Brain and behavior, environment of the neuron

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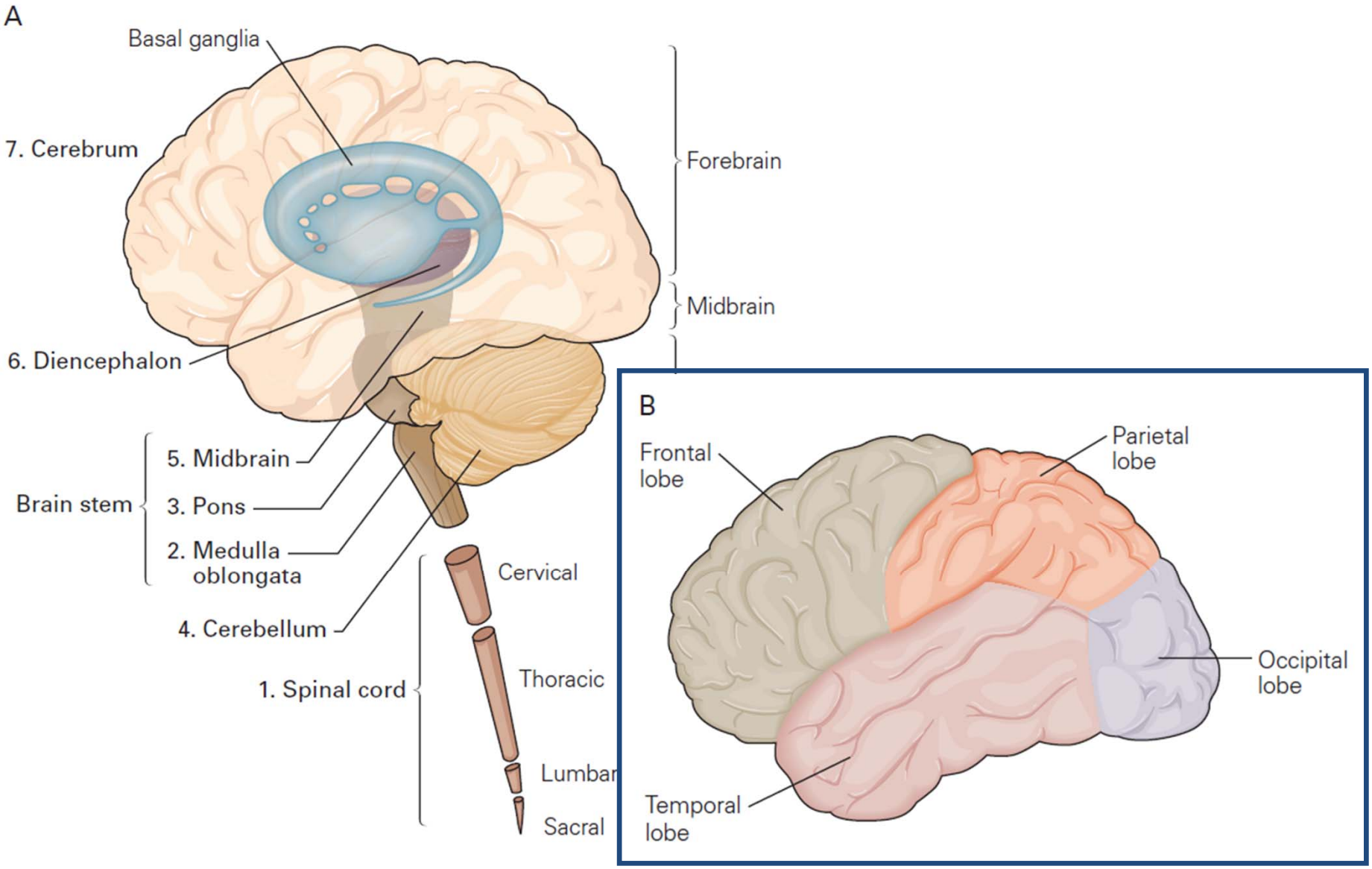
This presentation includes only the most important terms and facts. Its content by itself is not a sufficient source of information required to pass the Neuroscience exam.

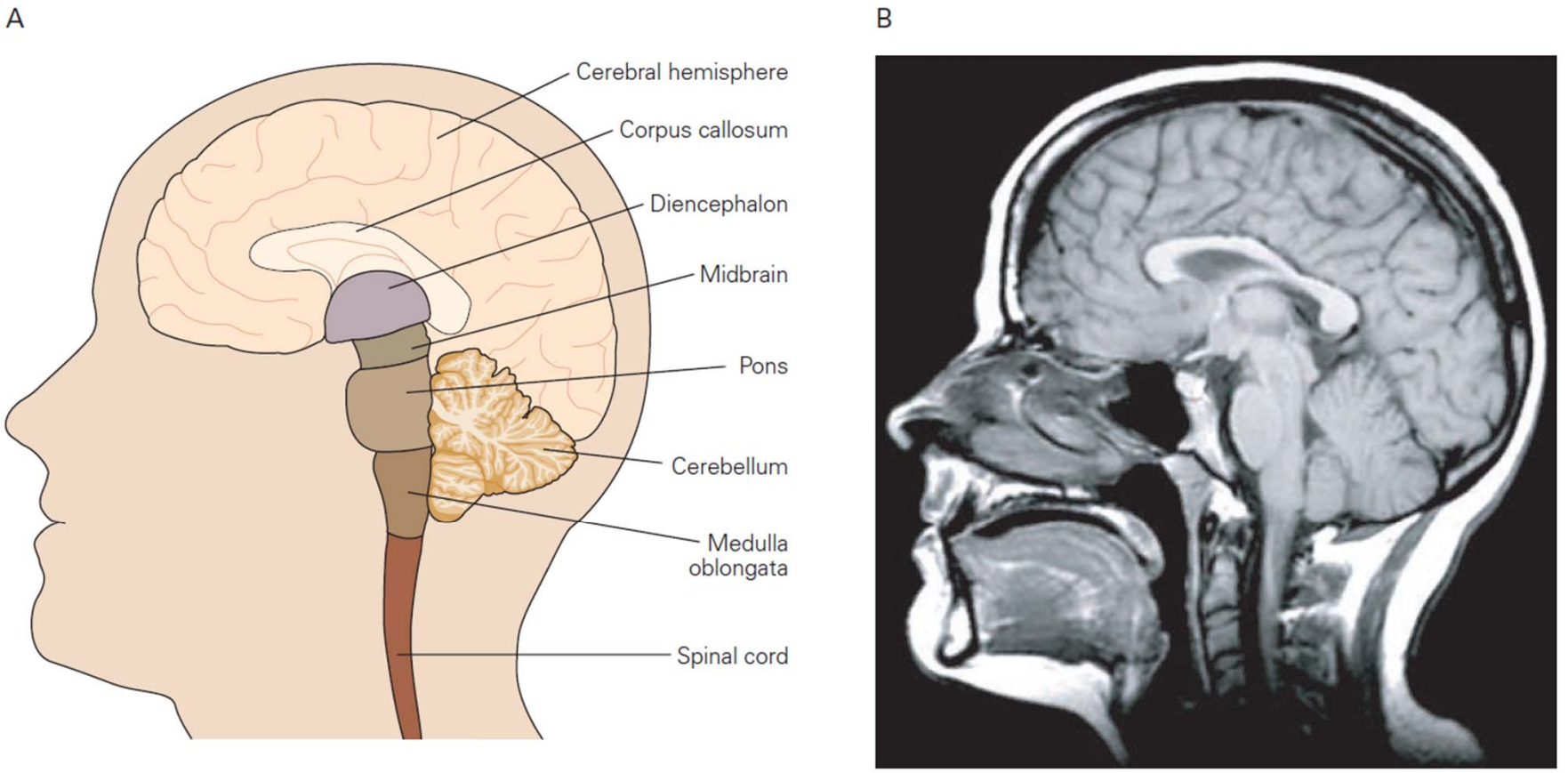
Figures and tables re-used from:

- Principles of Neural Science (5th ed.), Kandel et al. (2013)
- Medical Physiology (2nd ed.), Boron and Boulpaep (2012)
- Neuroscience (4th ed.), Purves et al. (2008)
- Medical Neurobiology (1st ed.), Mason (2011)
- Review of Medical Physiology (20th ed.), Ganong (2005)
- Atlas of Human Physiology (6th ed.), Silbernagl a Despopoulos (2004)

Functional regions of the CNS

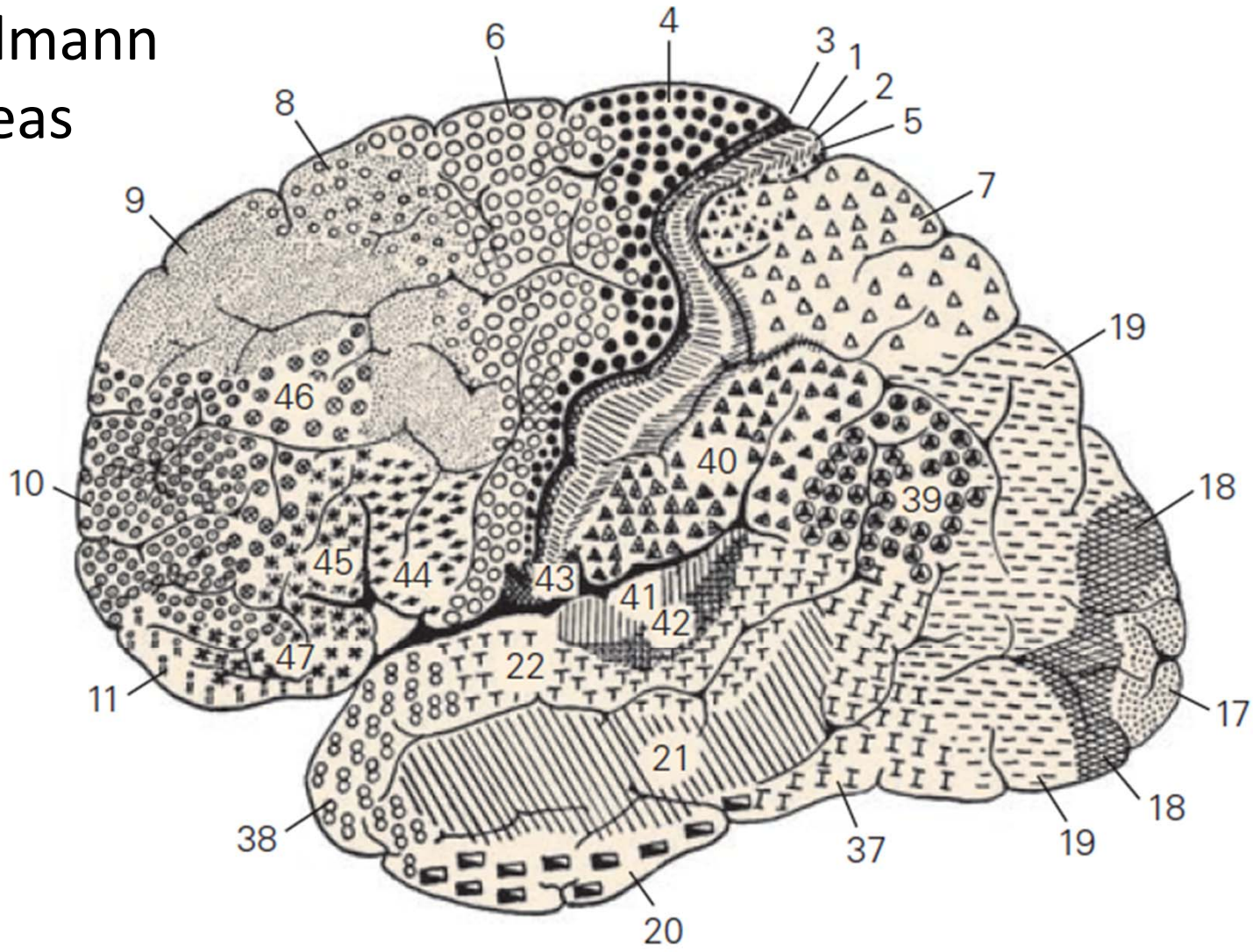


Functional regions of the CNS



Functional regions of the brain cortex

Broadmann
52 areas



Functional regions of the brain

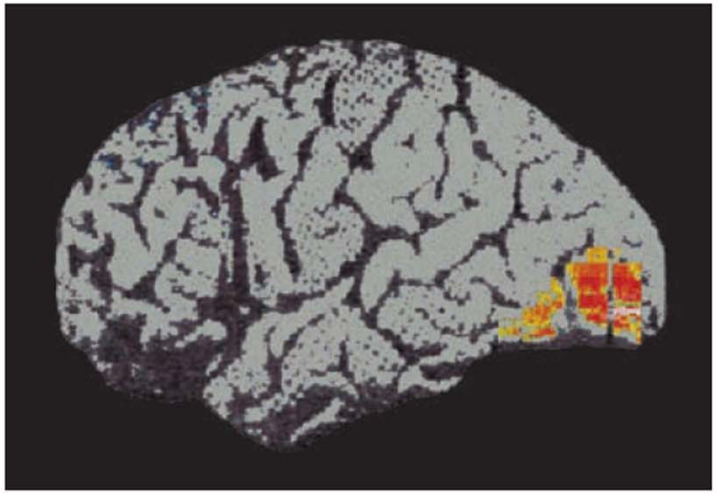
Methods for measurement of regional cerebral blood flow, thus, of brain activity

PET (positron emission tomography)

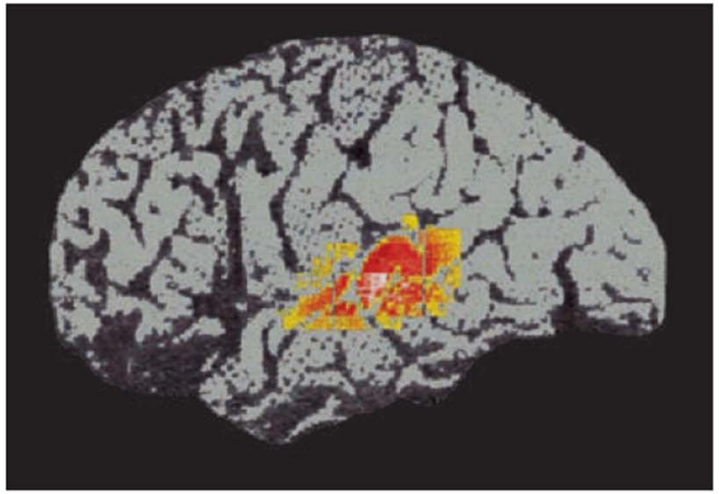
- a substance labelled by radionuclides with a short half time
- the substance is injected, the increase and following decrease of its concentration is evaluated by scintillation detectors placed around the head
- *e.g.* labelled 2-deoxyglucose – its consumption is a good indicator of the flow

Functional regions of the brain

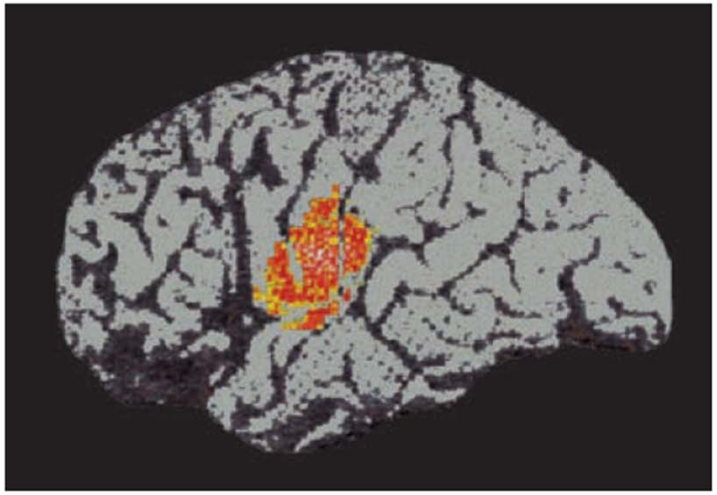
A Looking at words



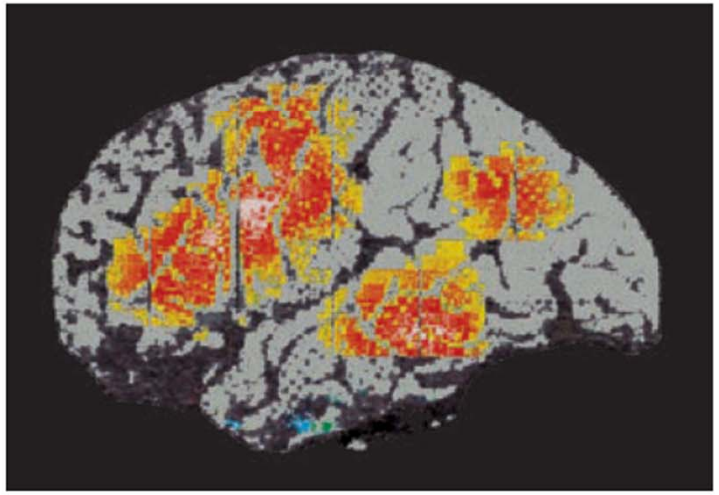
B Listening to words



C Speaking words



D Thinking of words



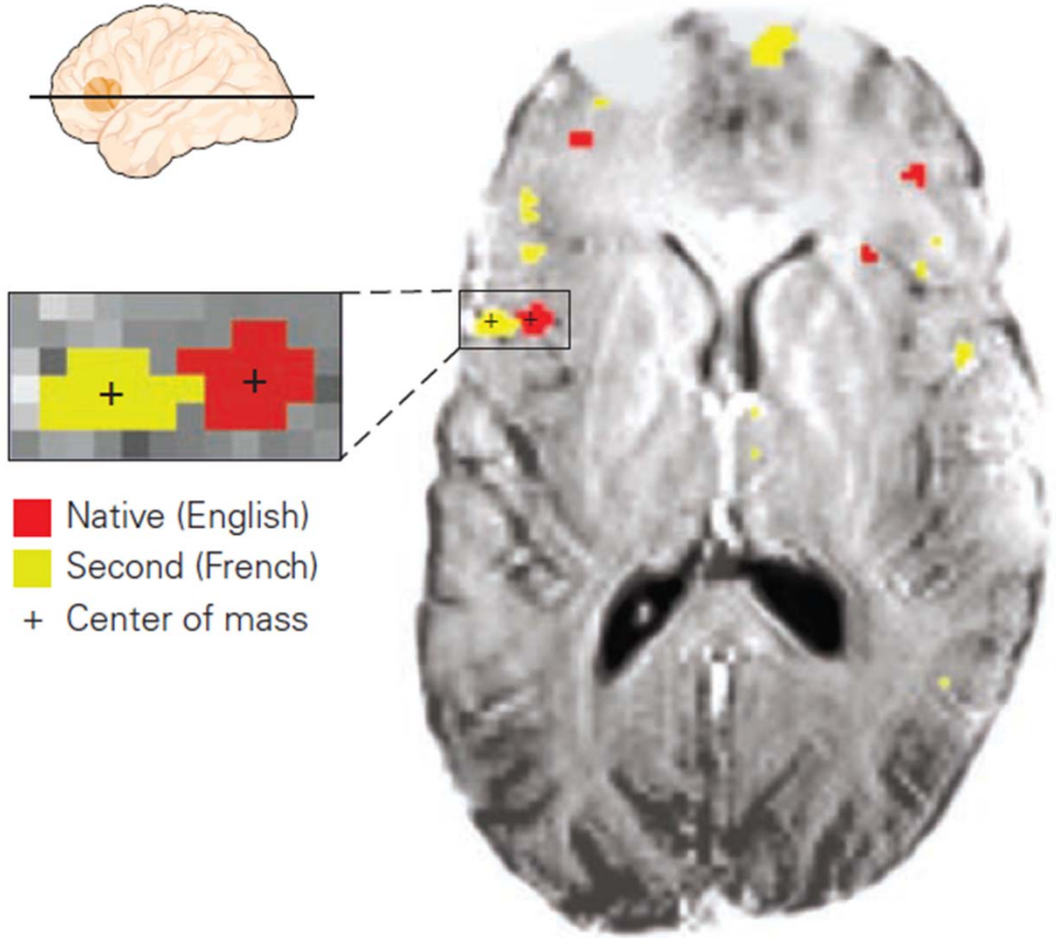
Functional regions of the brain

Methods for measurement of regional cerebral blood flow, thus, of brain activity

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

Functional regions of the brain



Homeostasis

- is the process of ensuring that bodily variables stay within a preferred range
- endocrine, nervous, immune systems

Homeostasis – nervous system

- brain is „smart“ – when possible **anticipate** challenges to homeostasis → all anticipatory homeostatic adjustments require intact forebrain (voluntary reaction)

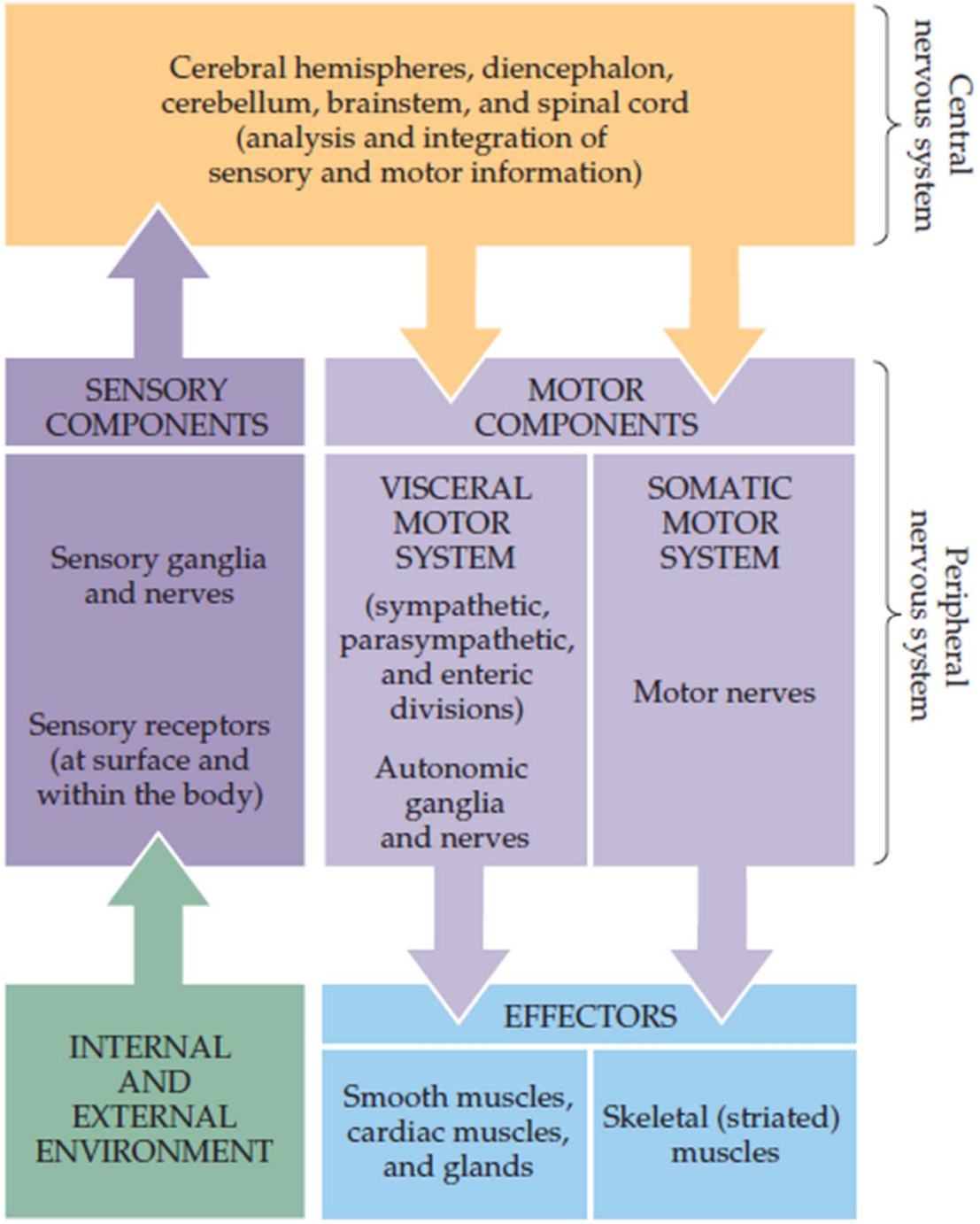
- unexpected challenges to homeostasis → met by largely unconscious reflexes mediated by the spinal cord and/or brainstem

Homeostasis – nervous system

- interactions with external environment require behavioural component as a function of the brain

- **behaviour** (from simple to complex) requires contribution of three main components:

  sensory, executive, motivational

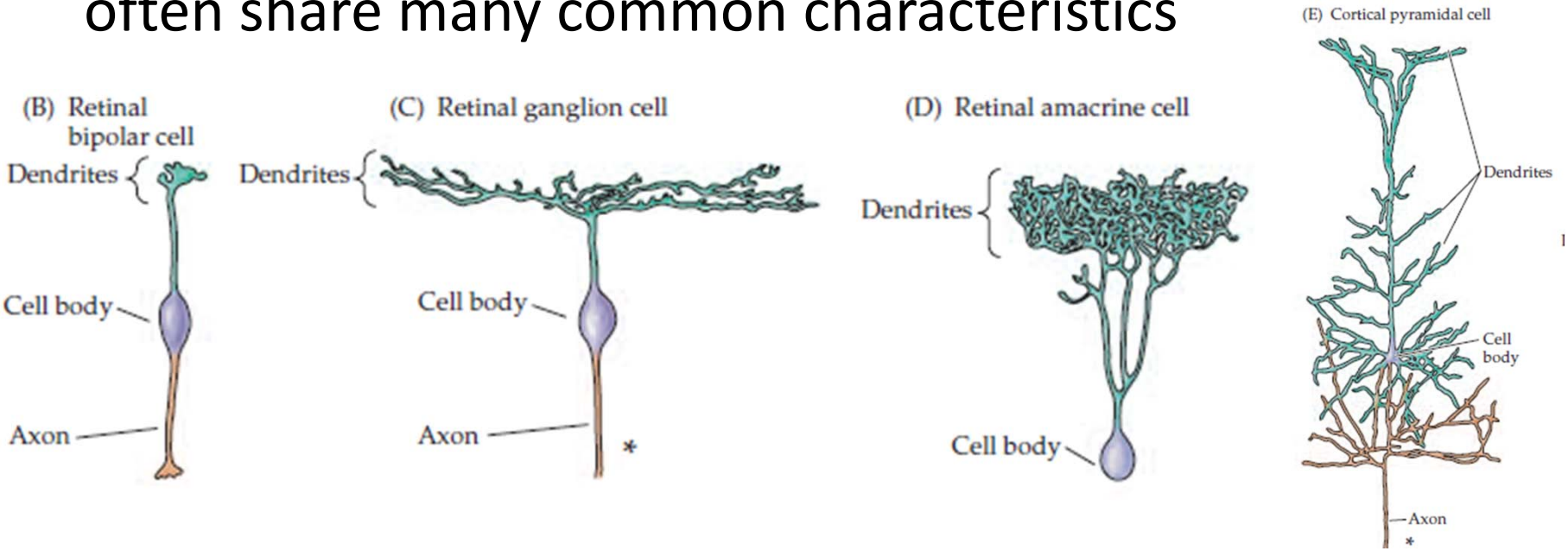

Cerebral hemispheres, diencephalon, cerebellum, brainstem, and spinal cord (analysis and integration of sensory and motor information)
Central nervous system
SENSORY COMPONENTS
MOTOR COMPONENTS
Sensory ganglia and nerves
Sensory receptors (at surface and within the body)
VISCERAL MOTOR SYSTEM
(sympathetic, parasympathetic, and enteric divisions)
Autonomic ganglia and nerves
SOMATIC MOTOR SYSTEM
Motor nerves
Peripheral nervous system
INTERNAL AND EXTERNAL ENVIRONMENT
EFFECTORS
Smooth muscles, cardiac muscles, and glands
Skeletal (striated) muscles

Goal directed behaviour

- energetic balance
- volume and osmolarity
- temperature
- performance
- strenghthen health
- reproduction
- defense
- .....

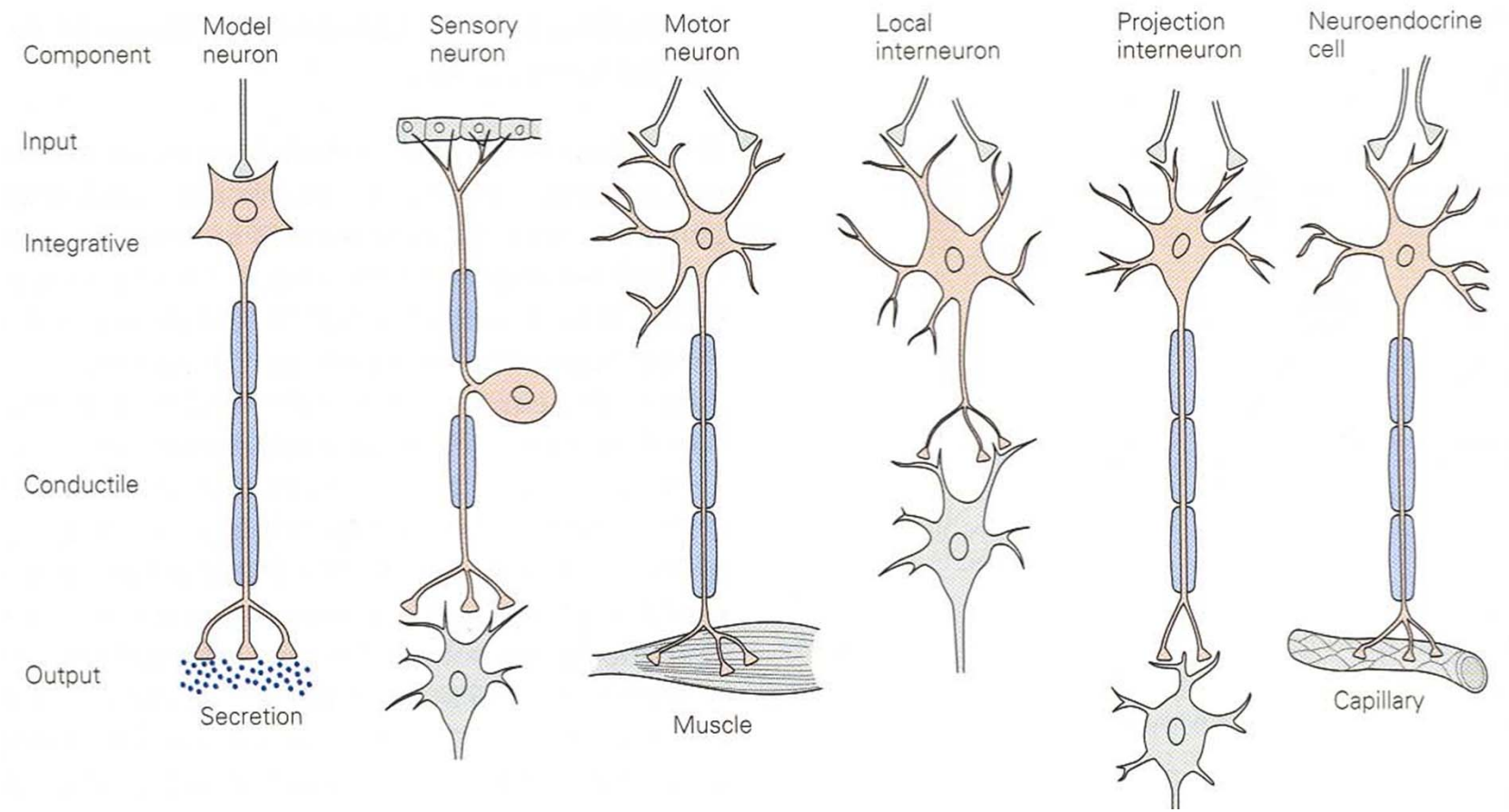
Neuron

- approx. 10^{11} of nerve cells (glial cells 10 times frequent)
- the most consistent neuronal trait - individuality
- neurons differ in location, morphology, connections, physiological characteristics
- cells within localized clusters (nuclei) or layers (laminae) often share many common characteristics



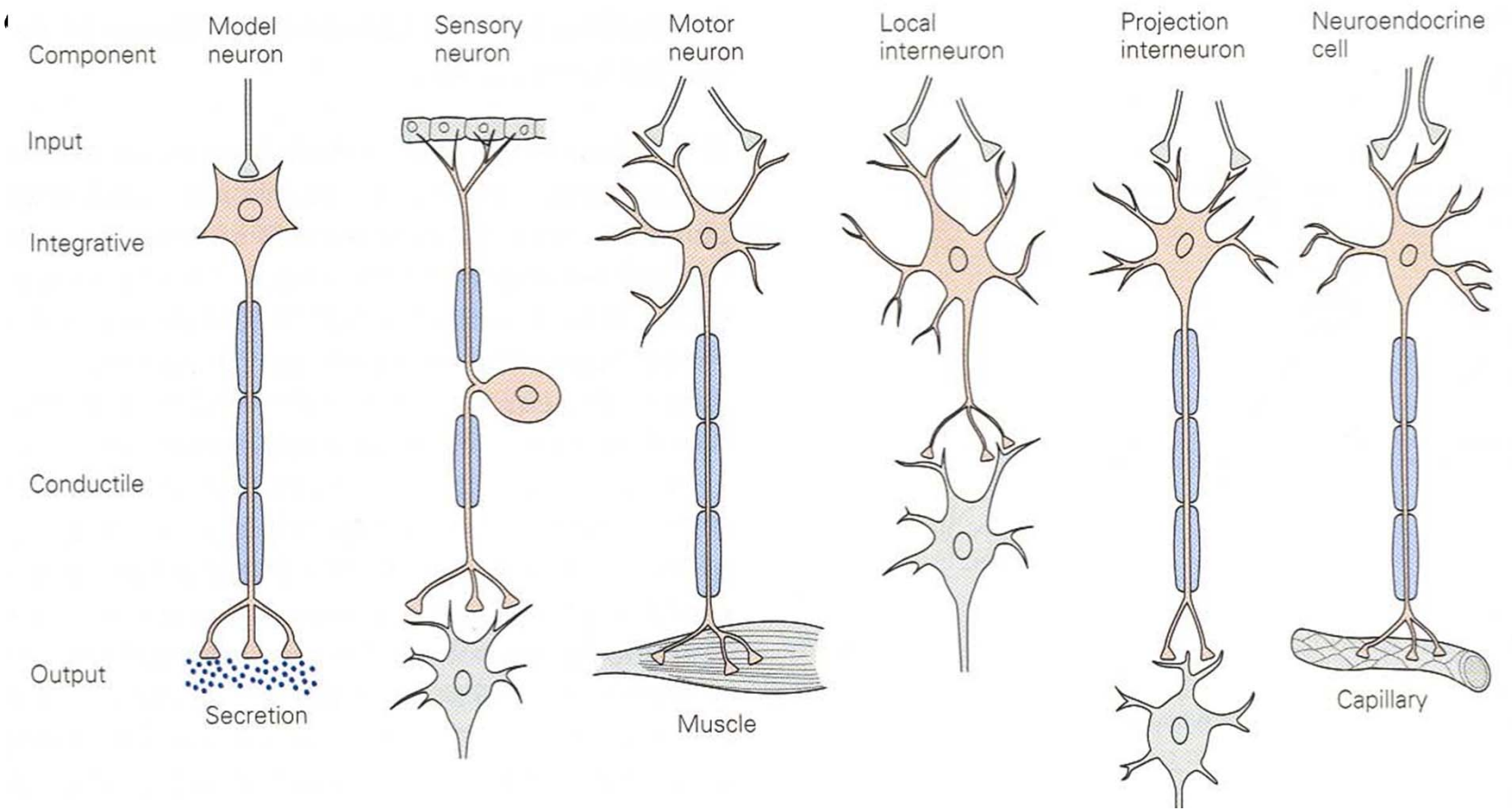
Most neurons share a group of traits:

- derive from ectoderm
- four morphological regions – dendrites, body, axon, synaptic terminals



Most neurons share a group of traits:

- four functional components – input, integrative, conductile, output
- generate electrical potentials



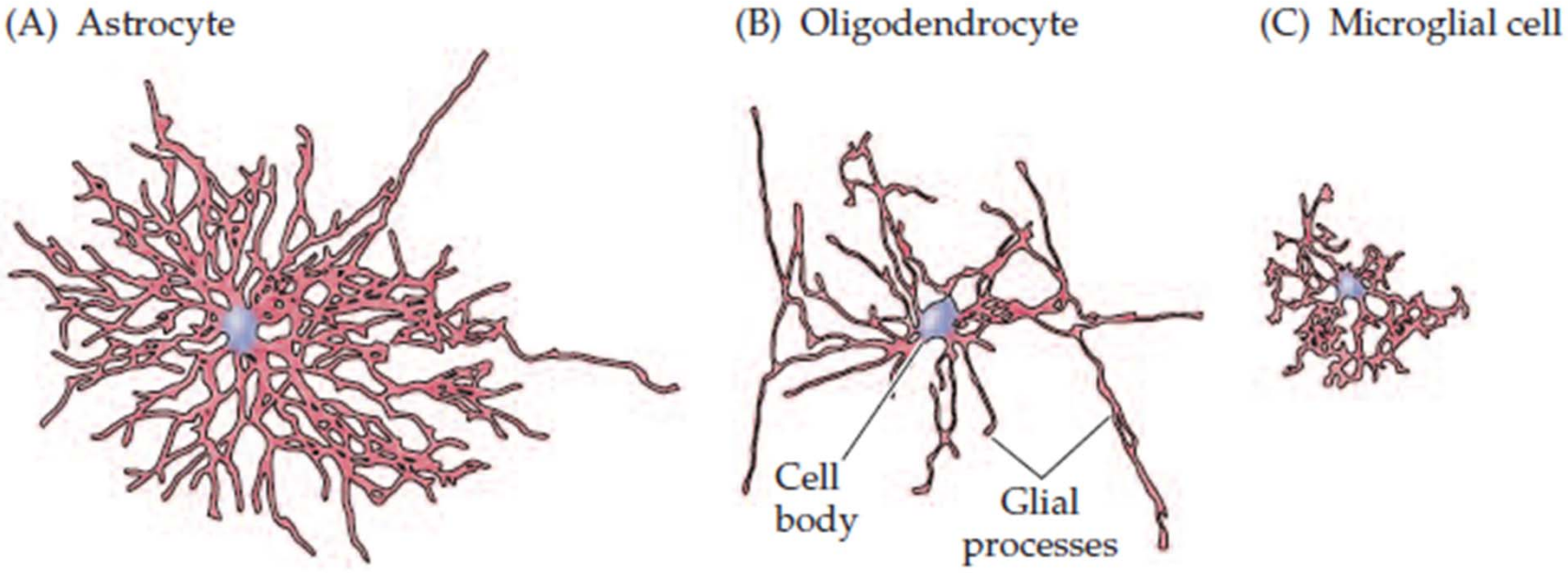
Neuron

The law (doctrine) of dynamic polarization:

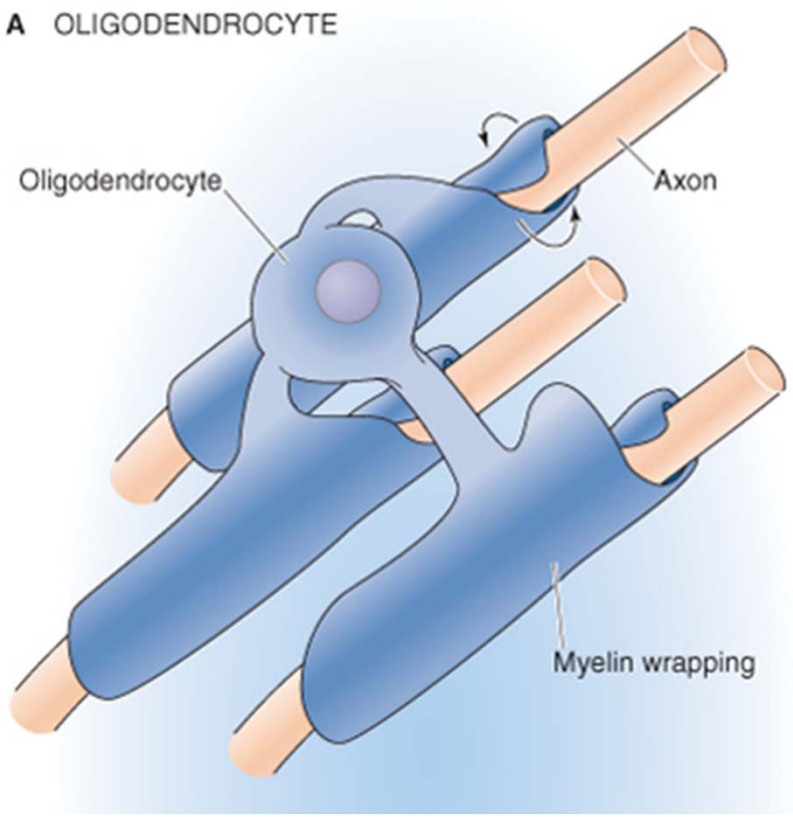
Neuronal information flows in one direction from the dendrites and the soma to the axon and synaptic terminals. (Cajal)

Glial cells

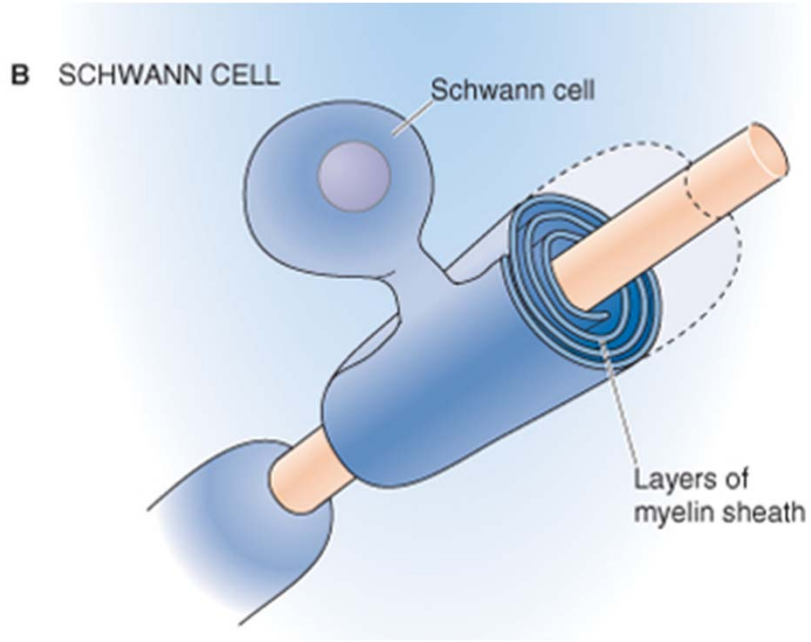
- CNS - oligodendrocytes, astrocytes, microglial cells
- PNS - Schwann cells
- critical for development of NS



CNS

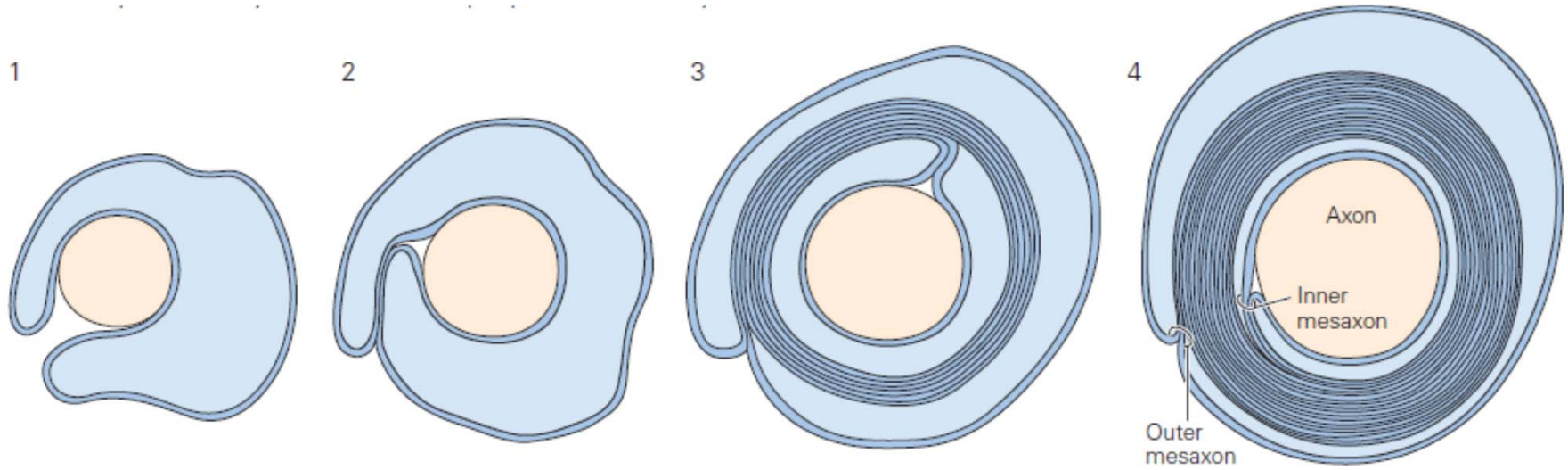

A OLIGODENDROCYTE
Oligodendrocyte
Axon
Myelin wrapping

PNS


B SCHWANN CELL
Schwann cell
Layers of
myelin sheath

Myelin

Myelin insulates axons – rapid (saltatory) conduction of AP.

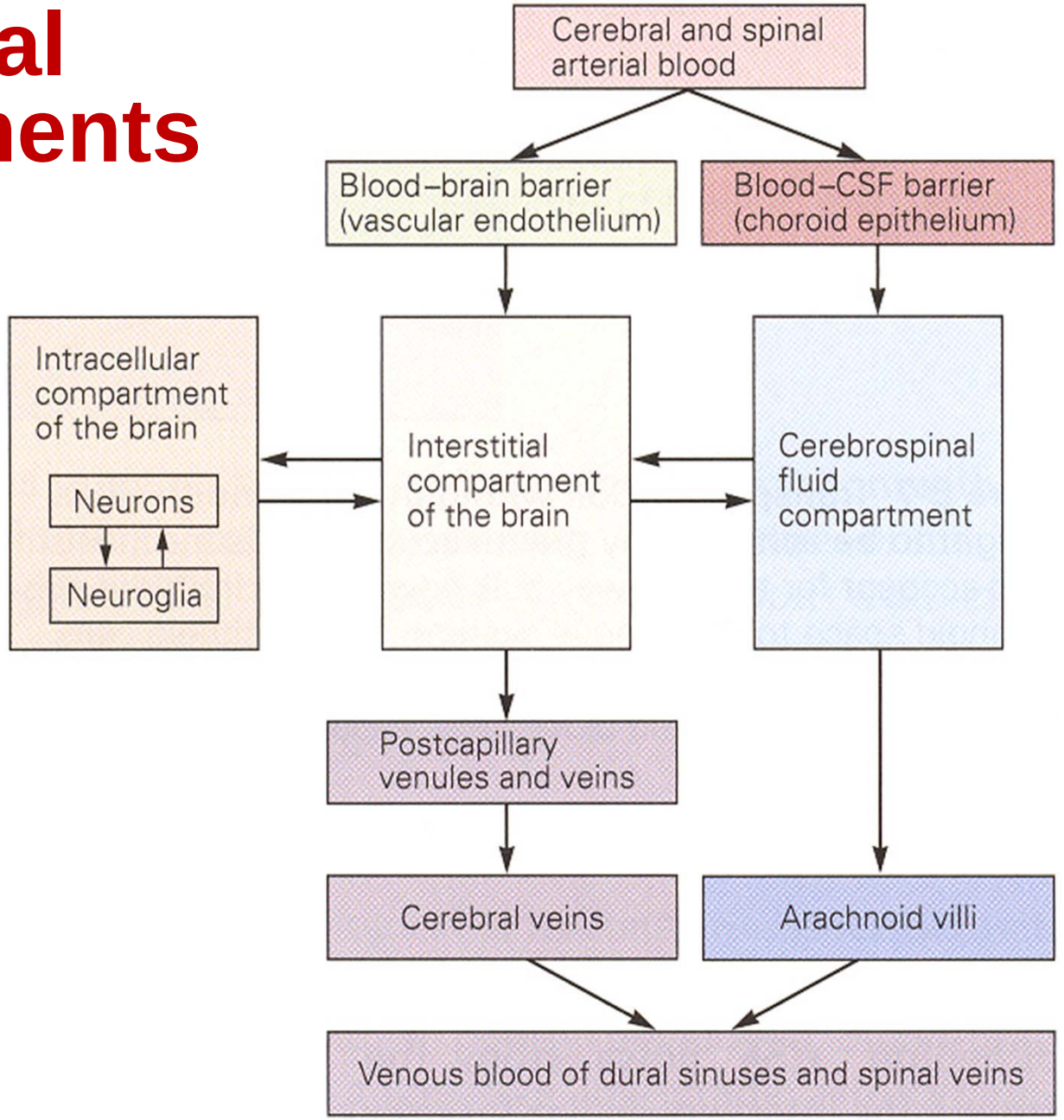


demyelination

Astrocytes

- metabolic functions: K^+, pH, oxidative stress (GSH), energy storage (glycogen), glutamate-glutamin shuttle
- modulation of synaptic activity, tissue repair

Cerebral Compartments



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

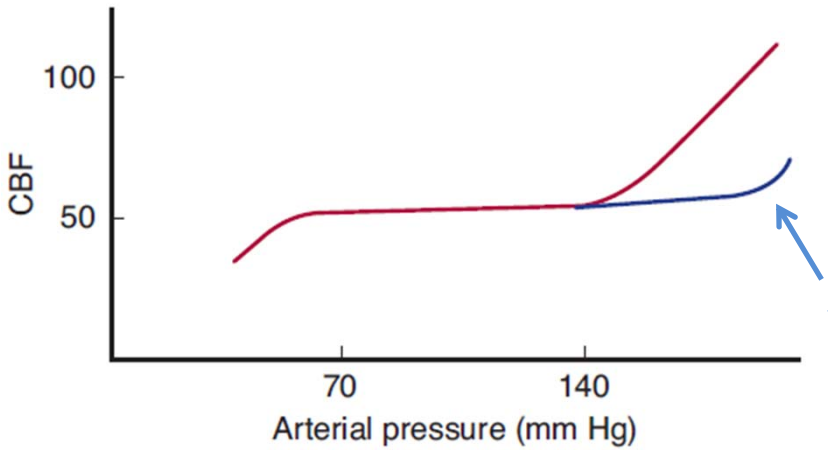
3) very short arteriols

   (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



sympathetic system

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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

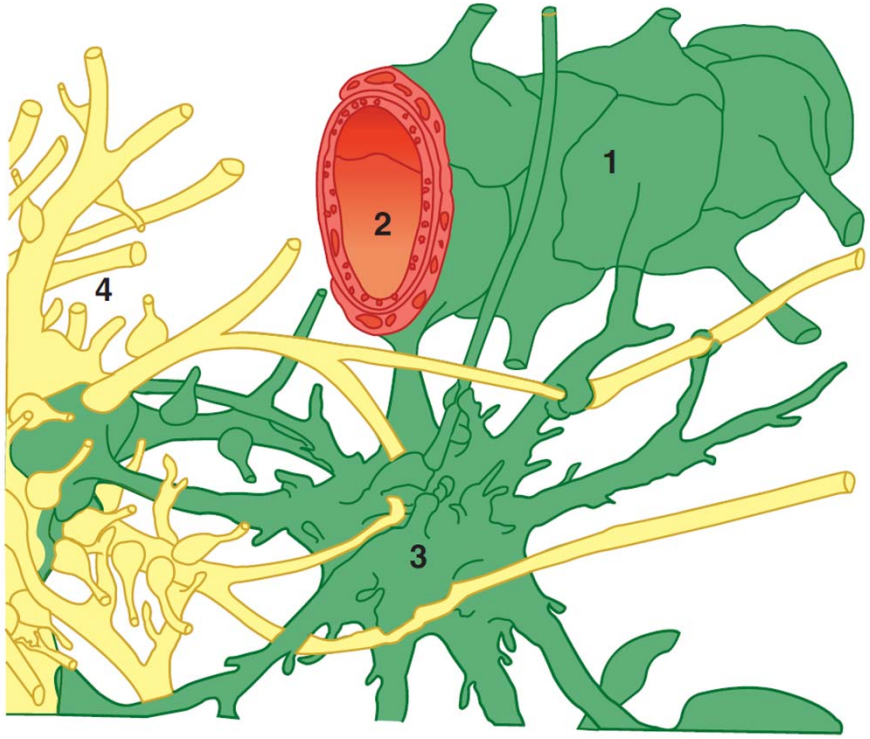
2) gravity

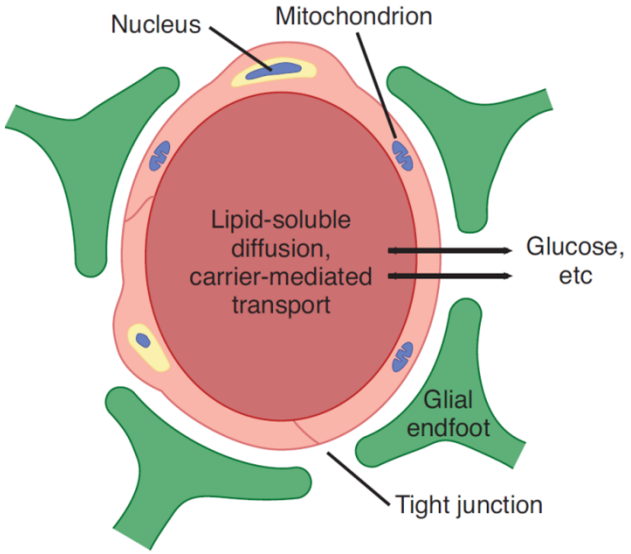
   orthostatic reaction (postural syncope)

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 !)

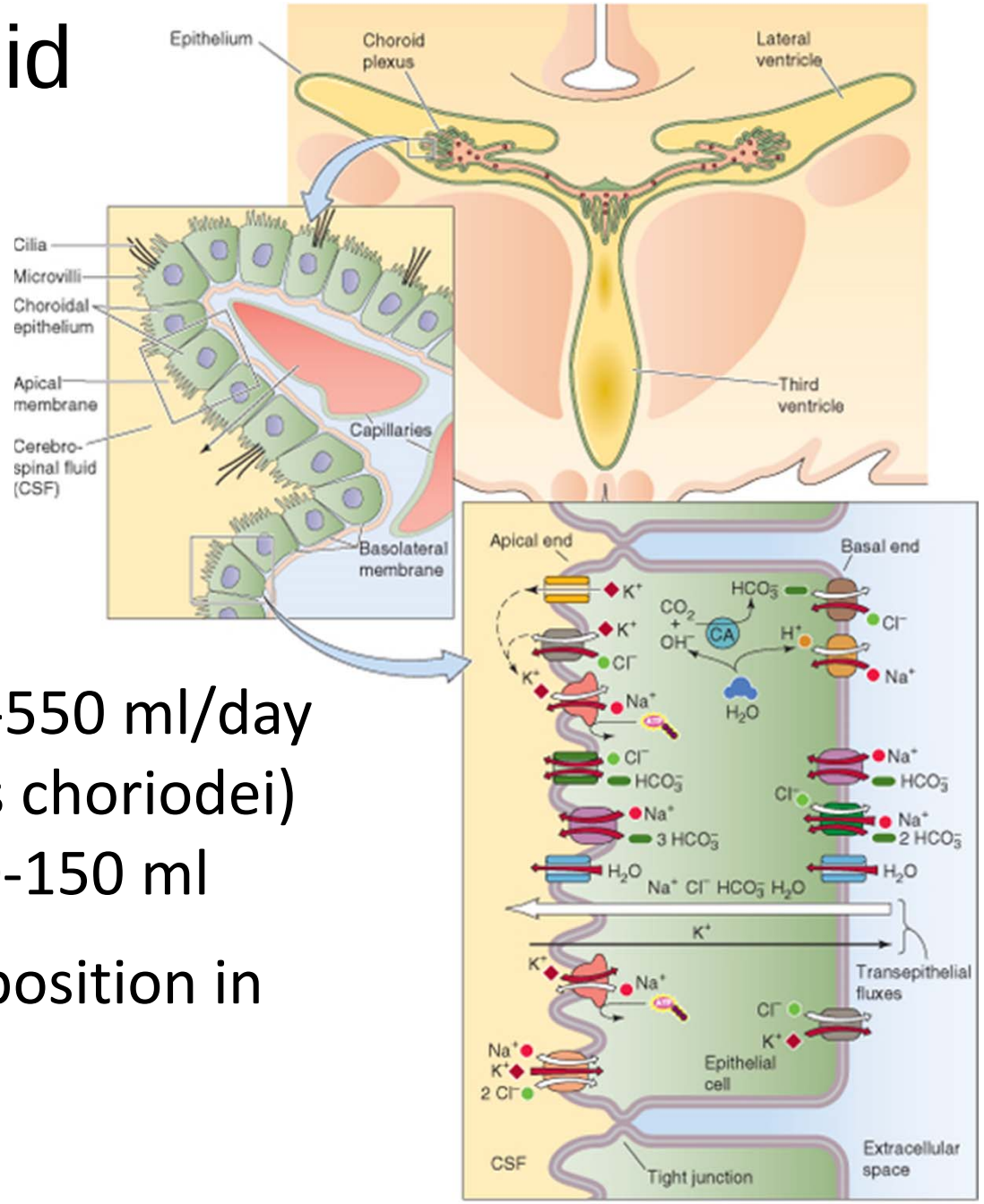
→ transporters for thyroid hormones, some organic acids, choline, precursors of nucleic acids, aminoacids, …

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

Cerebrospinal fluid
- production -



rate of production: 450-550 ml/day
(70 % come from plexus choriodei)
circulating volume: 130-150 ml

CSF pressure in supine position in lumbar region:
70-180 mmH_2O

Cerebrospinal fluid - composition -

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

Cerebrospinal fluid - circulation

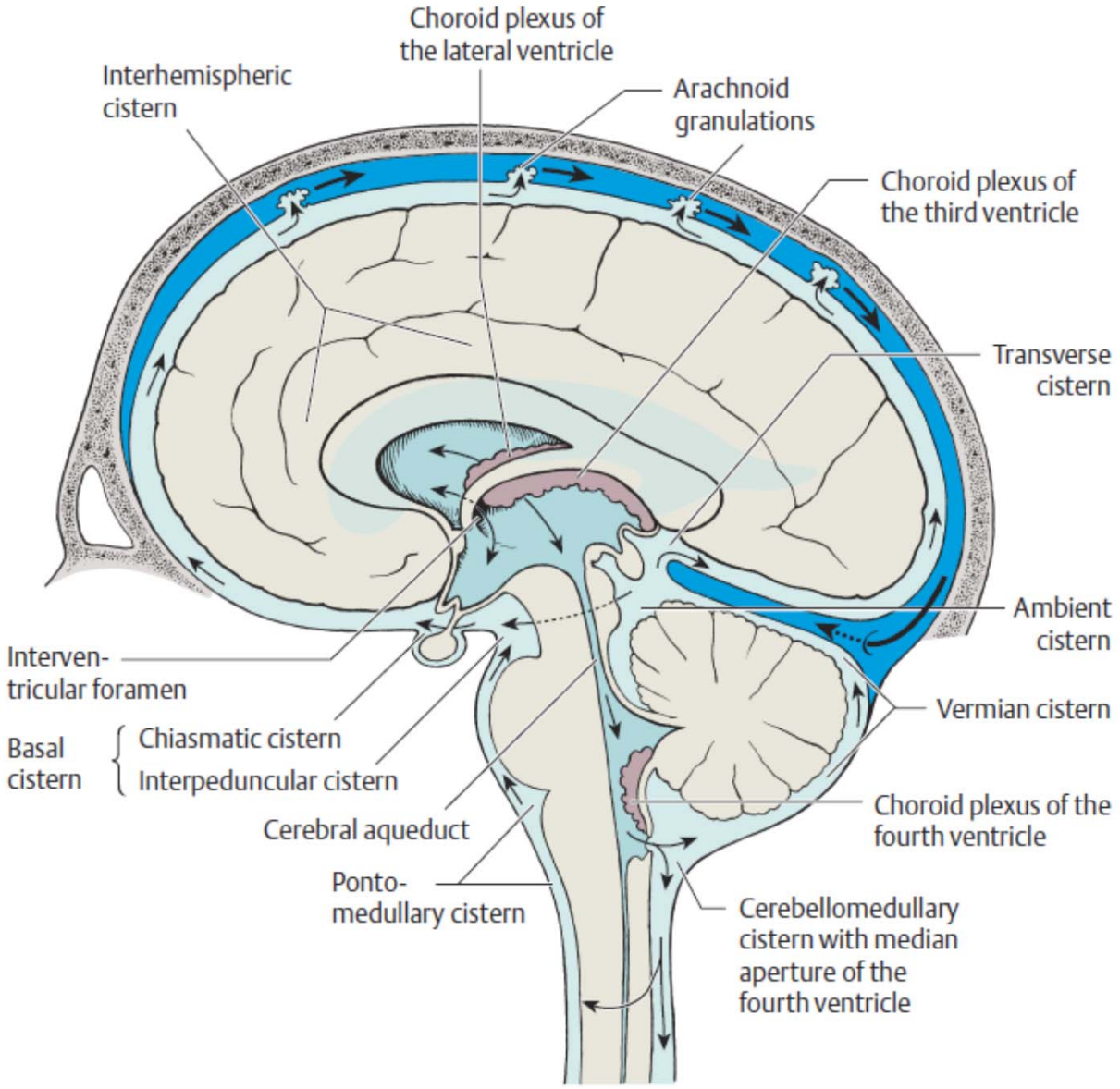
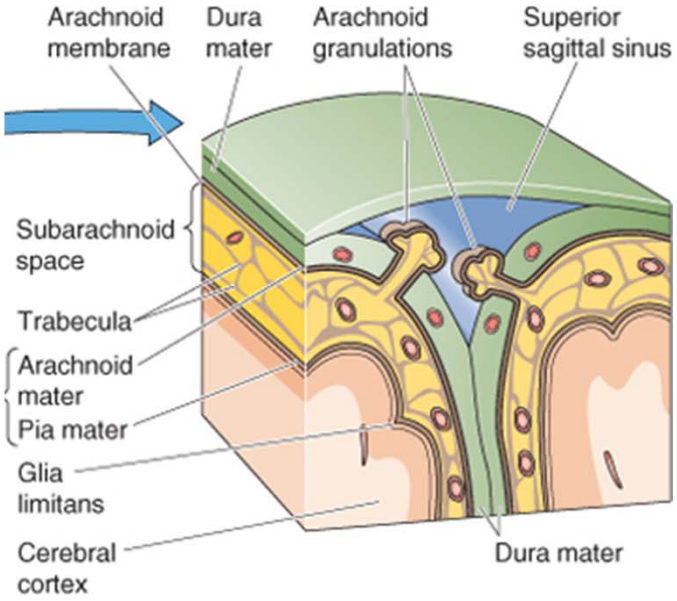
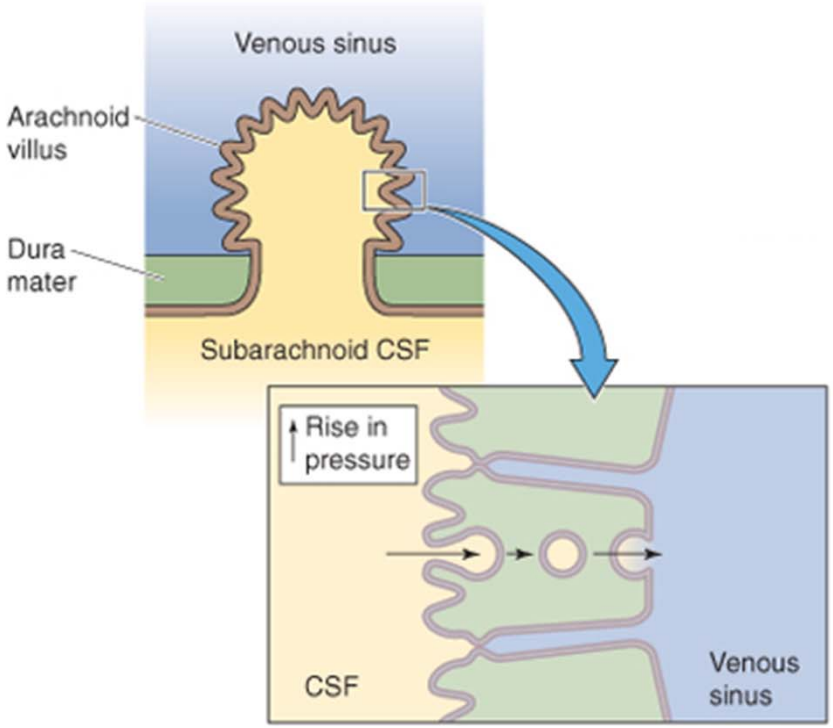


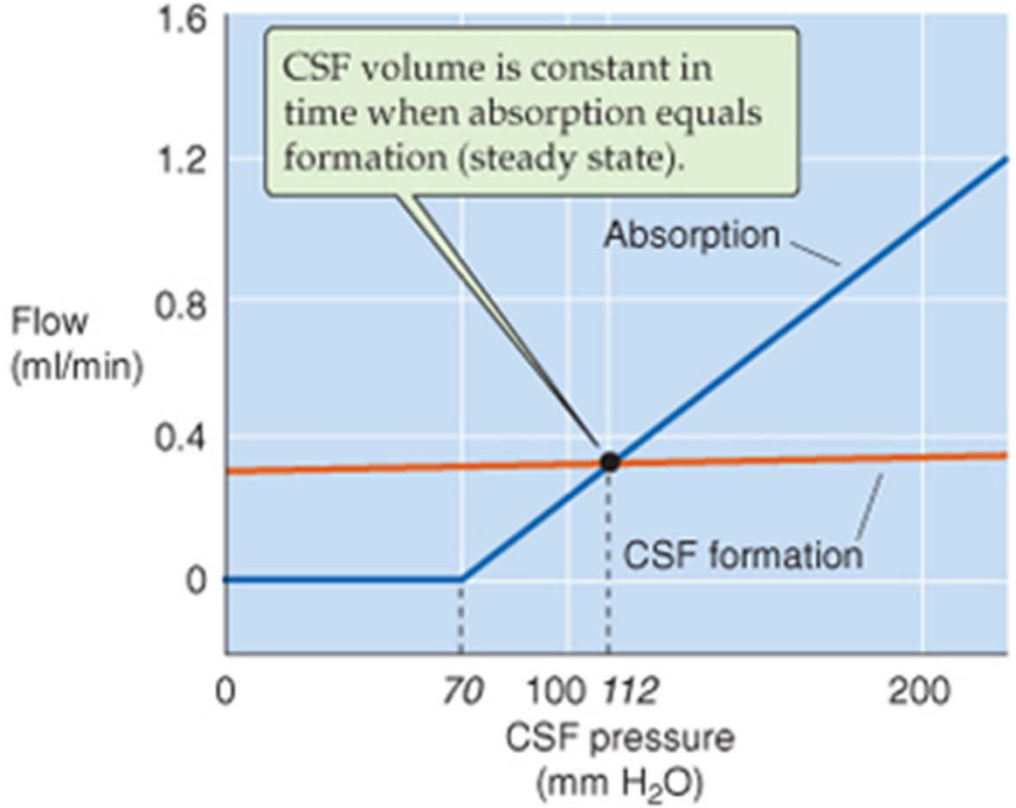
Fig. 10.4 **Circulation of the cerebrospinal fluid**



A MECHANISM OF CSF ABSORPTION



B RATE OF CSF ABSORPTION



Cerebrospinal fluid - function

- mechanical and protective
- drainage
- homeostatic
- information transfer

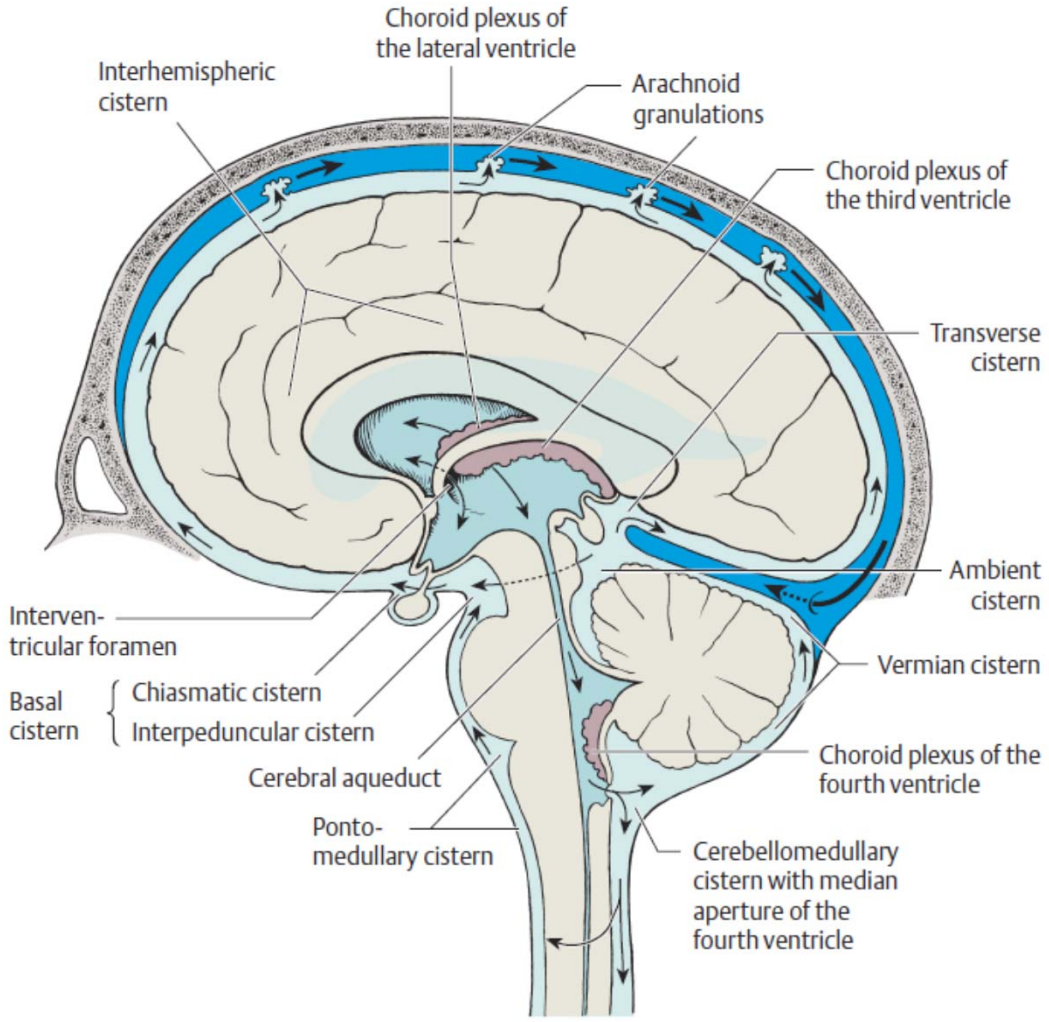


Fig. 10.4 **Circulation of the cerebrospinal fluid**

Cerebrospinal fluid - function

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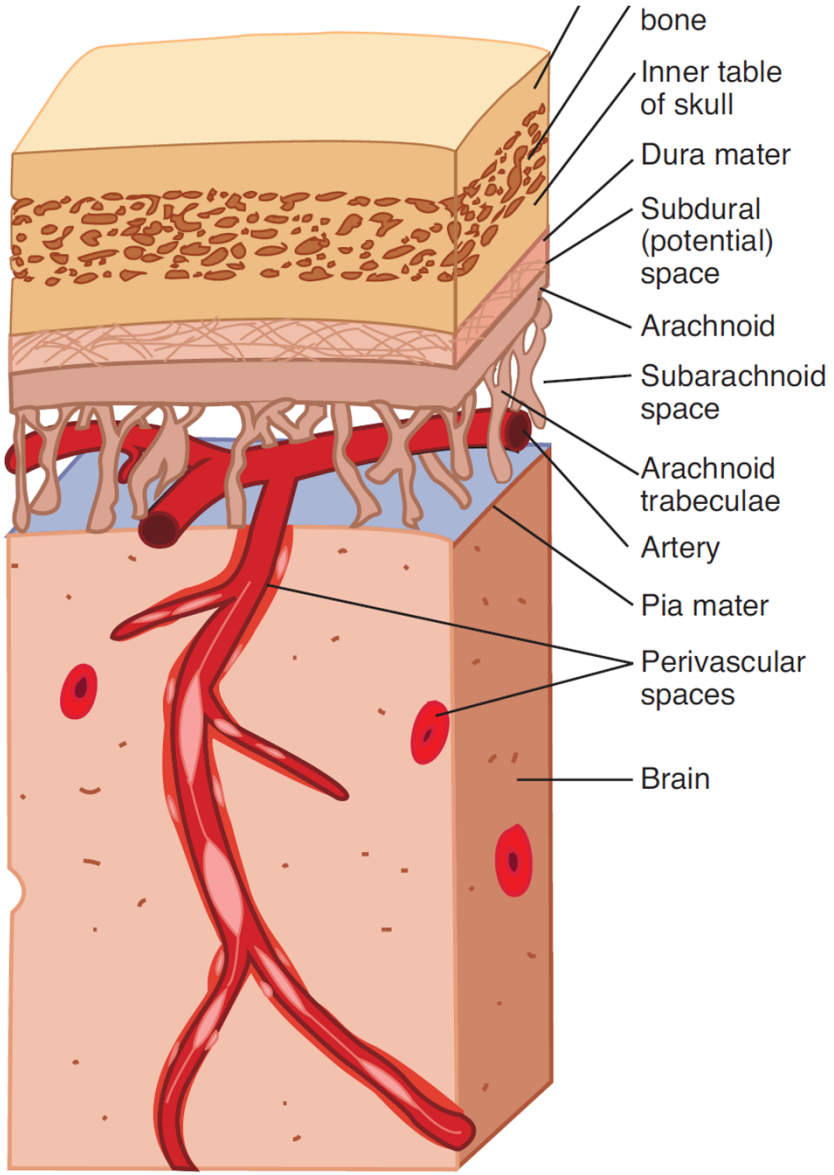
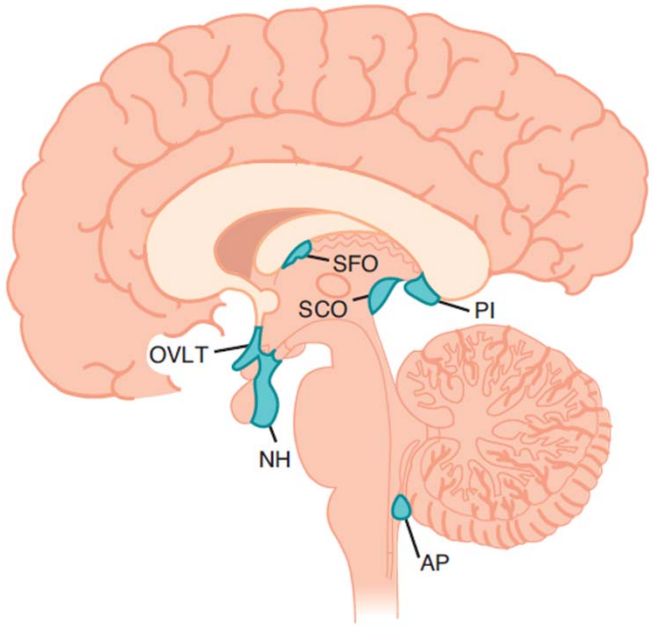


Cerebral Circulation

- 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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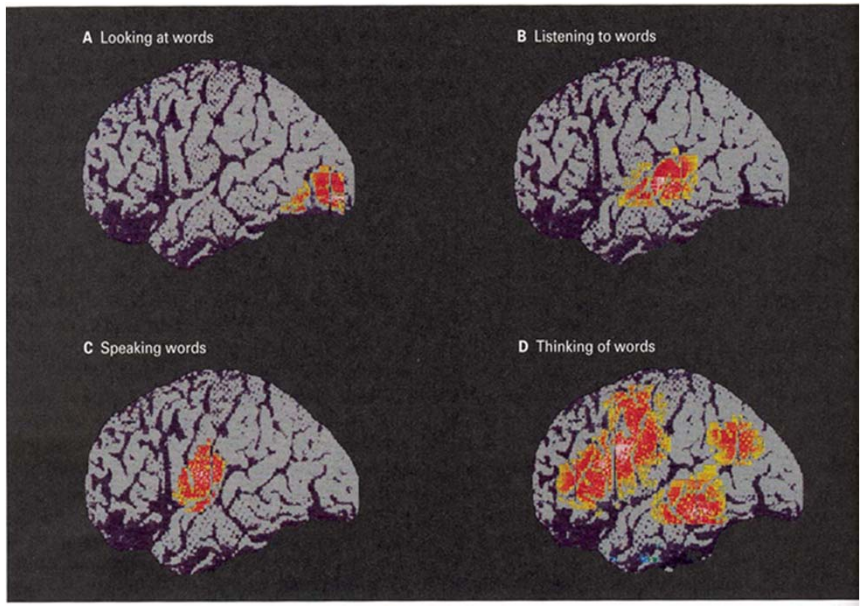
Blood flow in brain - methods

- global: Fick principle - Kety method using inhaled nitrous oxide (N_2O)
- Perfusion CT
- Invasive methods (local monitoring in neurosurgery):

  flow: probe with thermistors

  pO2
- magistral arteries ultrasound
- transcranial Doppler ultrasound
- PET, fMRI



Energy sources

- glucose (does not need insulin)
  - astrocytes GLUT 1 (→ lactate)
  - neurons GLUT 3
- under some conditions also:
  - ketone bodies: starvation and diabetes
- new-borns also FFA during breastfeeding

Energy sources

- most of the energy is needed to maintain ion gradients across cell membranes and transmit electrical impulses
- part of glucose in neurons is converted to amino acids and lipids
- part of the total glucose is utilised by glial cells

Ammonium

- glutamate entering the brain takes up ammonia and leaves as glutamine

→ opposite to the reaction of kidney

- ammonium is very toxic for neural tissue
- hepatic encephalopathy