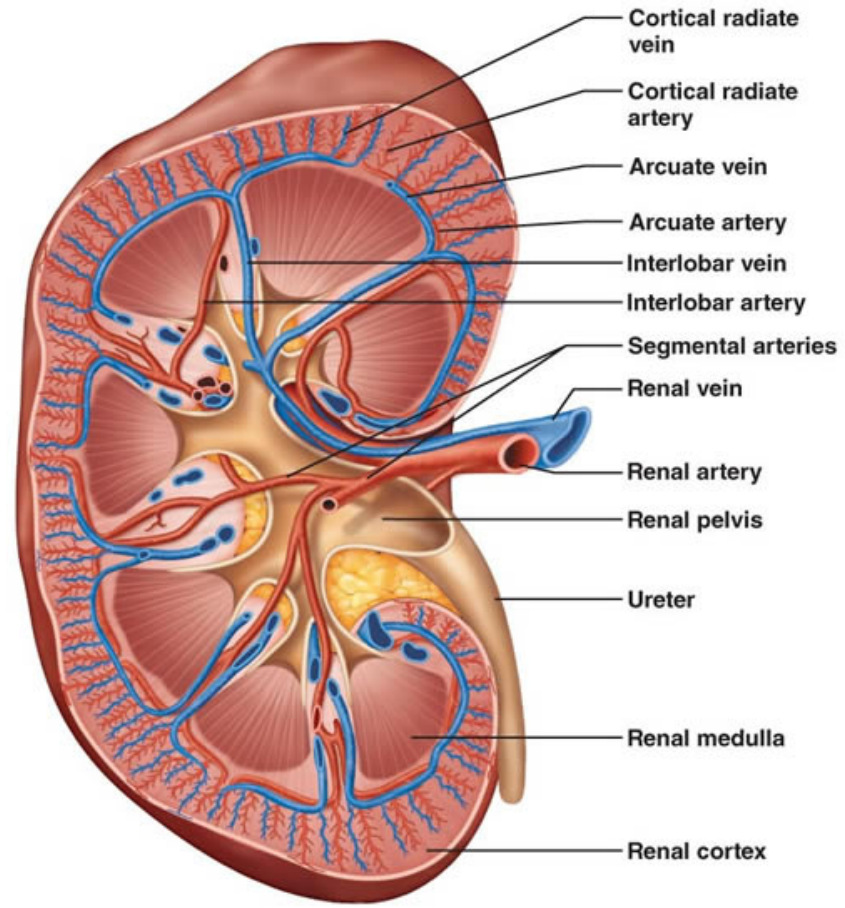
Renal Circulation

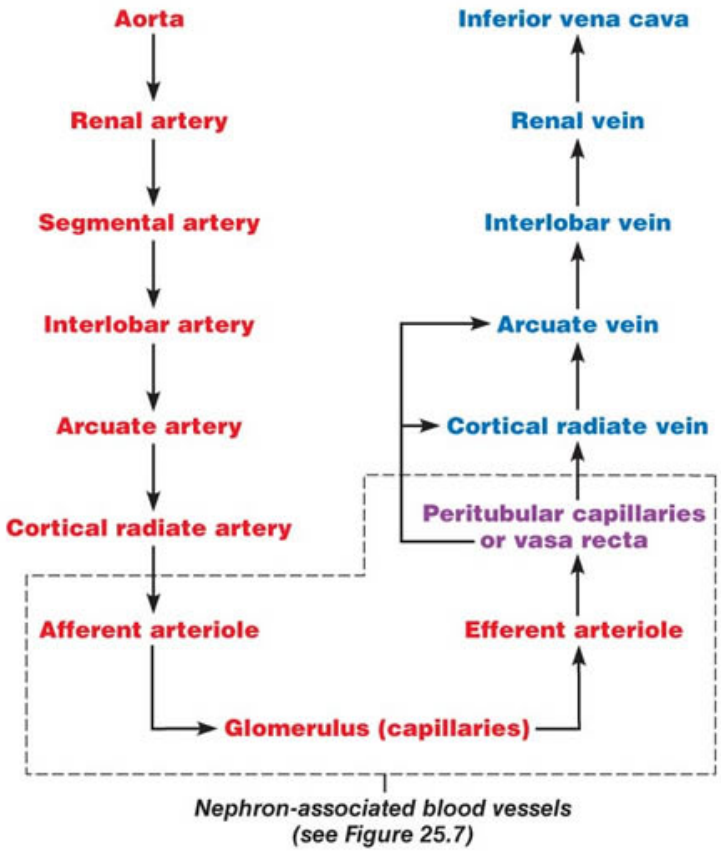
Renal Circulation

- 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

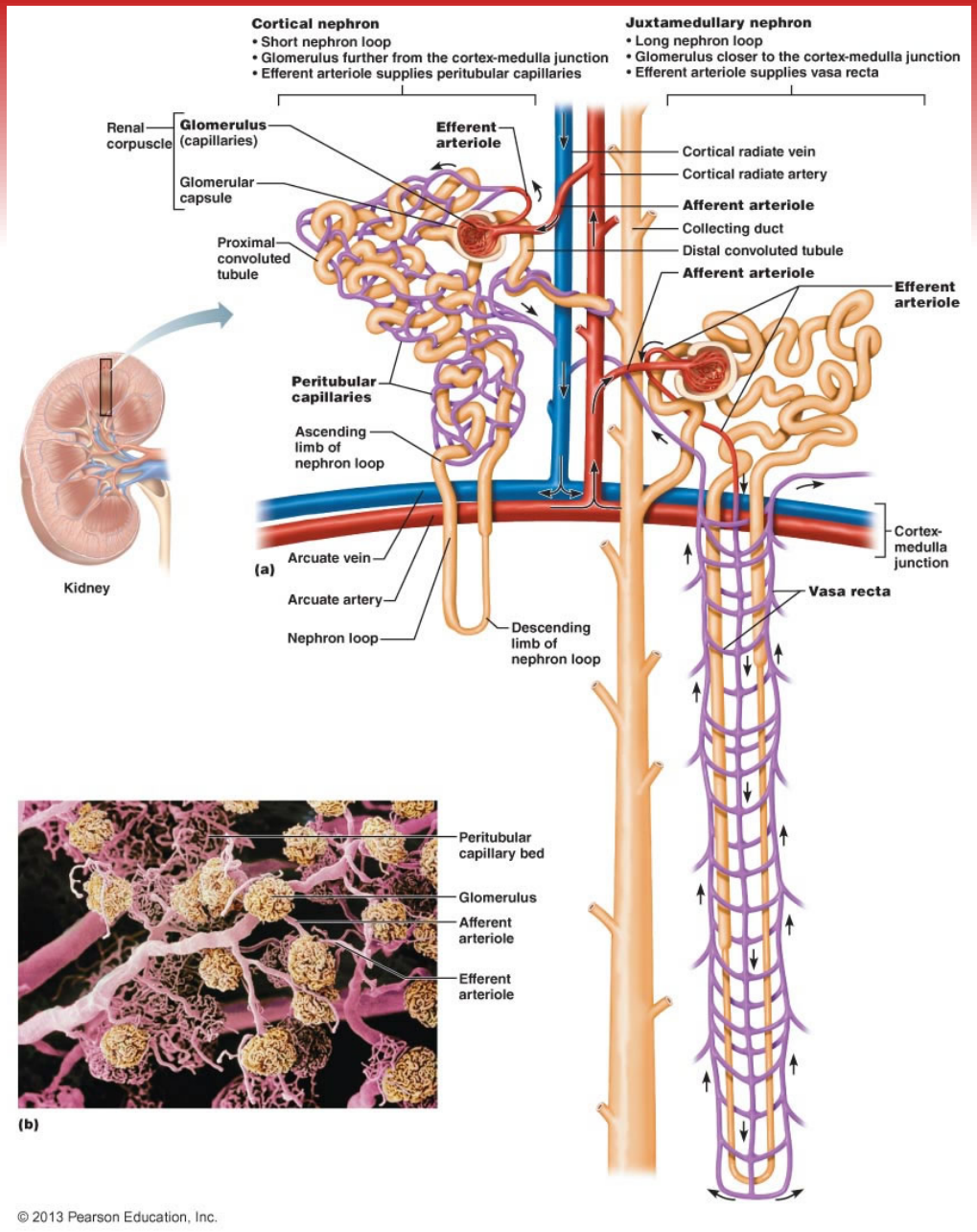


(a) Frontal section illustrating major blood vessels



(b) Path of blood flow through renal blood vessels

http://classes.midlandstech.edu/carterp/Courses/bio211/chap25/chap25.htm



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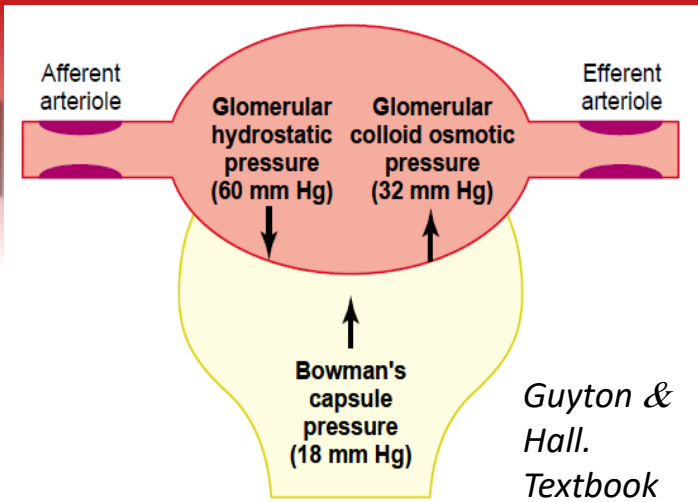
Renal Circul



Guyton & Hall. Textbook of Medical Physiology

- *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 $\rightarrow \downarrow$ 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 $\rightarrow \downarrow$ 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

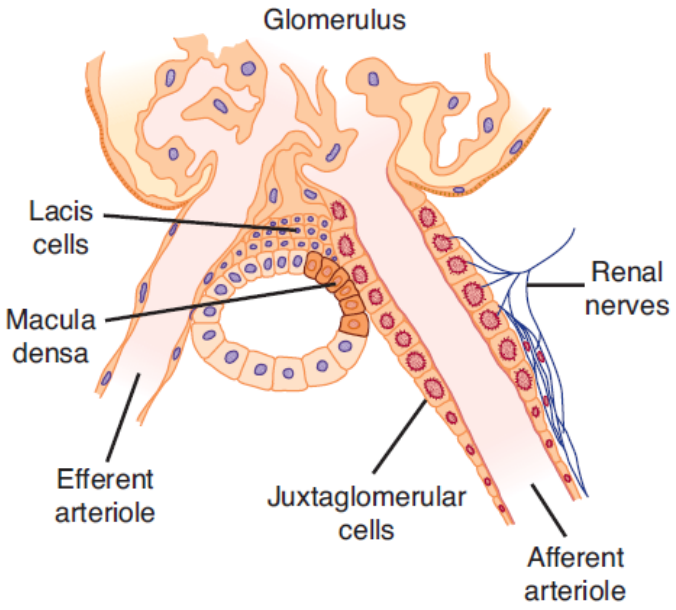
  non-steroidal anti-inflammatory agents during stress!

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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