



David Kala

Cévní zásobení mozku, autoregulace

15. 4. 2020

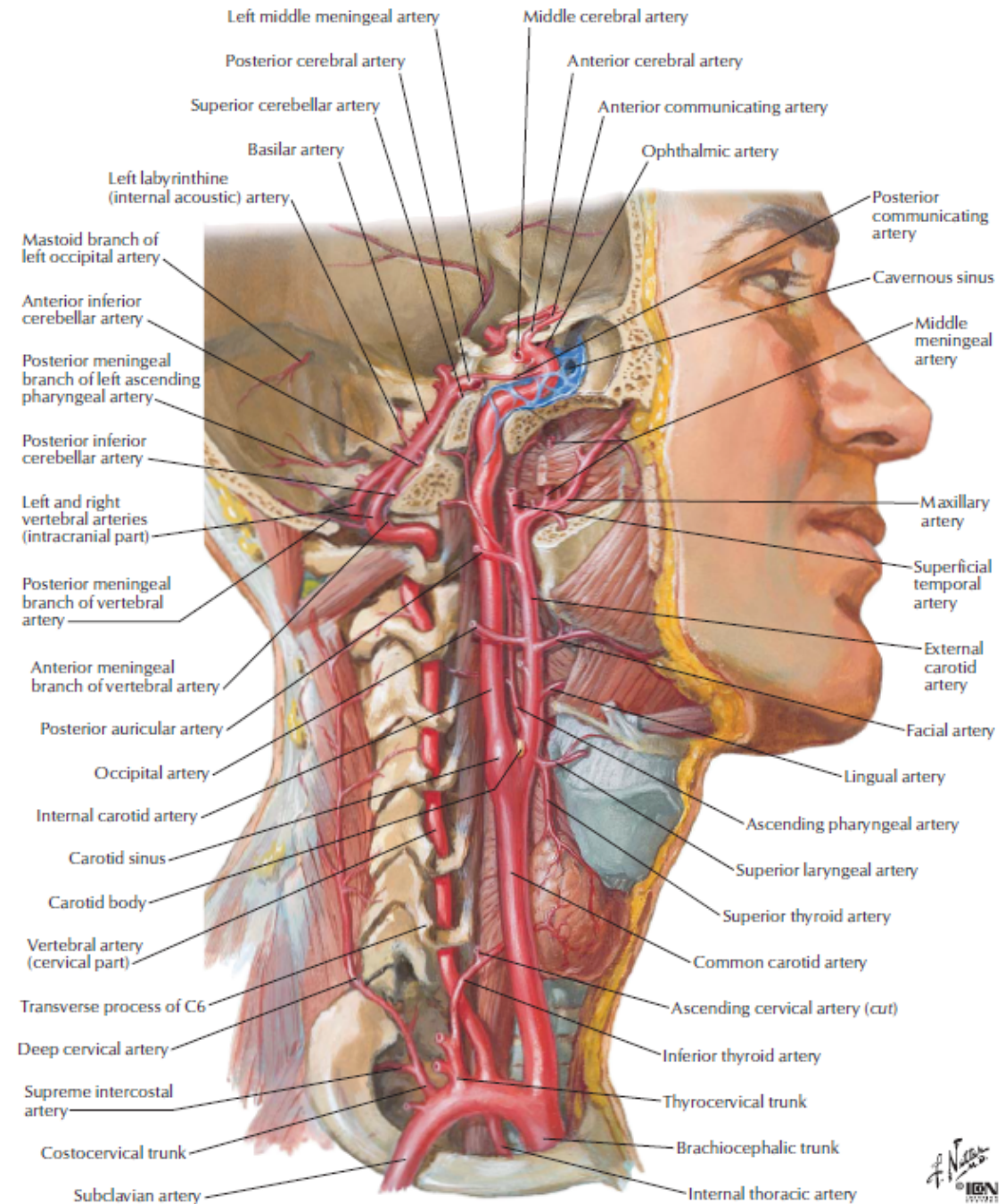
Oddělení vývojové epileptologie FGÚ AV ČR

david.kala@fgu.cas.cz

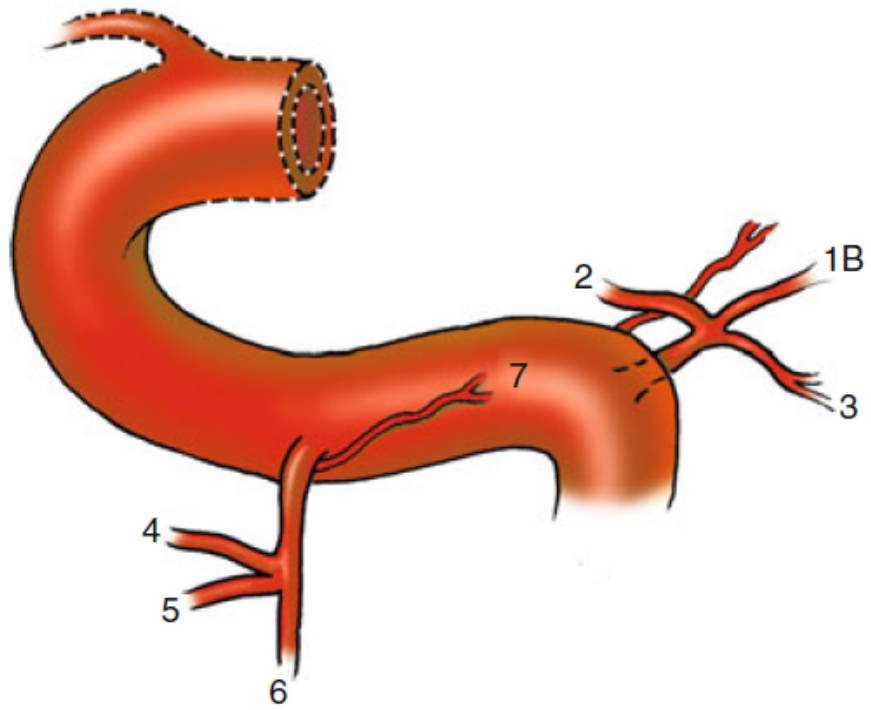
- 15% metabolismu lidského těla (pouze 2% objemu těla)
- V klidových podmínkách spotřebuje v průměru ~7.5 krát více energie než ostatní tkáň
- Velmi krátkodobá schopnost anaerobního fungování (~ do 2 min)
- Náhlý pokles zásobení mozku nebo jeho zastavení vede ke ztrátě vědomí do 5 až 10 vteřin
- **Cerebral Metabolic Rate for Oxygen (CMRO₂)** je ~ 45ml/min
- Mozek spotřebovává 12 – 15% srdečního výdeje
- Krevní průtok (Cerebral blood flow) ~750ml/min

Energetické potřeby mozku

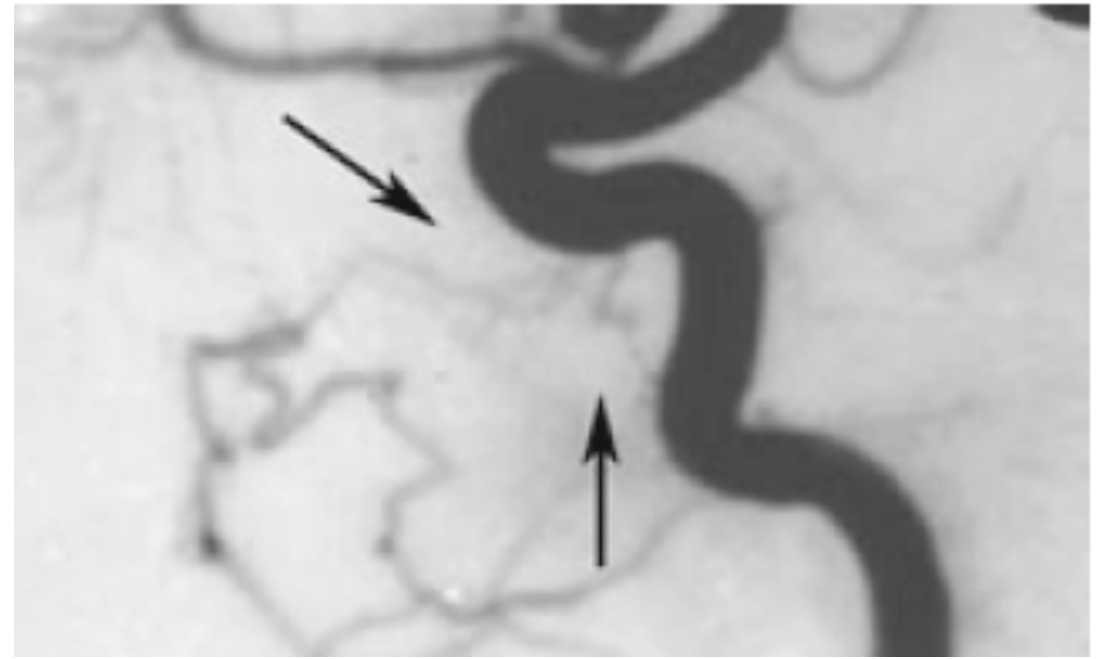
- L/P krkavice (common carotid)
- I/P vnitřní karotida (internal carotid)



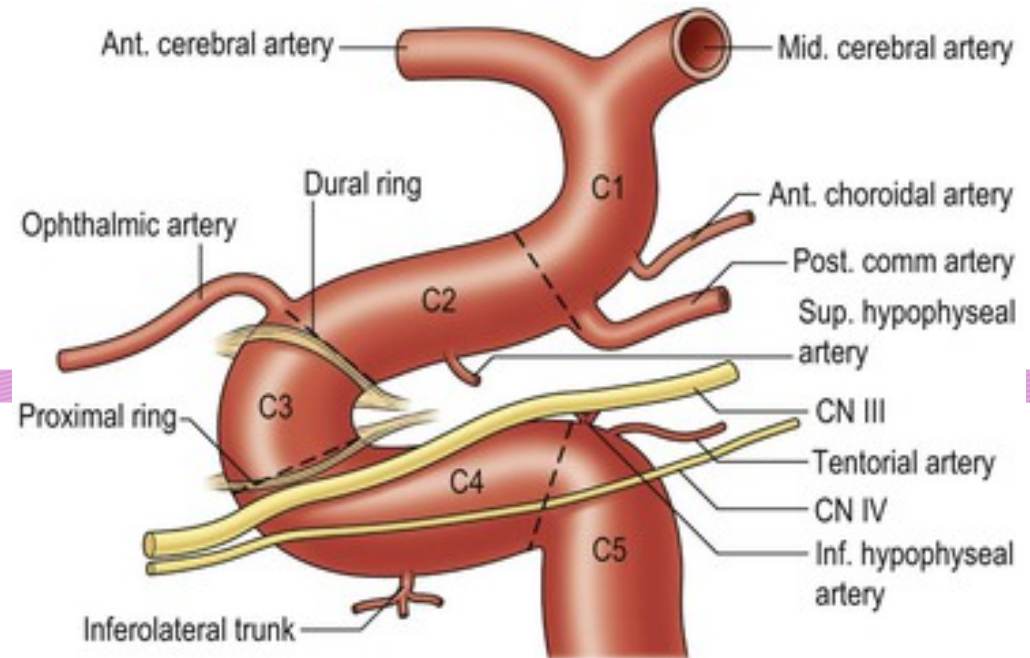
Přívodné cévy mozkové



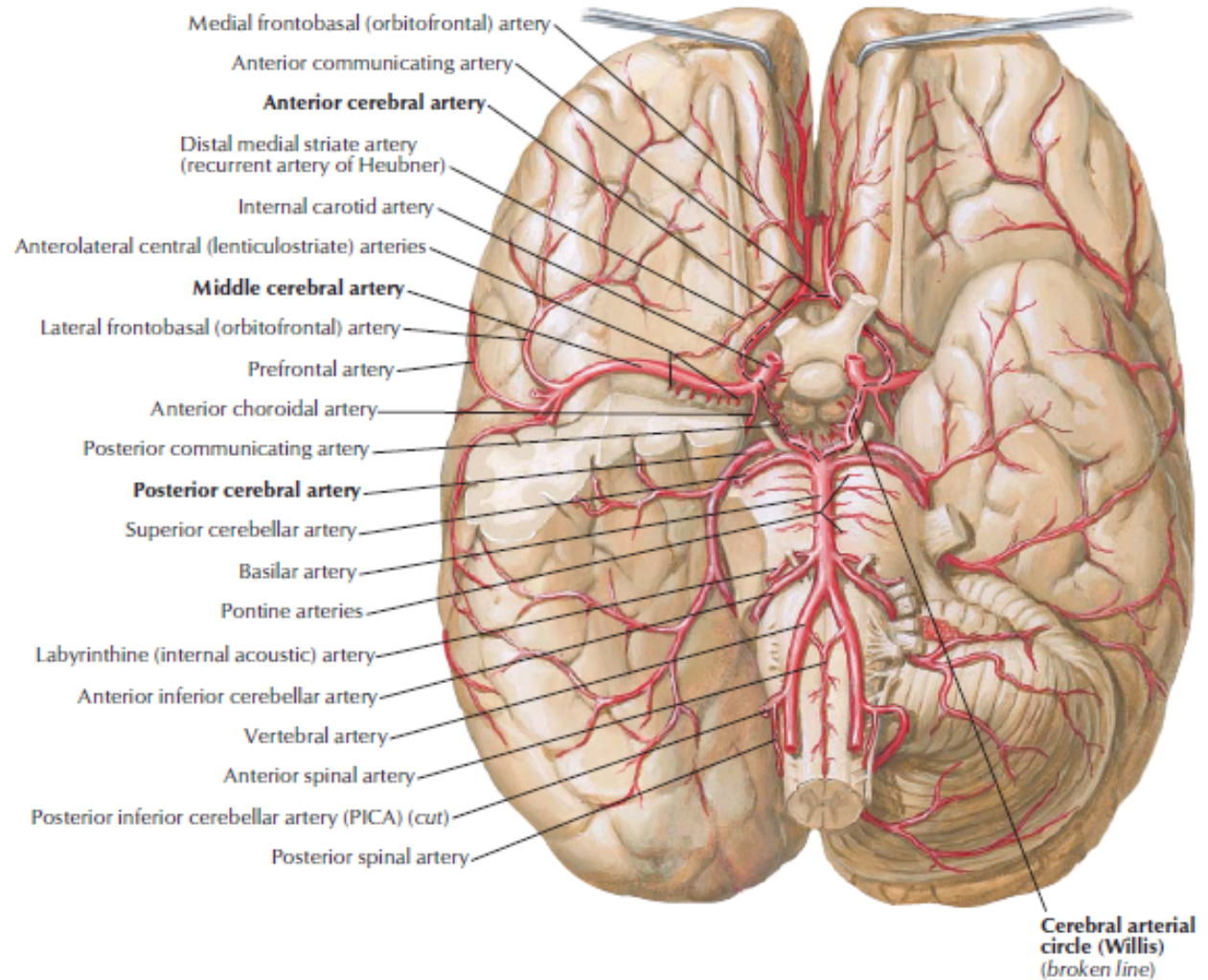
- Carotid sifon



Přívodné cévy mozkové

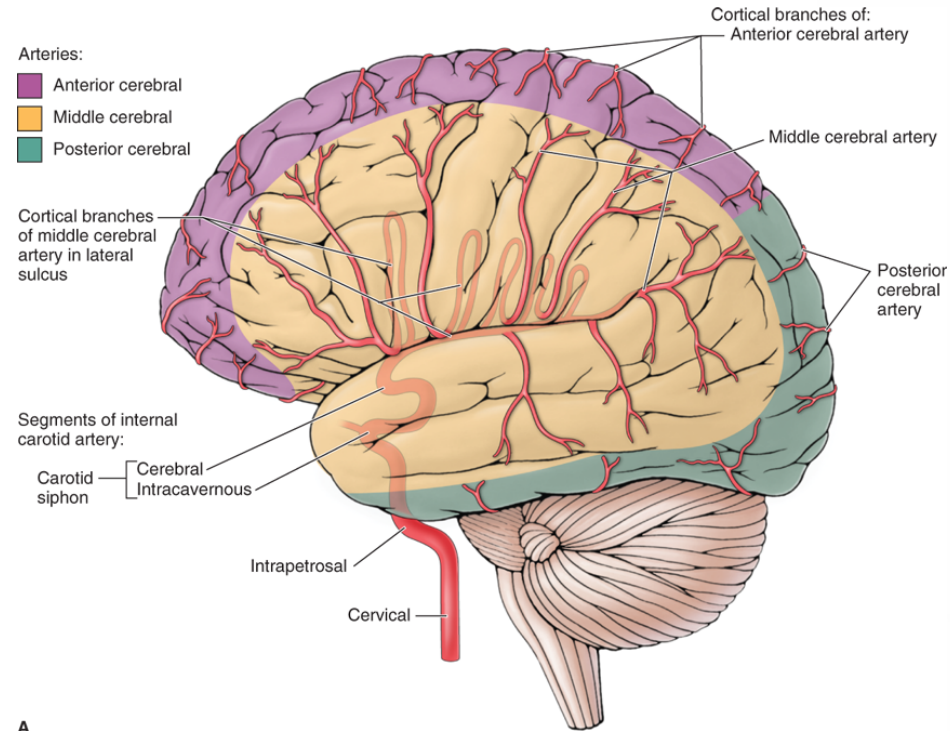


- Willisův tepenný okruh
- Arteria cerebri anterior, middle, posterior



Přívodné cévy mozkové

- Willisův tepenný okruh
- Arteria cerebri anterior, middle, posterior

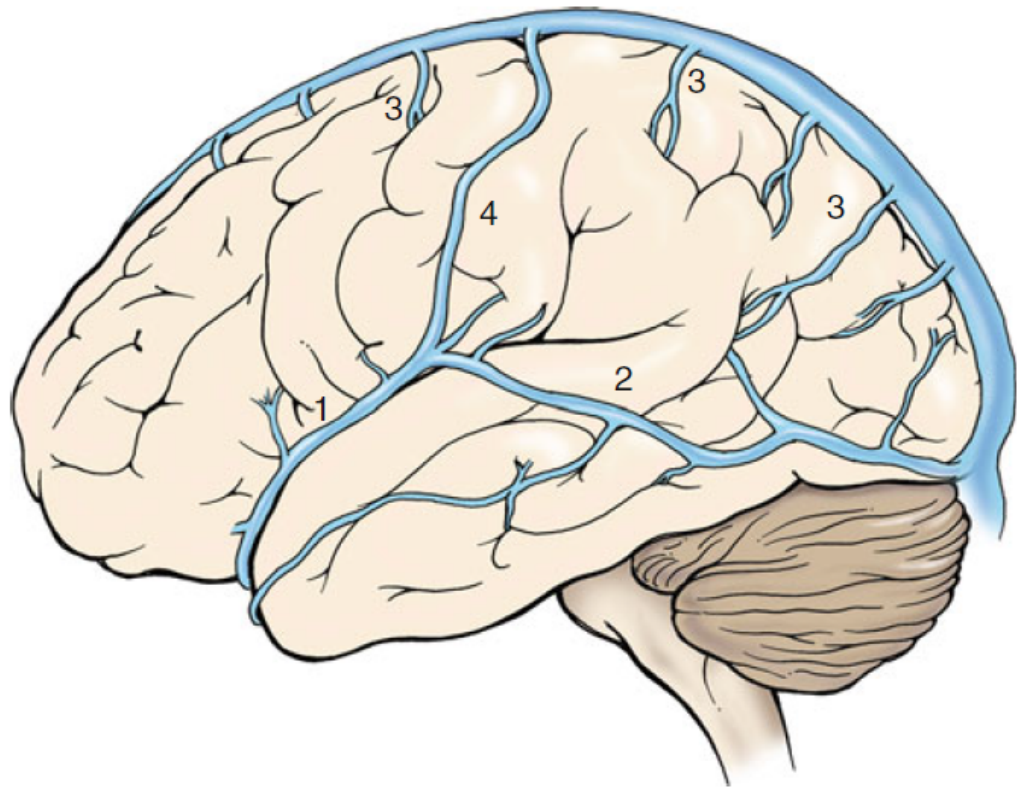


A
Source: Aaron L. Berkowitz: Clinical Neurology and Neuroanatomy: A Localization-Based Approach
www.neurology.mhmedical.com
Copyright © McGraw-Hill Education. All rights reserved.

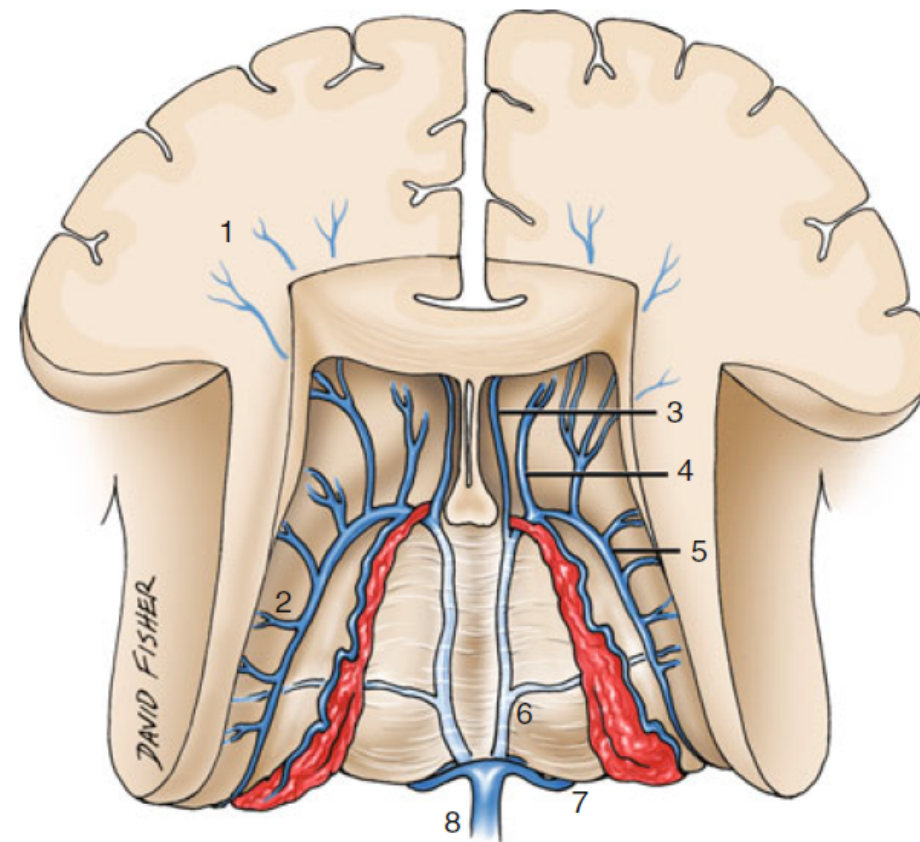


Přívodné cévy mozkové

povrchové

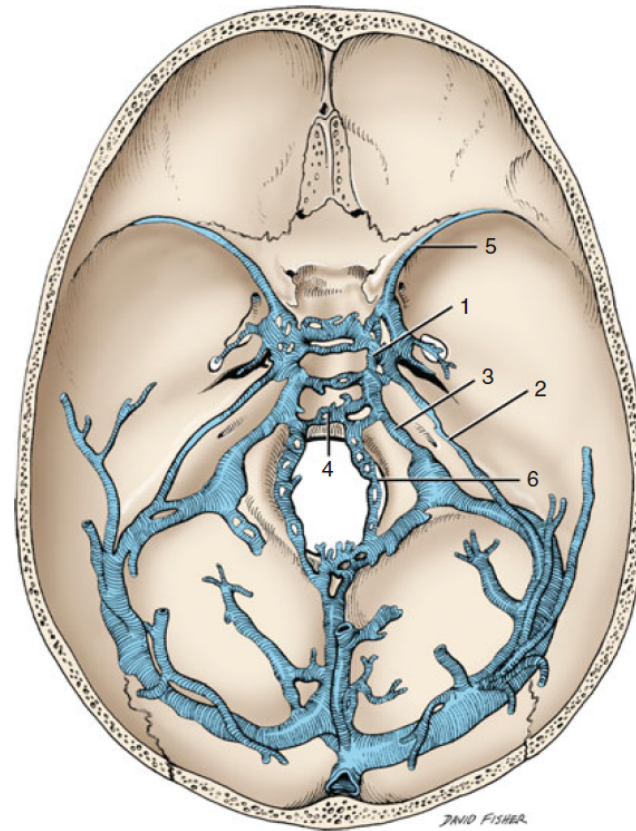
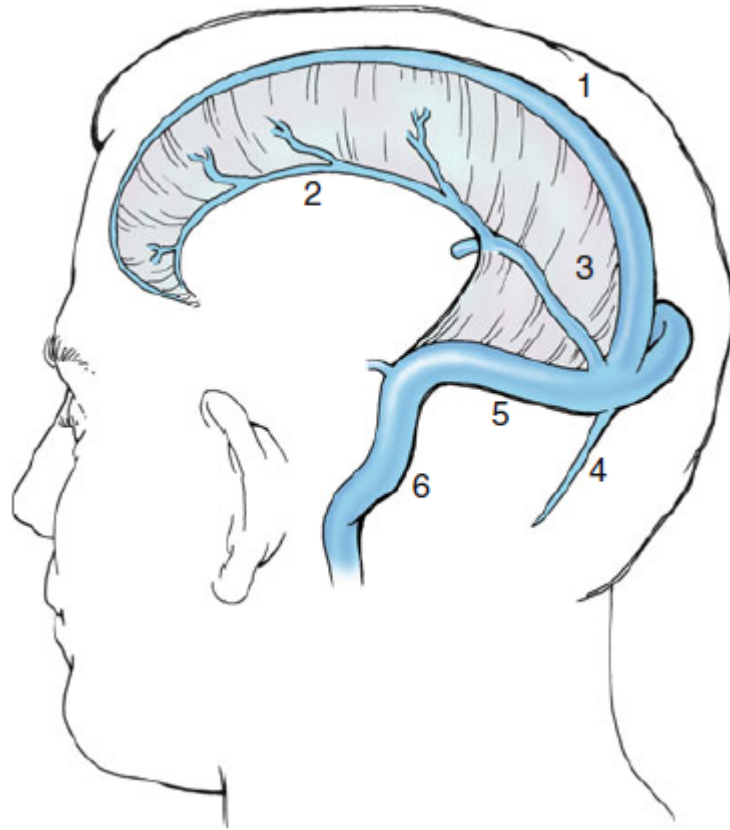


hluboké



Mozkové žíly

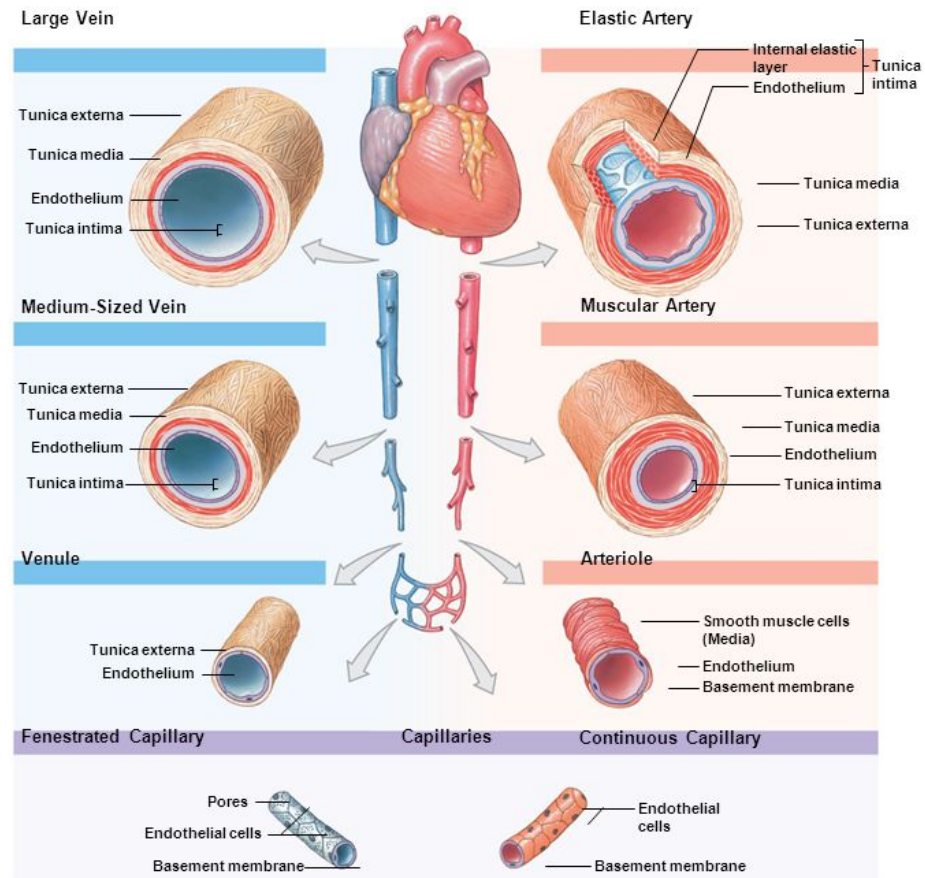
Žilní splavy (venous sinuses)



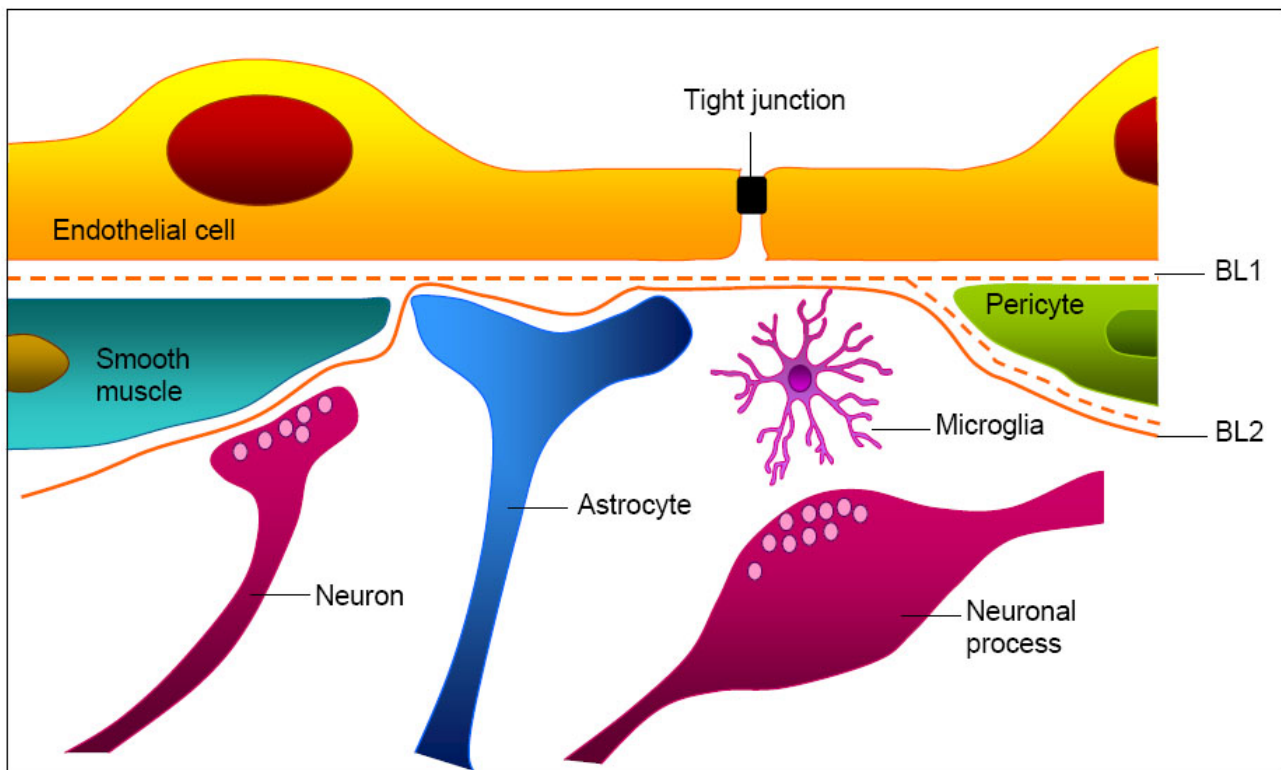
- Vena jugularis

Mozkové žíly

Histological Structure of Blood Vessels

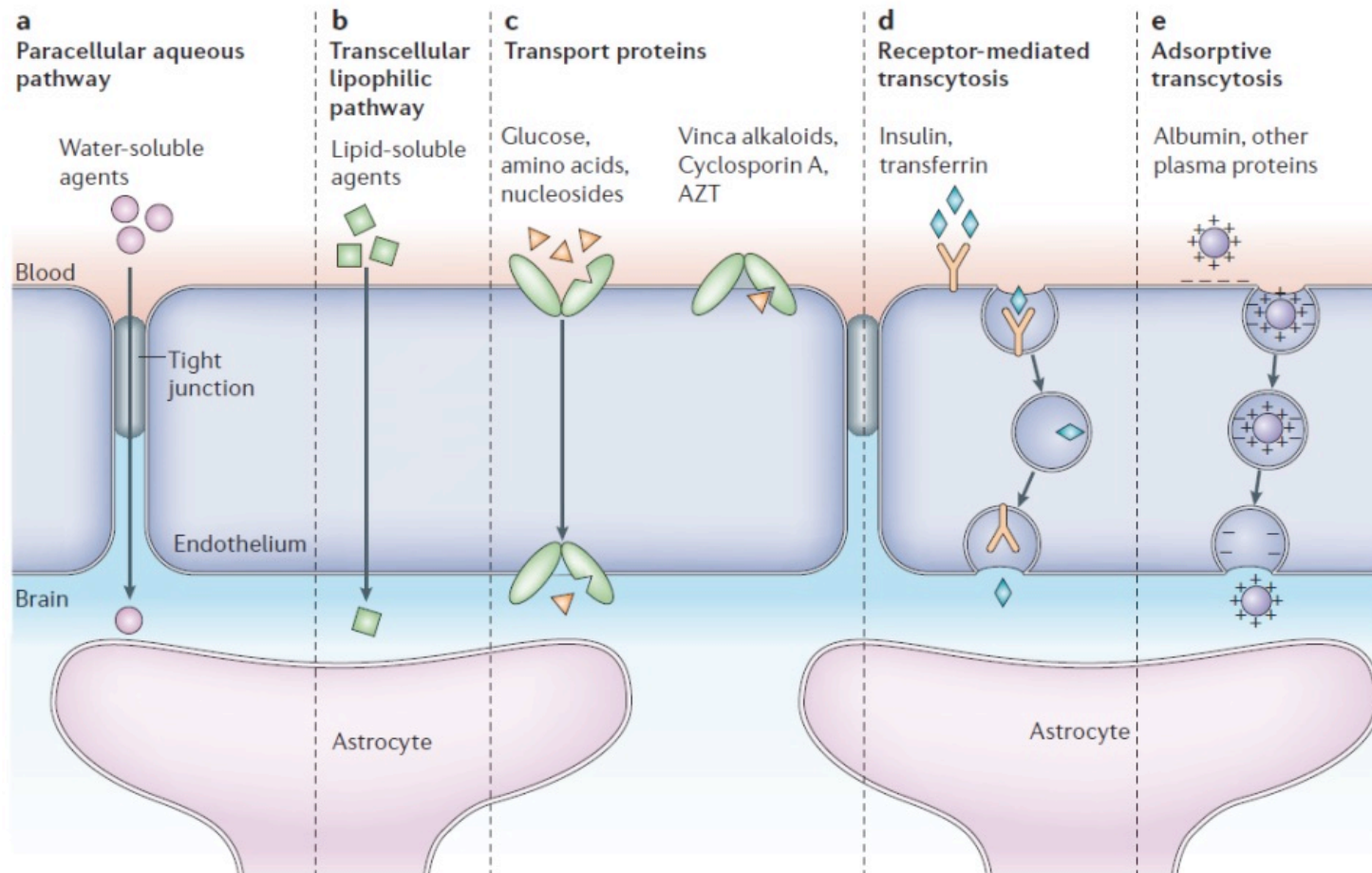


Odlišná stavba cévní stěny



HEB je tvořena těsnými spoji
endotelu kapilární stěny

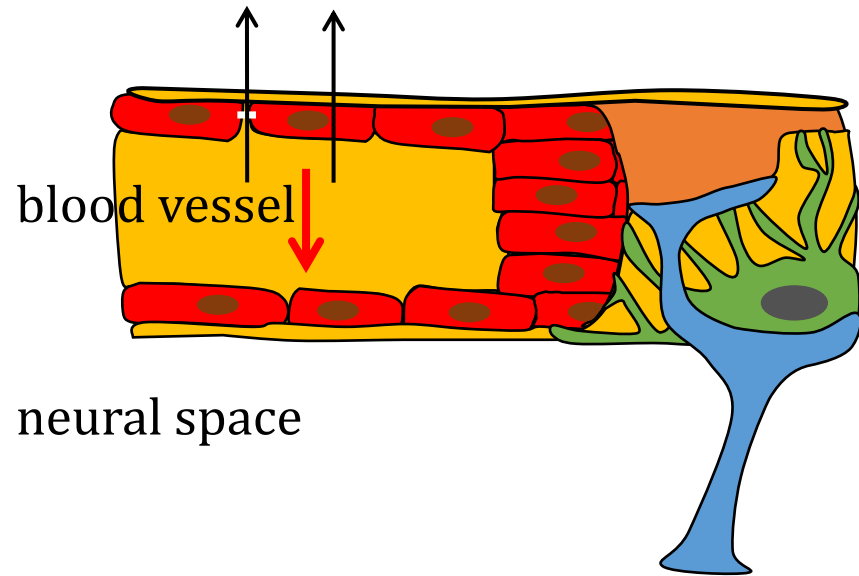
Hematoencefalická bariera



Udržení iontové rovnováhy

Hematoencefalická bariera

Healthy

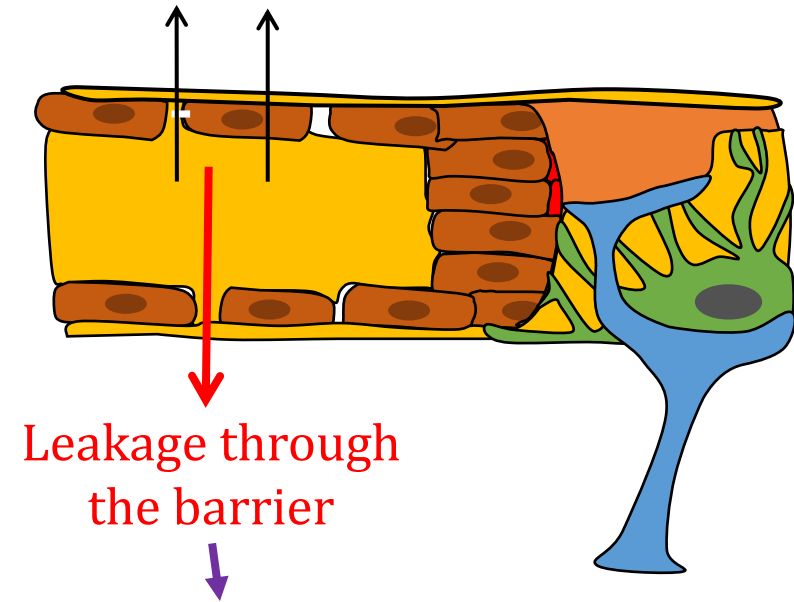


blood vessel

neural space

Udržení iontové rovnováhy

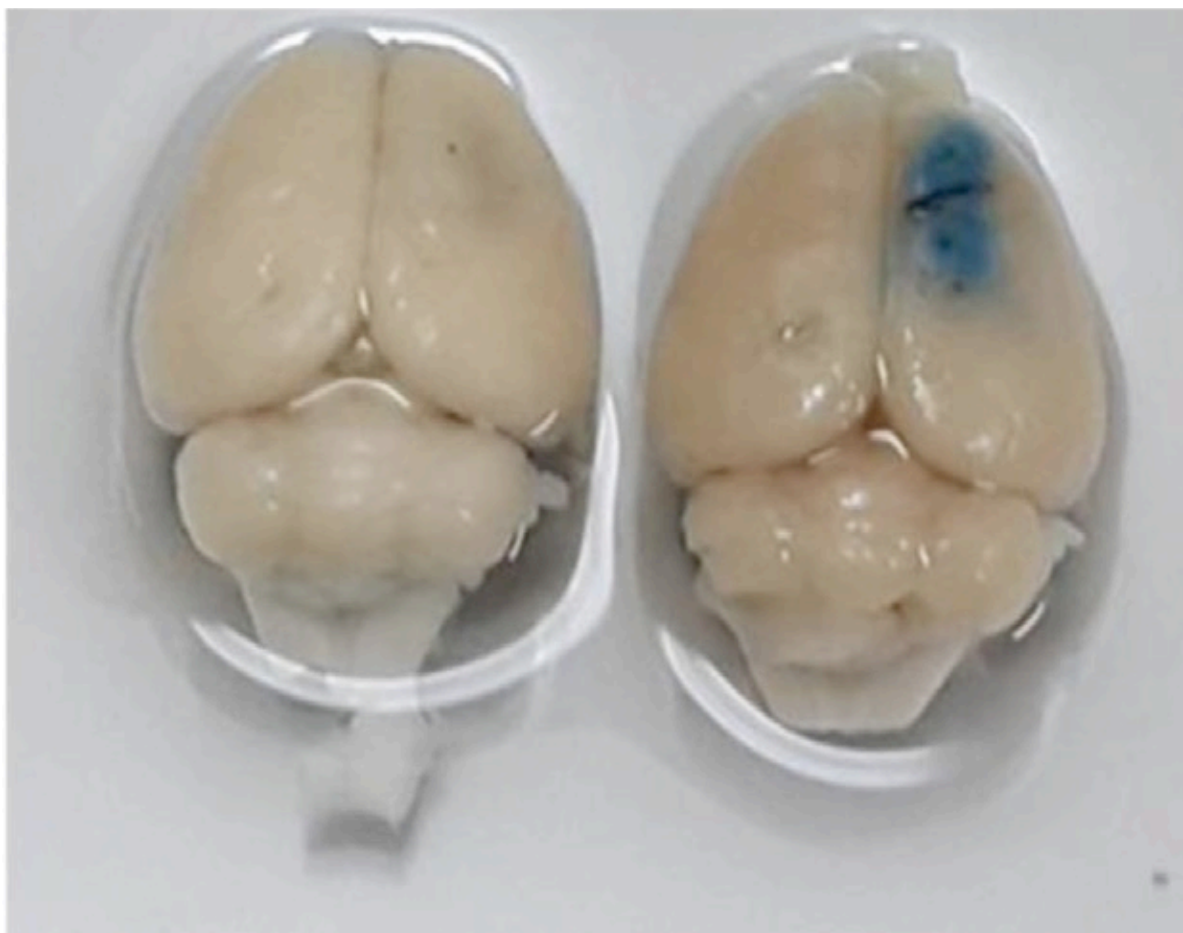
Impaired



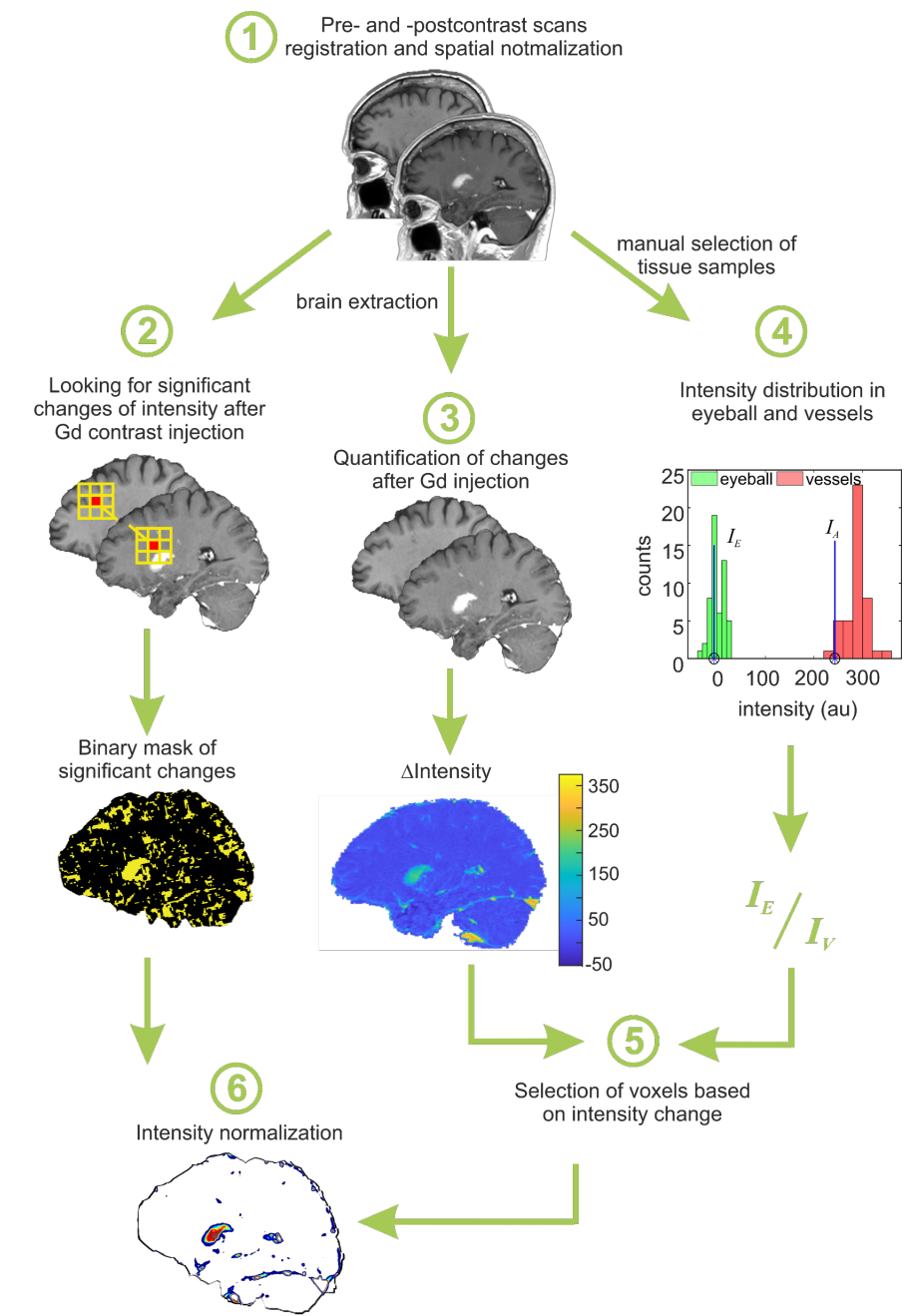
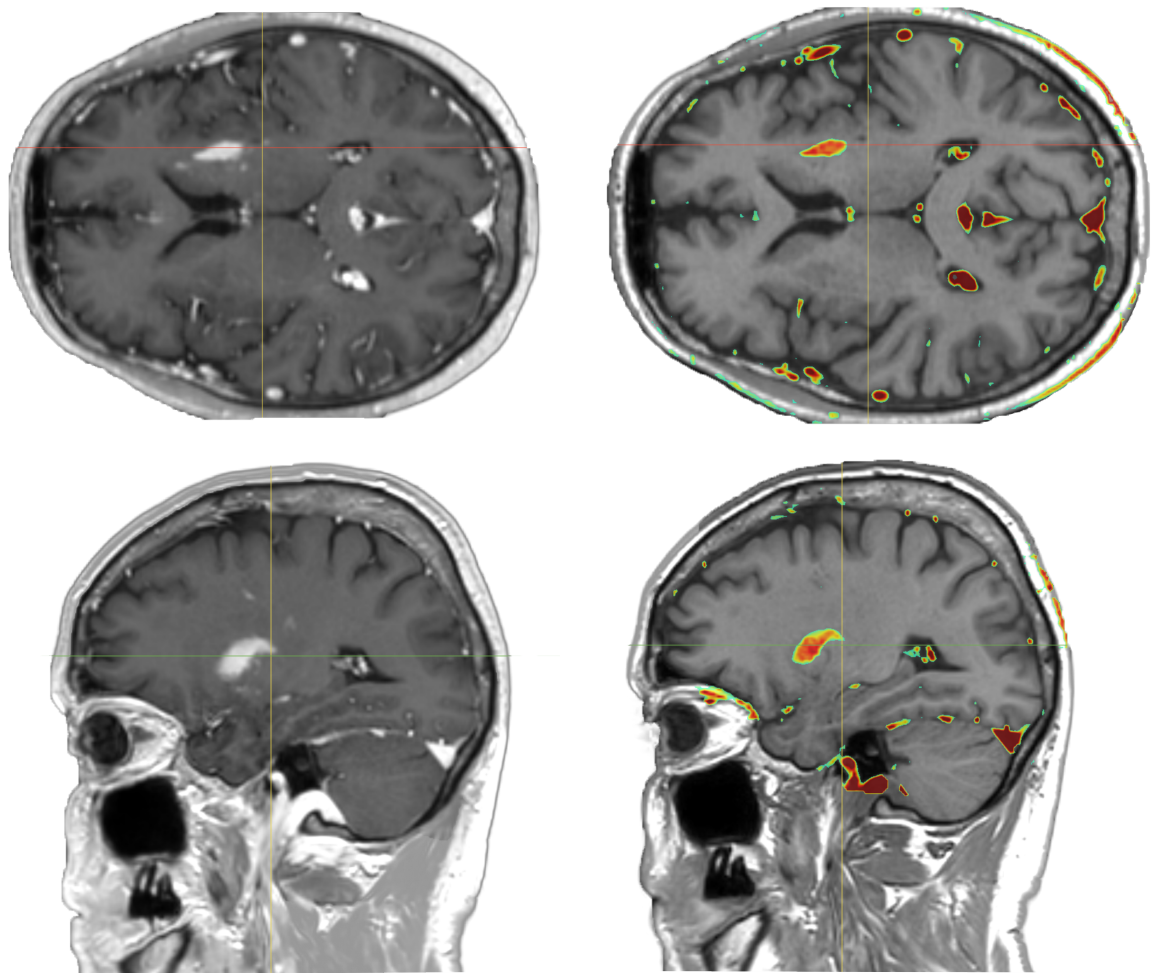
Leakage through
the barrier

Inflammation

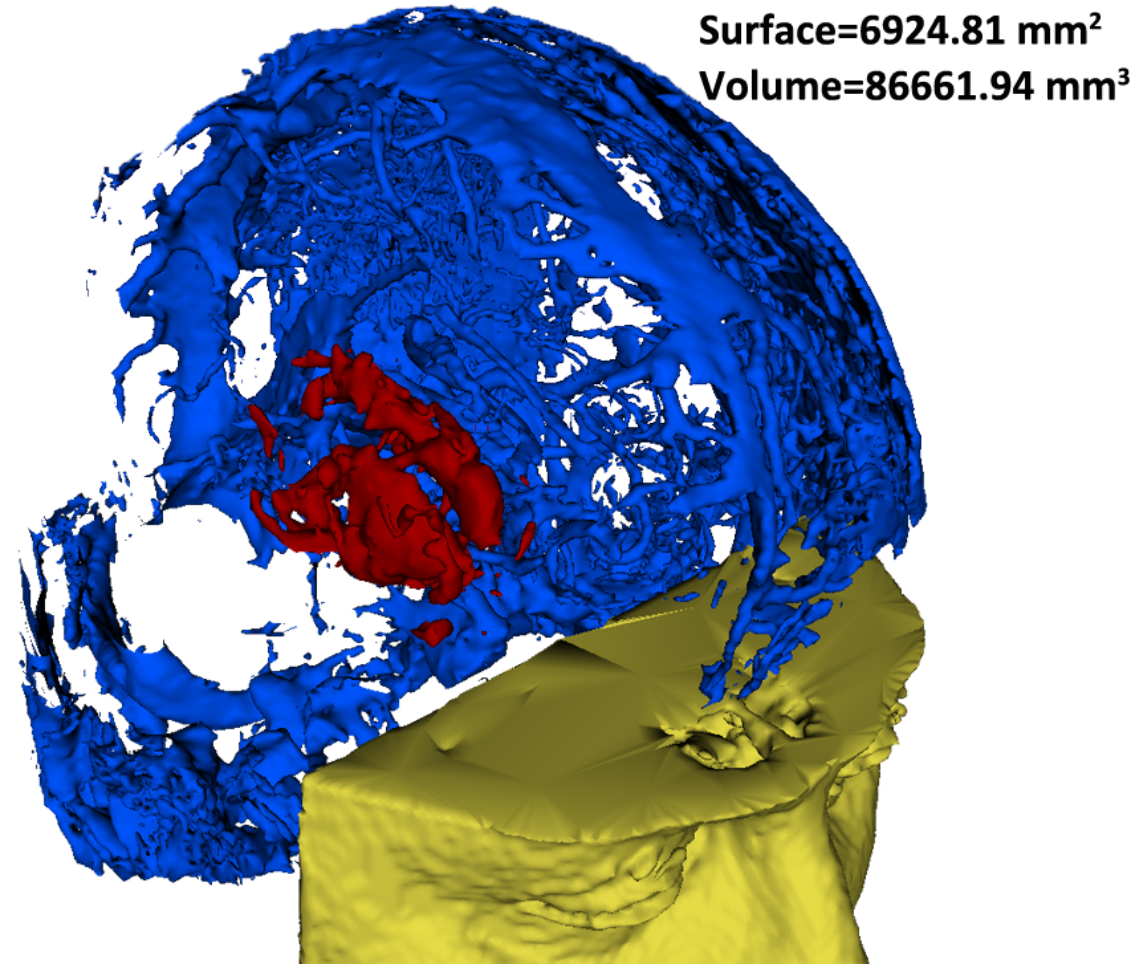
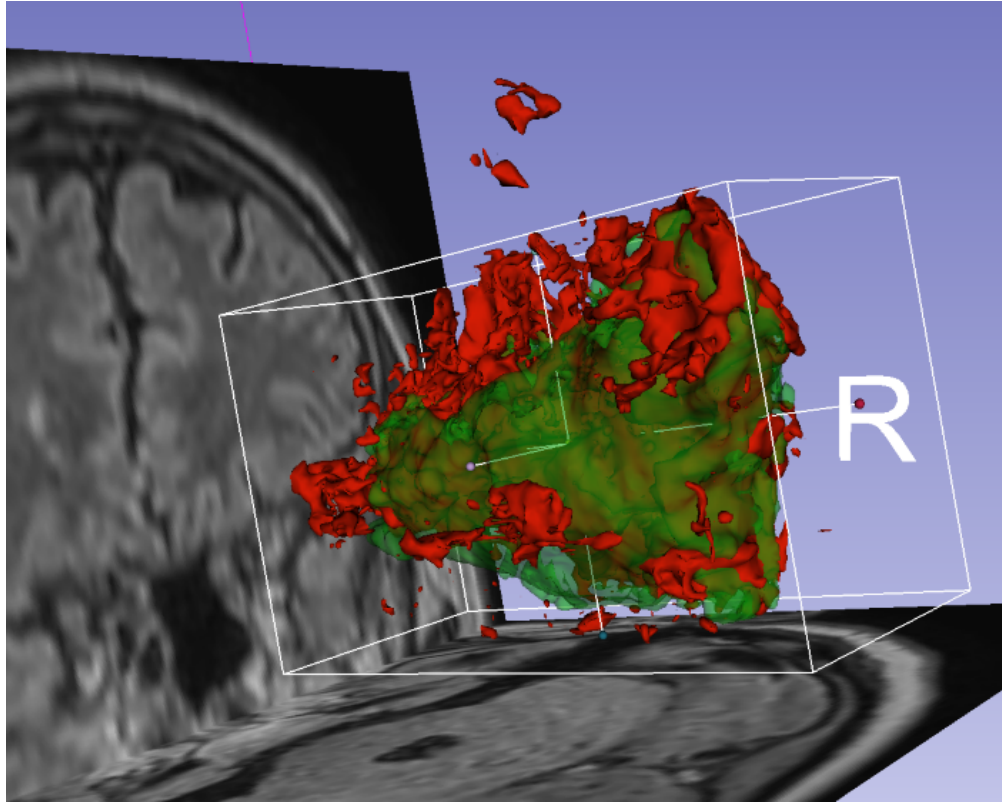
Hematoencefalická bariera



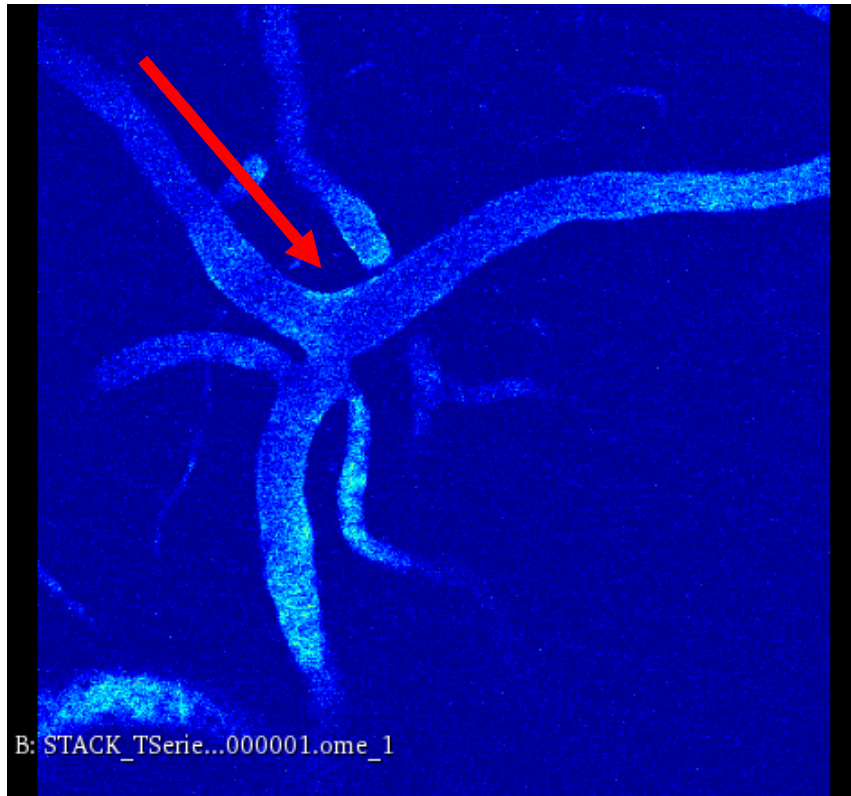
Poškození bariery



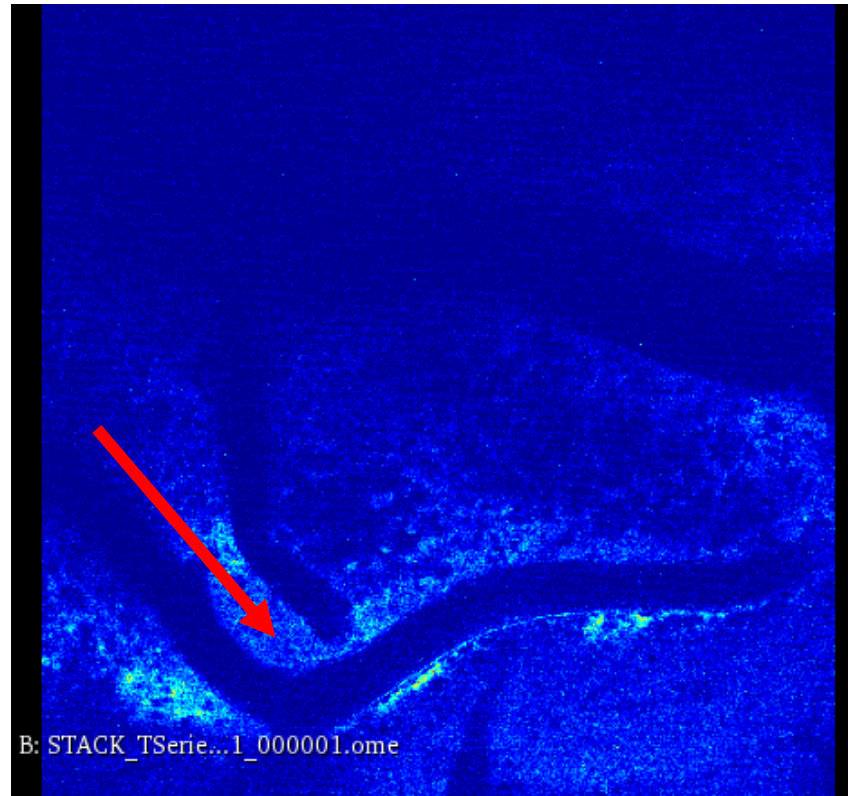
Porucha bariery u pacientů po mrtvici



Porucha bariery u pacientů po mrtvici

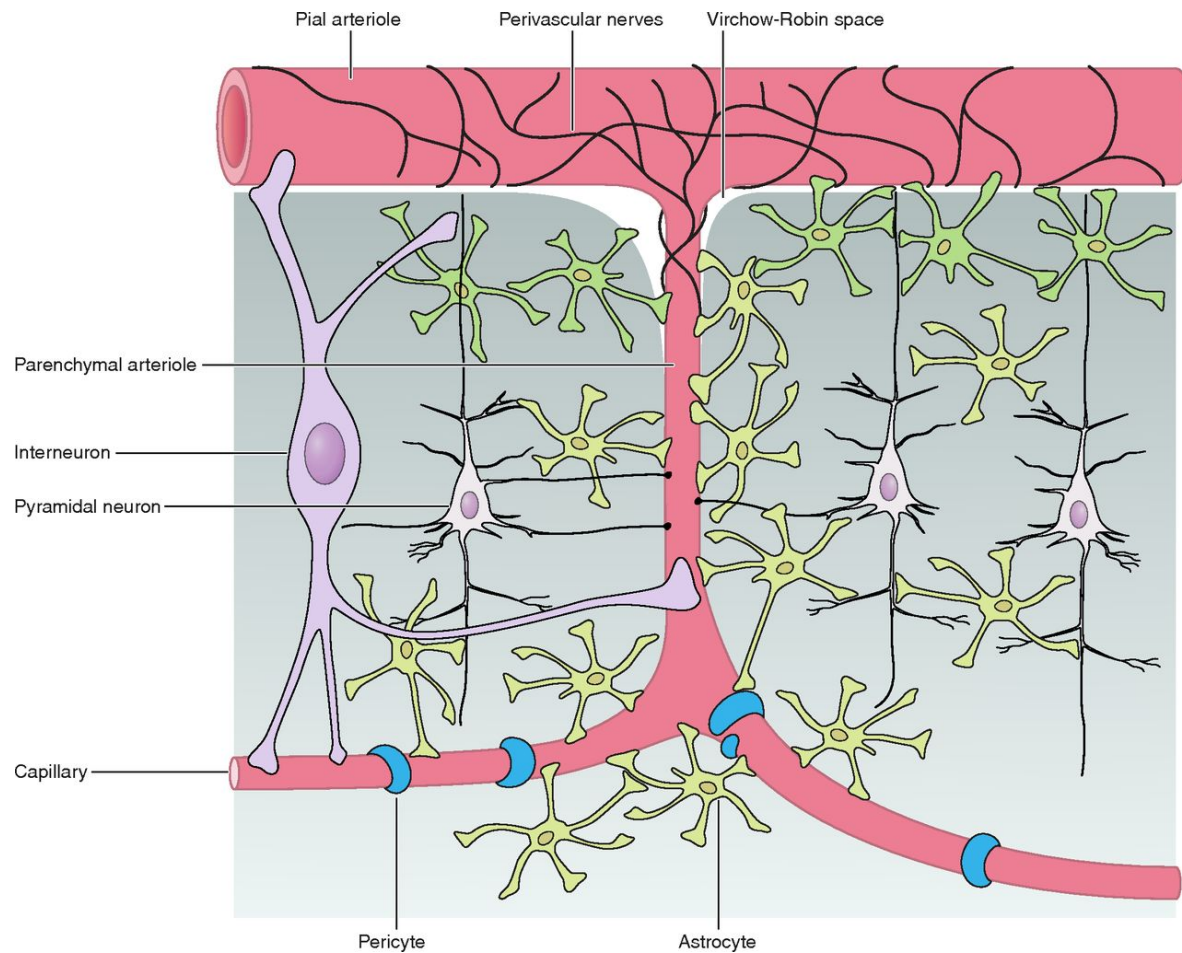


before

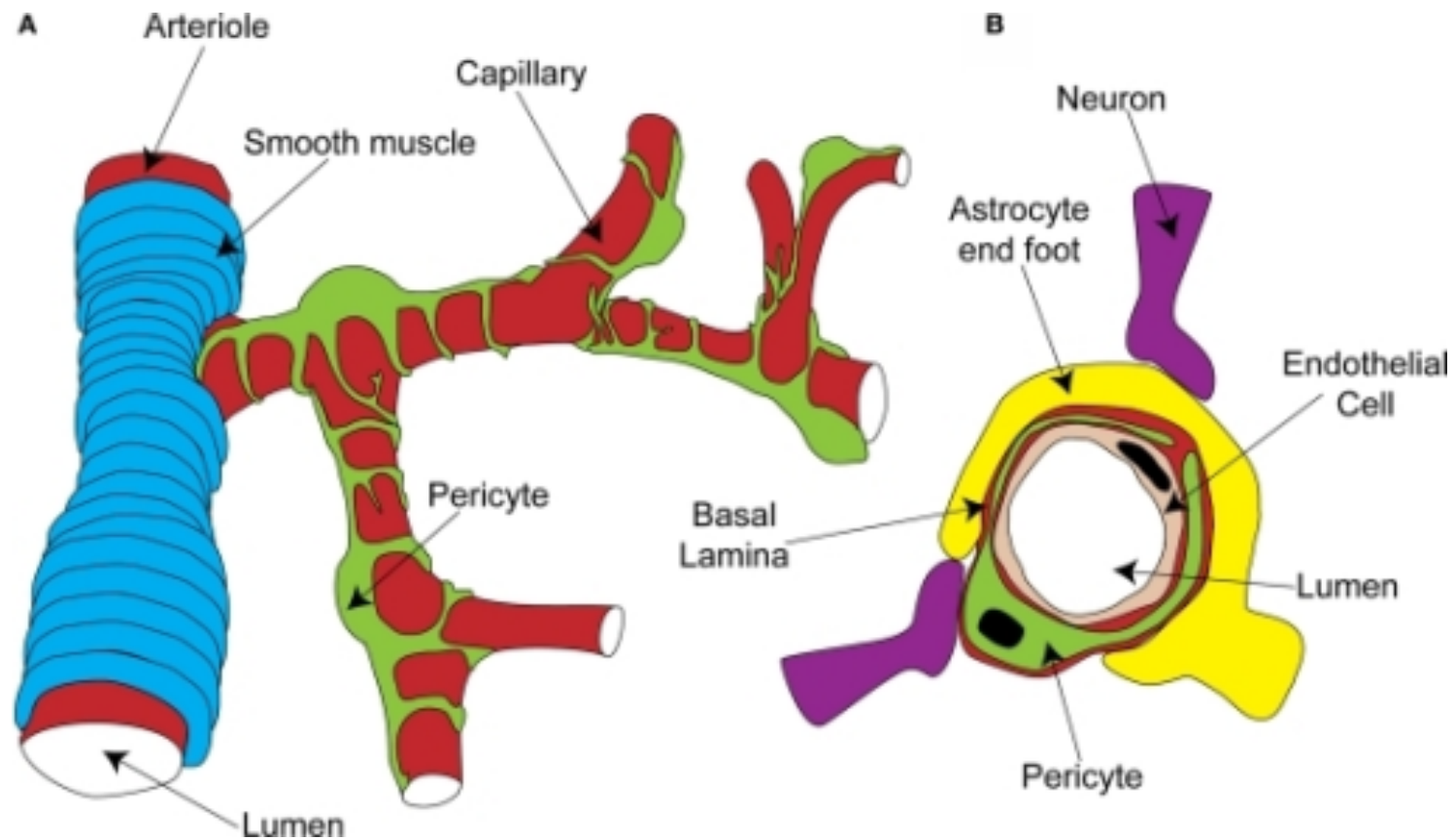


20 min after occlusion

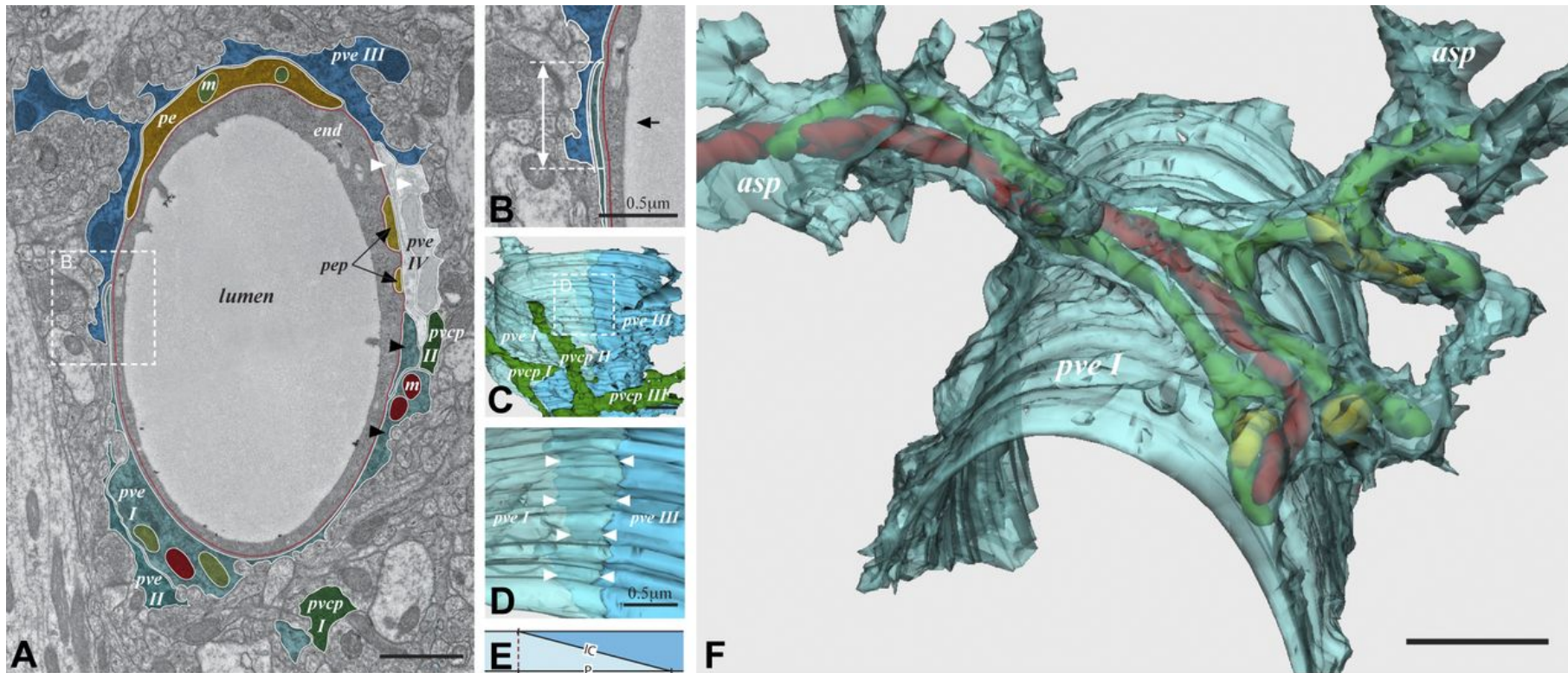
Porucha bariery u pacientů po mrtvici



Neurovaskulární jednotka – energie z krve k neuronům



Neurovaskulární jednotka – energie z krve k neuronům



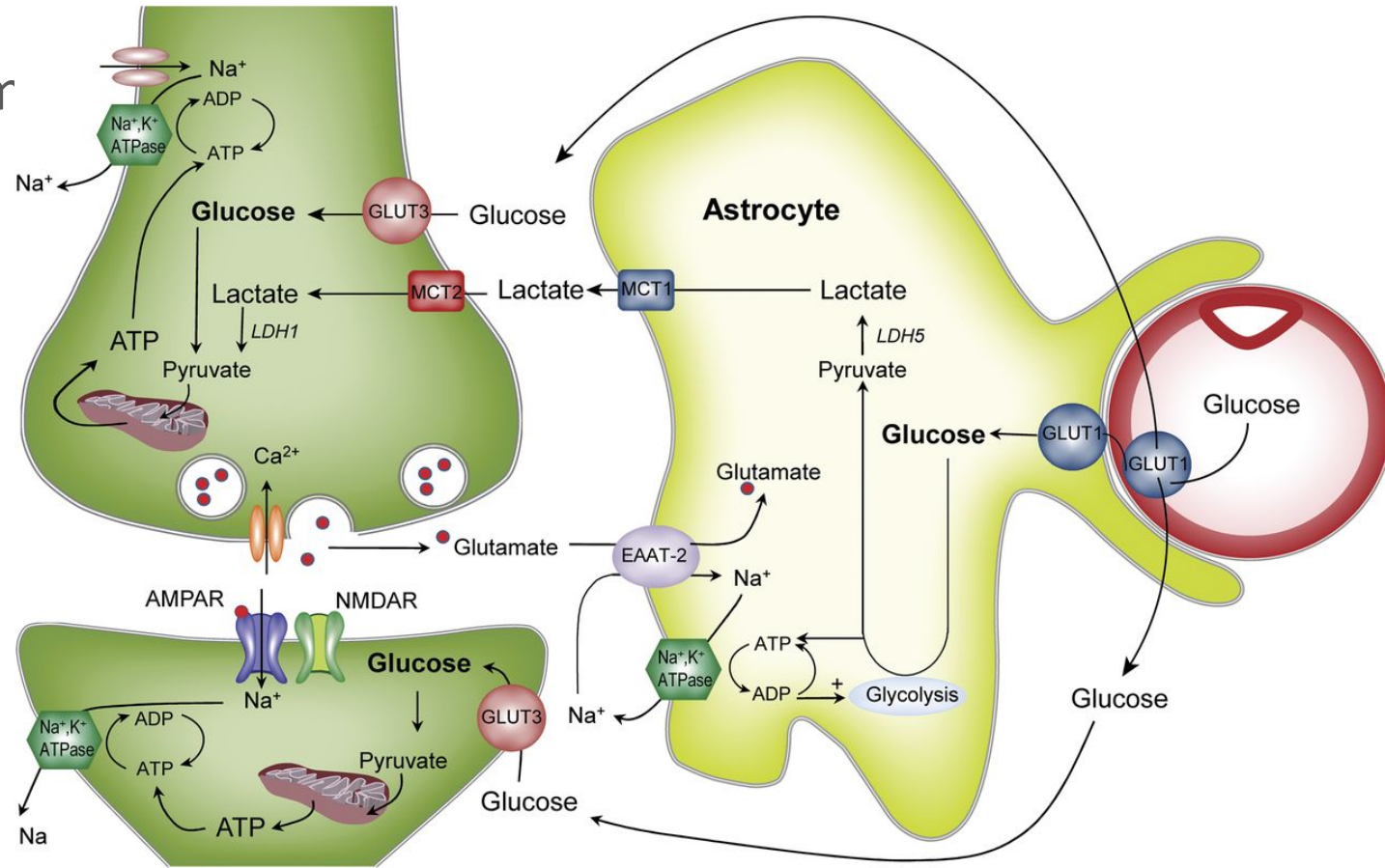
Neurovaskulární jednotka – energie z krve k neuronům

Glukoza je hlavním energetickým zdrojem
Neurony jí však neumí zpracovat

Nejprve štěpena astrocyty na laktát a
pyruvát

Aktivita astrocytů je synchronizována s
aktivitou neuronů

Pro správnou funkci – **konstantní přítok
krve (kyslíku)**

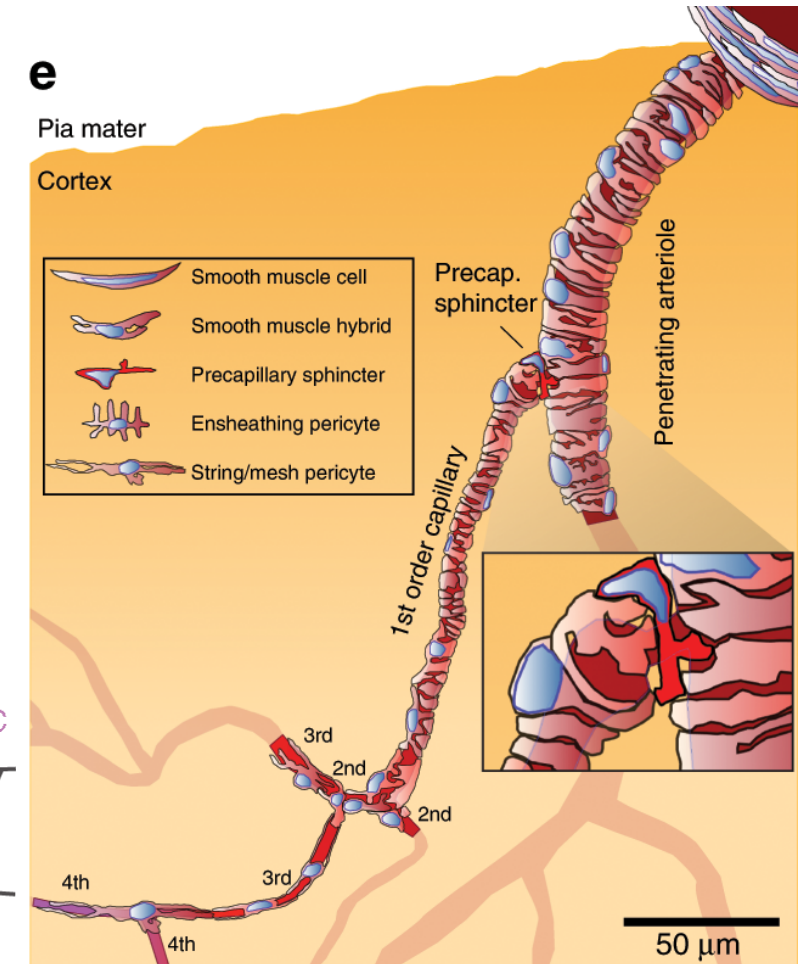
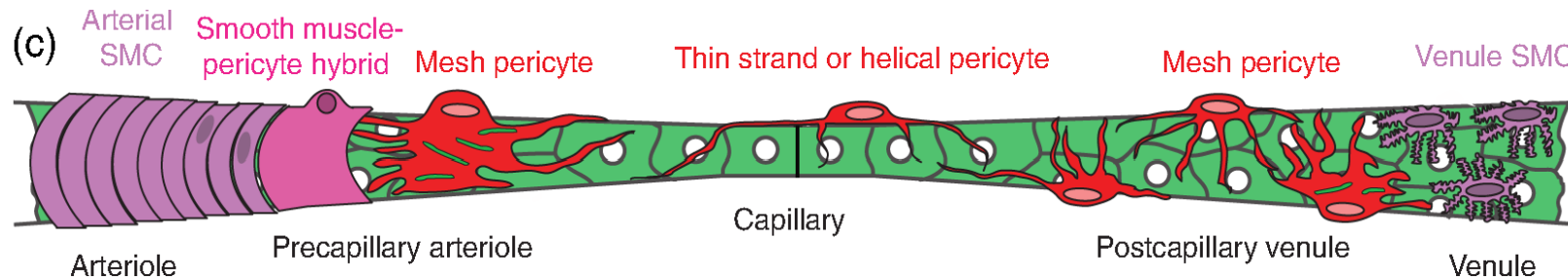


Energetický metabolismus neuronu

Neurovaskulární coupling

Kapiláry nejsou schopny kontraktility

- Prekapilární svěrače
- pericyty

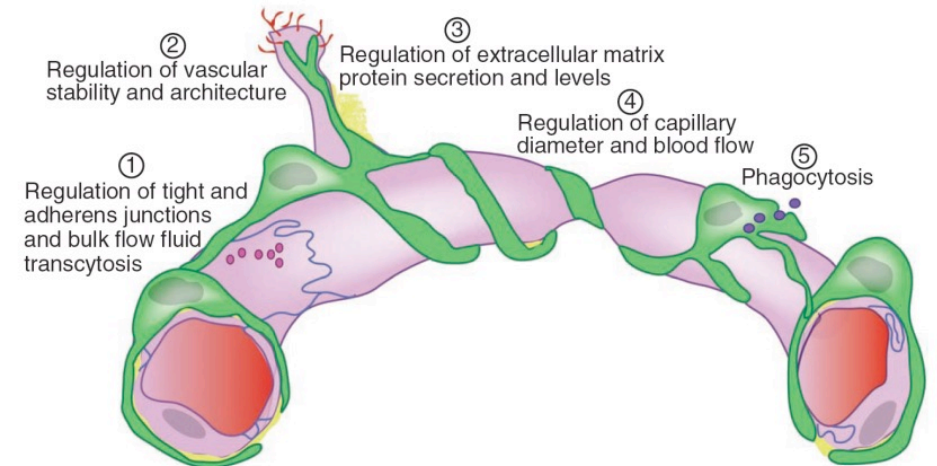
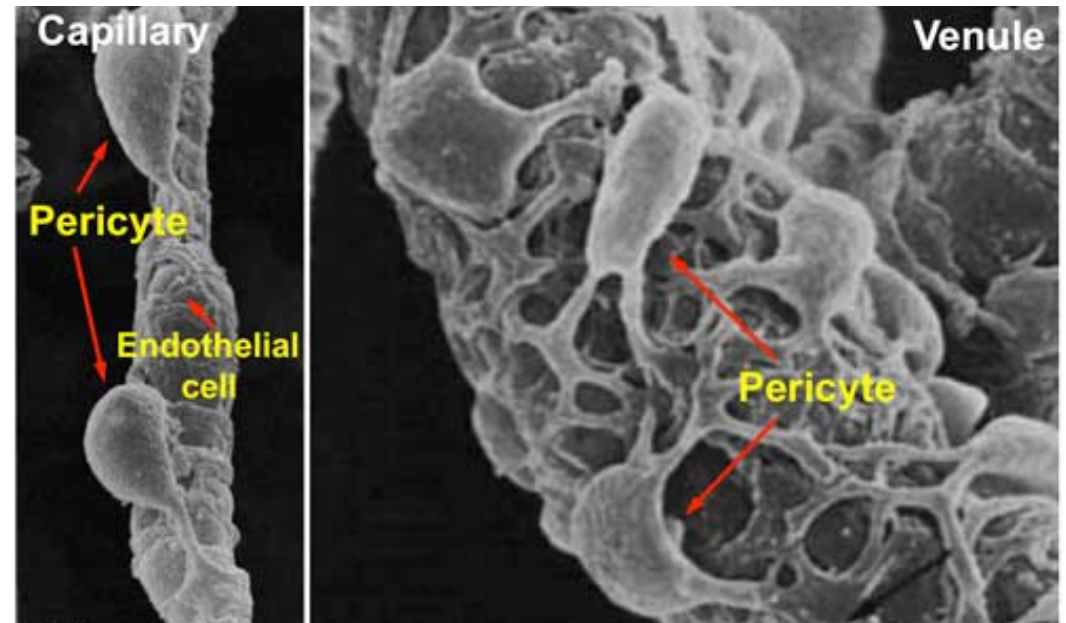


Regionální regulace na mikro úrovni

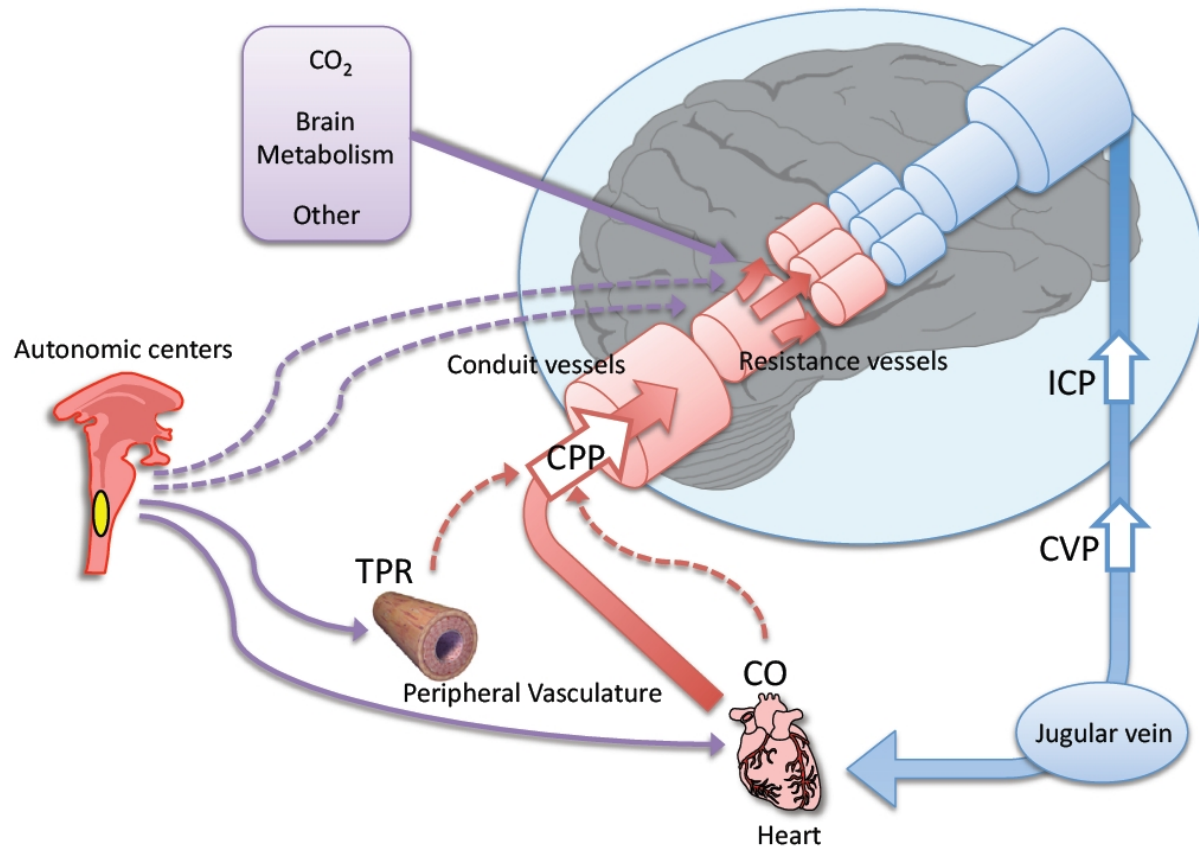
Neurovaskulární coupling

Kapiláry nejsou schopny kontraktility

- Prekapilární svěrače
- **pericyty**



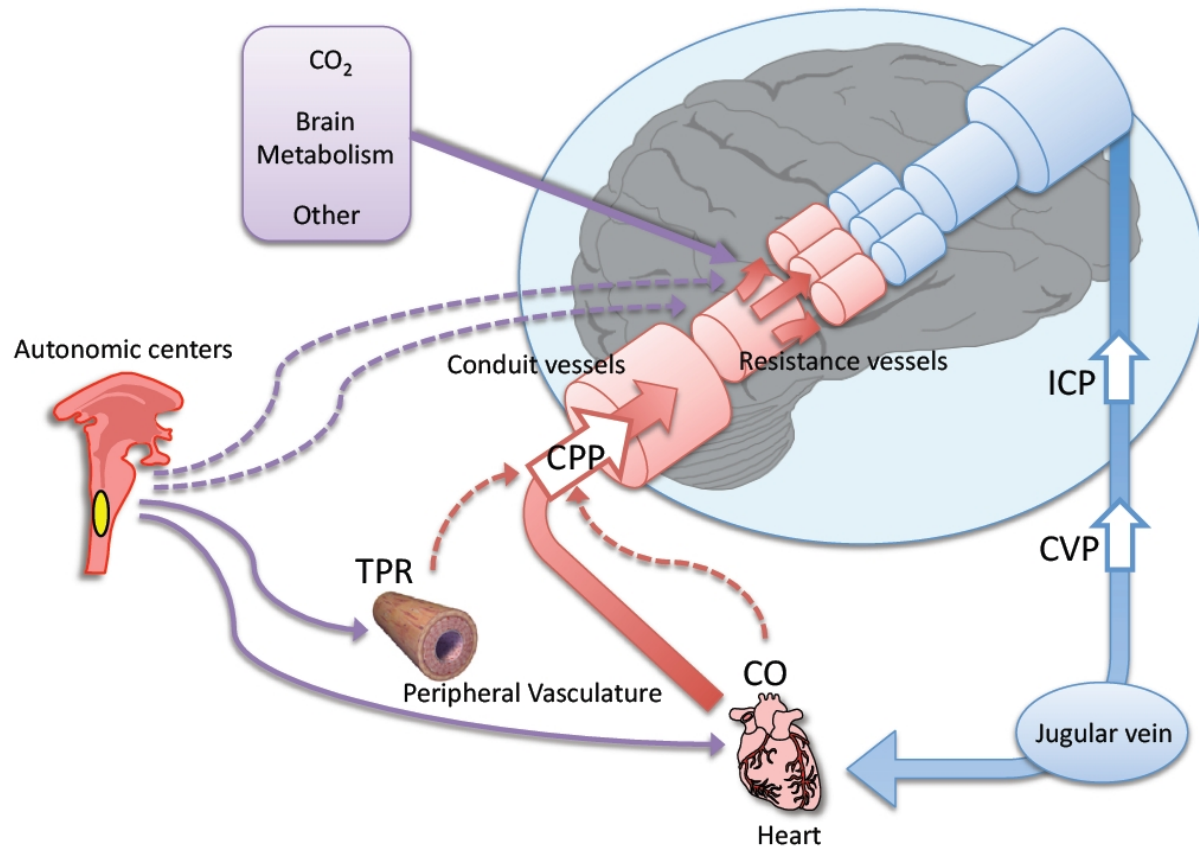
Regionální regulace na mikro úrovni



CPP - cerebral perfusion pressure
ICP – intra-cranial pressure
MAP – mean arterial pressure

$$CPP = MAP - ICP$$

Tlakový gradient v mozku

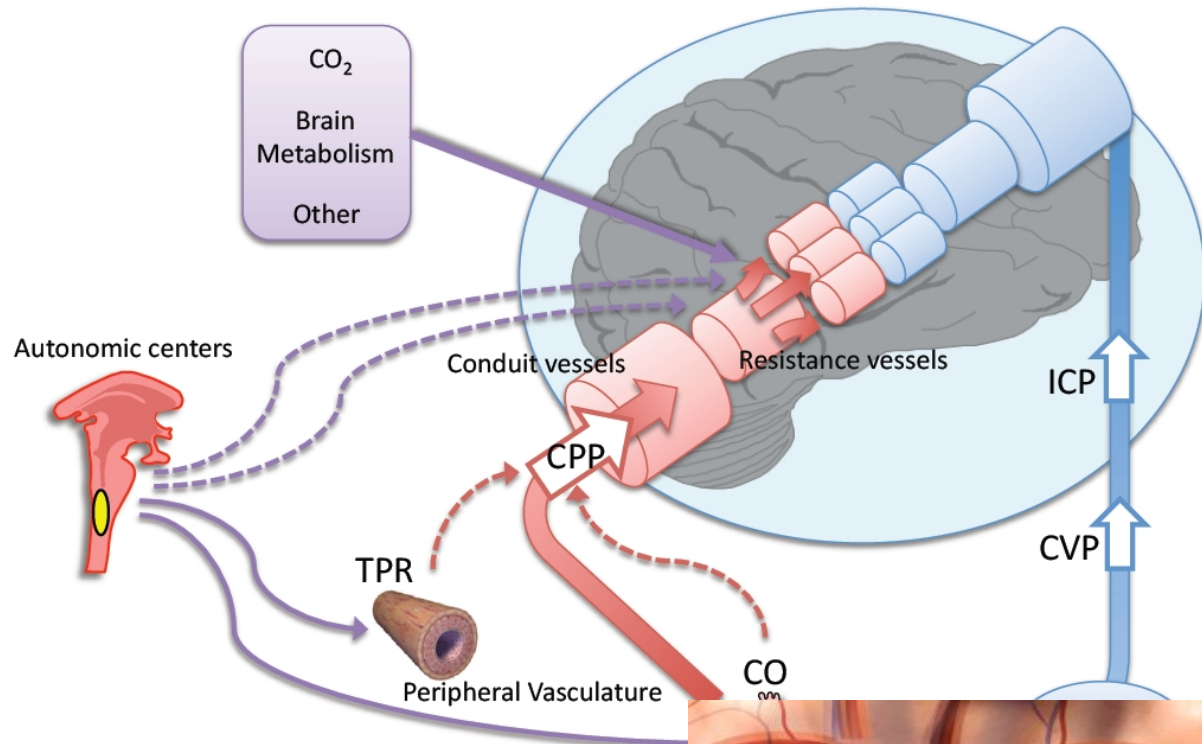


CPP - cerebral perfusion pressure
 ICP – intra-cranial pressure
 MAP – mean arterial pressure

$$CPP = MAP - ICP$$

Ohmův zákon $I = U/R$

Srdce jako pumpa

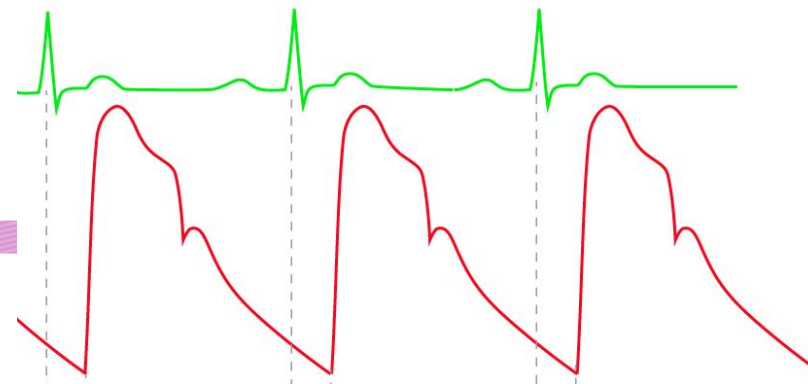
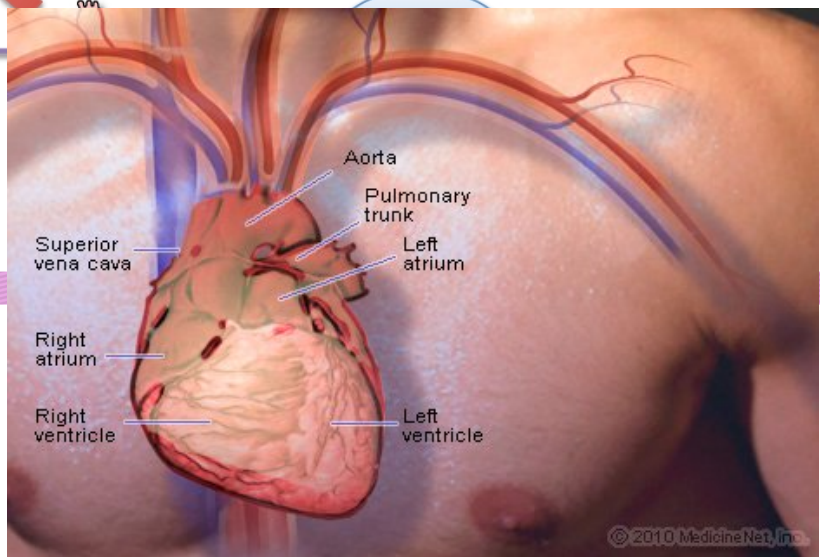


CPP - cerebral perfusion pressure
 ICP – intra-cranial pressure
 MAP – mean arterial pressure

$$CPP = MAP - ICP$$

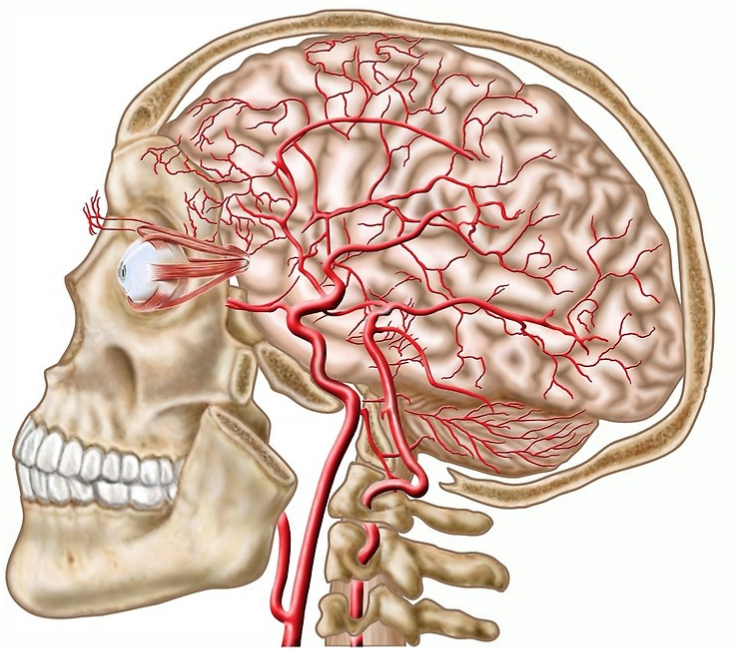
Ohmův zákon $I = U/R$

Srdce jako pumpa



Monroe – Killie doctrine

- Due to rigid skull the intracranial volume is constant

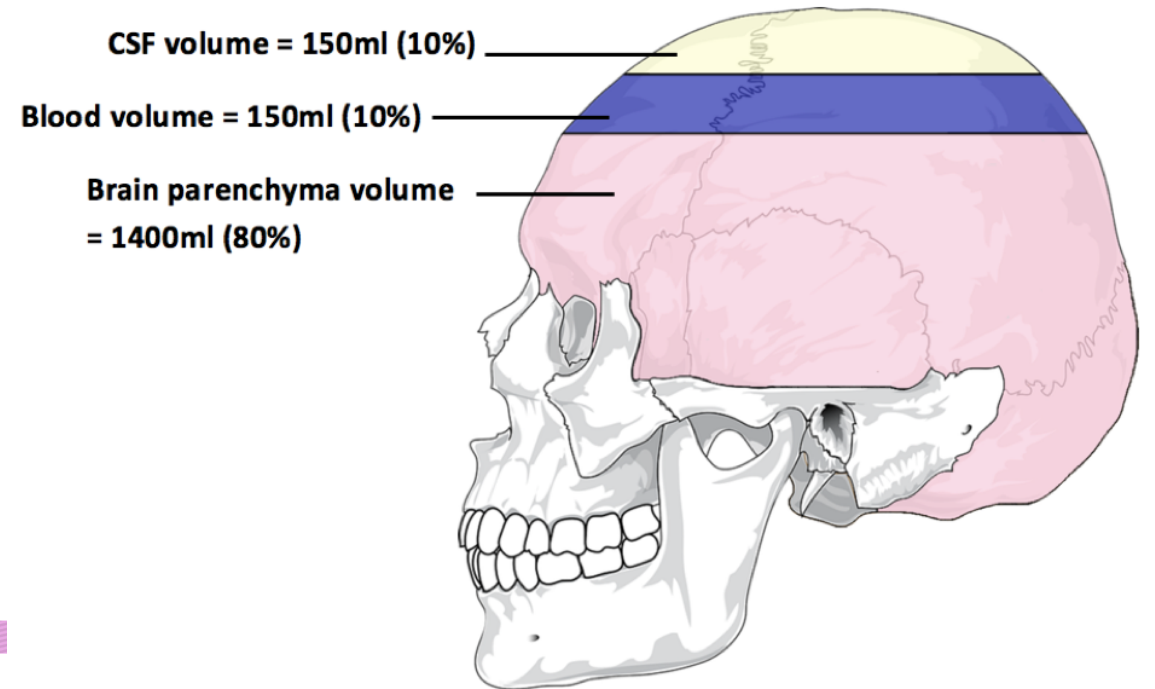
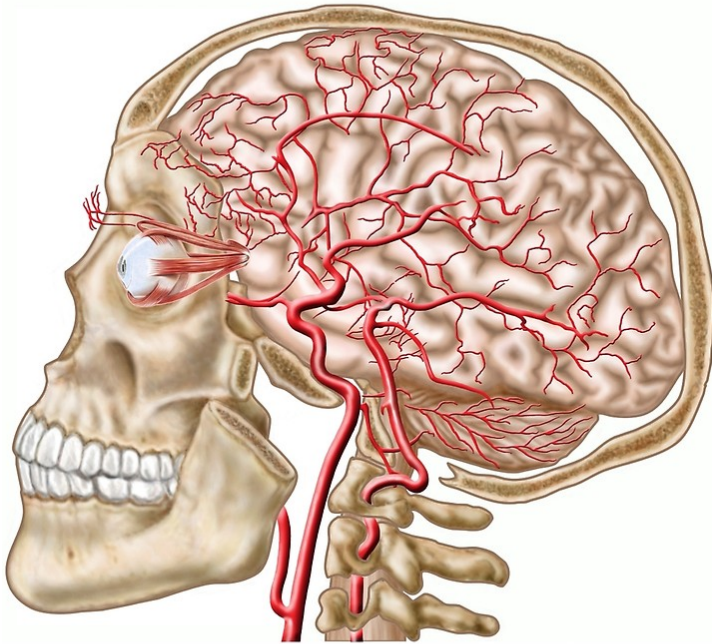


Mozek = viskozni těleso v rigidním těle

Monroe – Killie doctrine

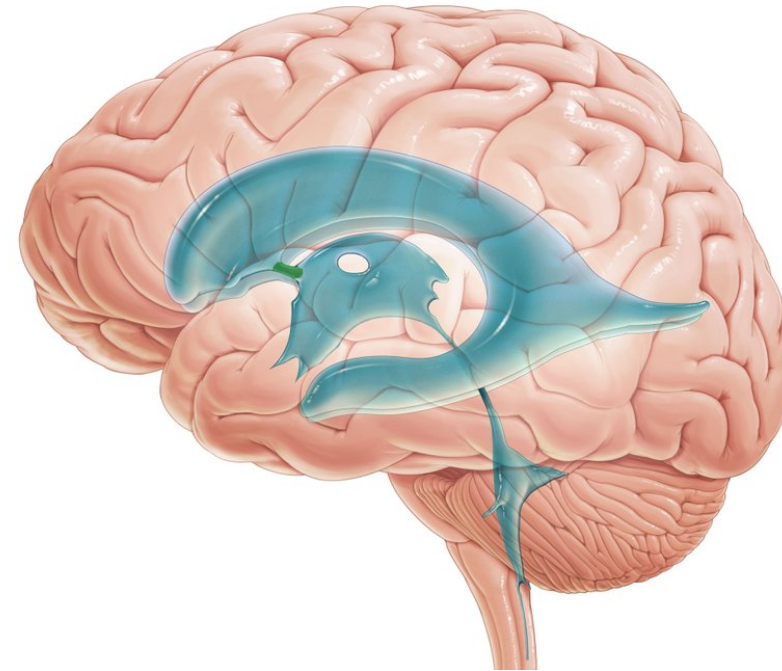
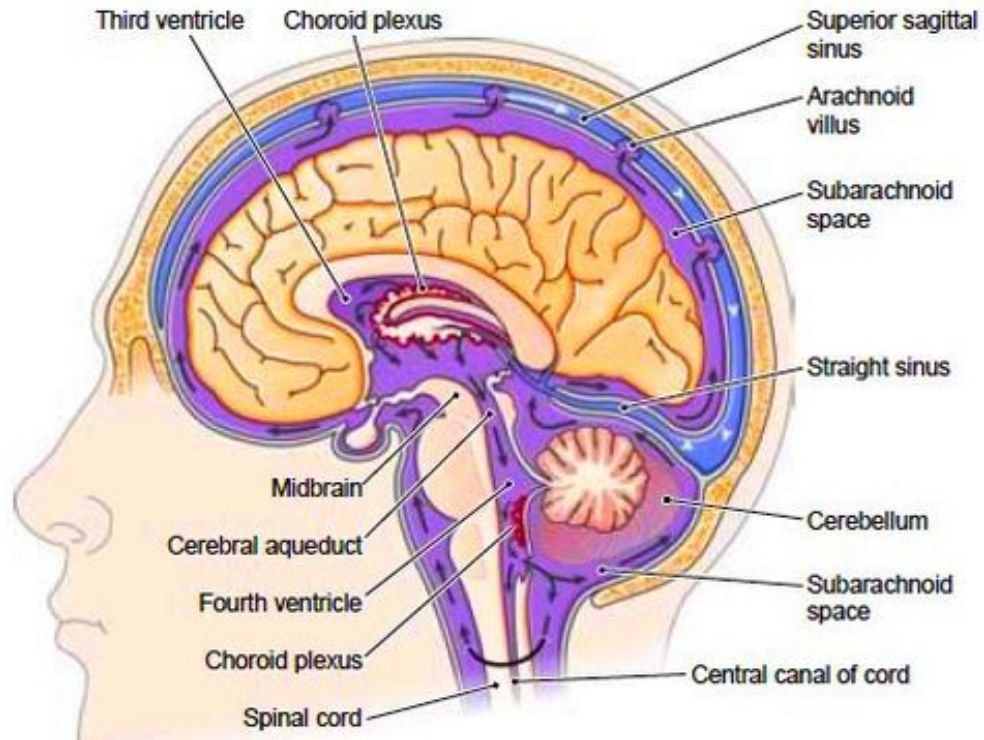
- Due to rigid skull the intracranial volume is constant

$$V_{ic} = V_{blood} + V_{CSF} + V_{brain}$$

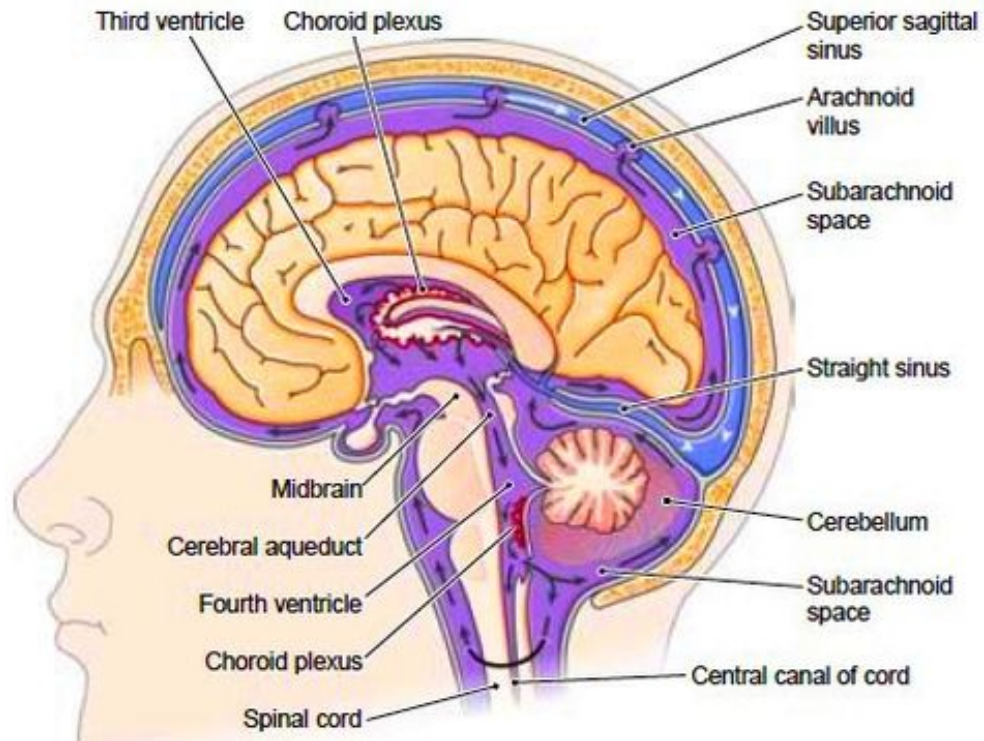


Zákon zachování hmoty

Tekutina v arachnoidálním prostoru a mozkových komorách napojená na páteřní kanál



Cerebro-spinální tekutina (CSF)



Tekutina v arachnoidálním prostoru a mozkových komorách napojená na páteřní kanál

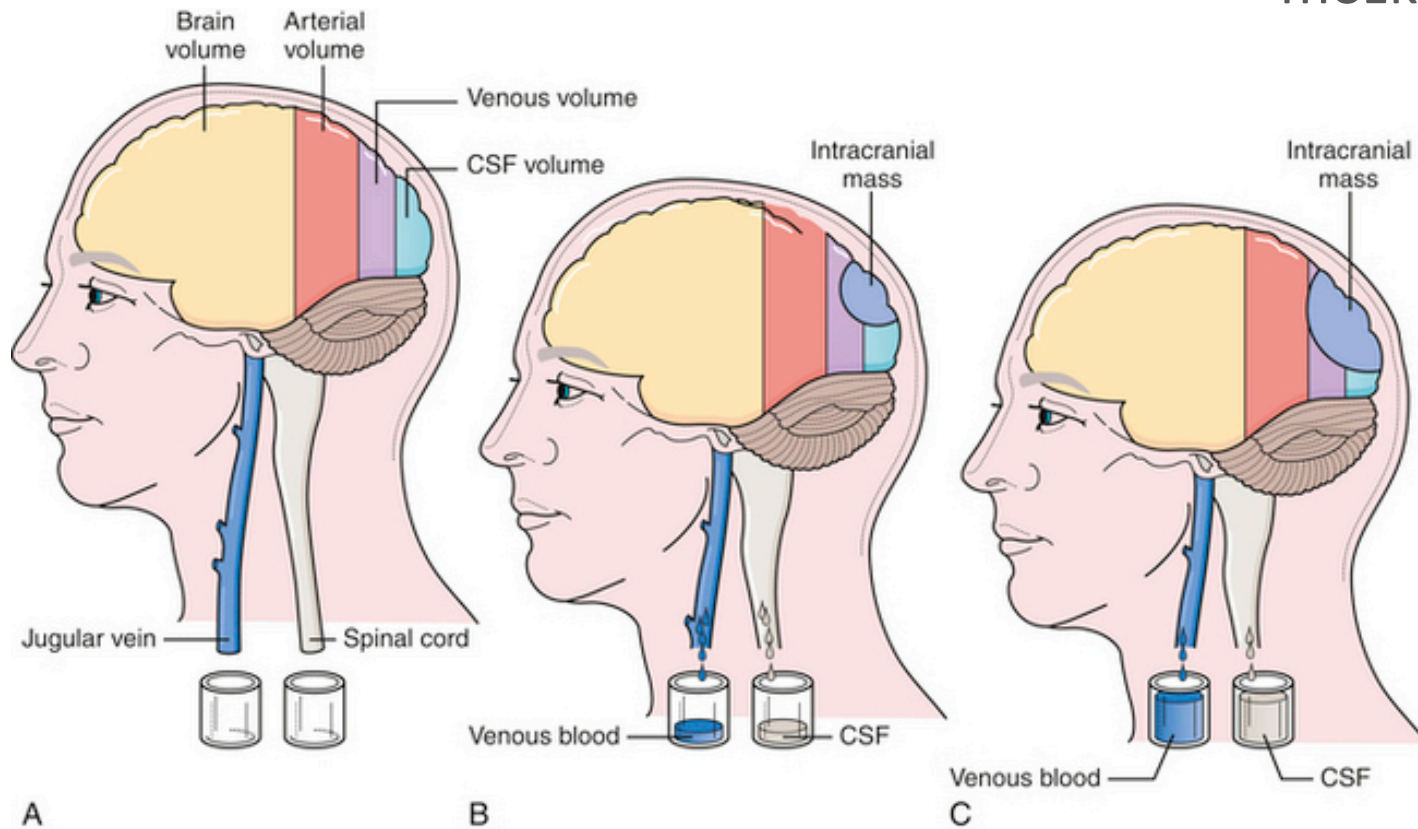
Objem ~125ml

Produkována v choroidálním plexu

Tlak 7-15 mmHg

Cerebro-spinální tekutina (CSF)

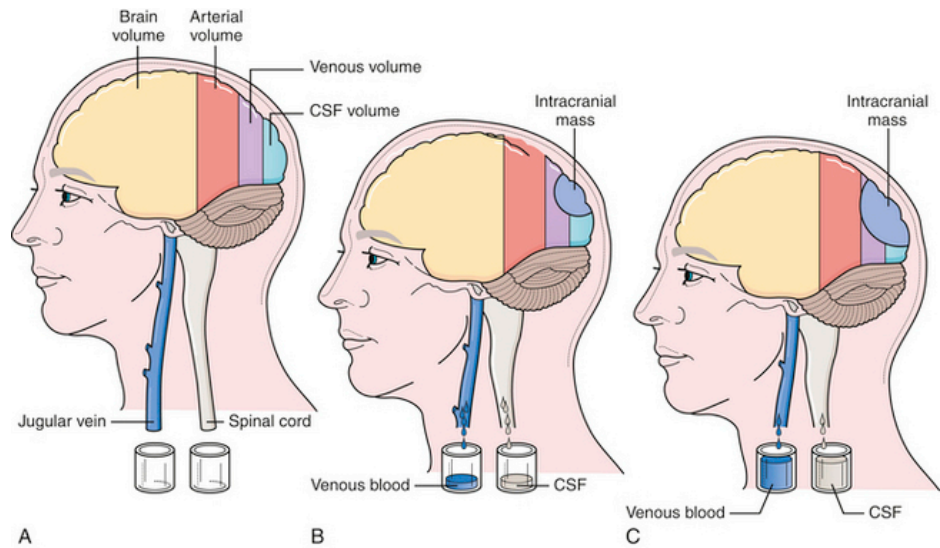
Tekutina v arachnoidálním prostoru a mozkových komorách napojená na páteřní



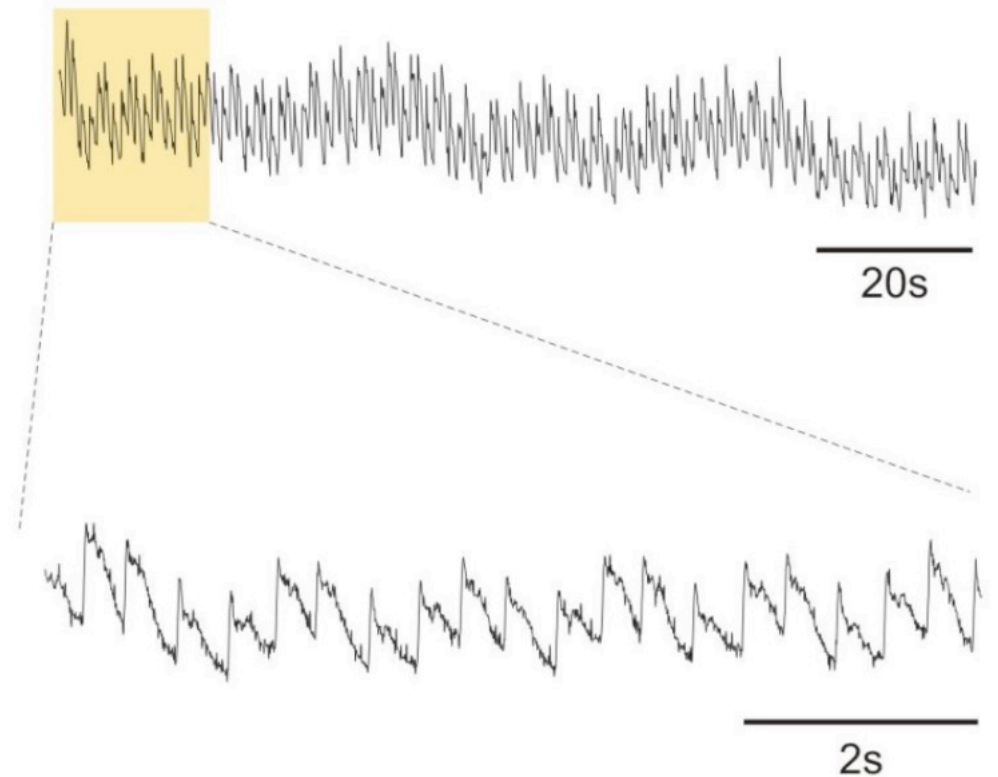
$$V_{ic} = V_{\text{blood}} + V_{\text{CSF}} + V_{\text{brain}}$$

Cerebro-spinální tekutina (CSF)

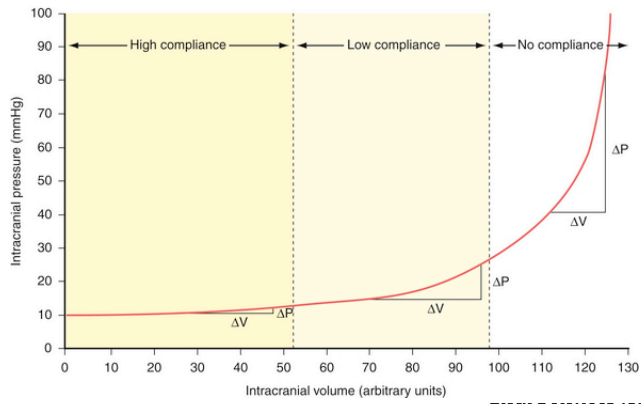
Tekutina v arachnoidálním prostoru a mozkových komorách napojená na páteřní kanál



Její cirkulace kompenzuje srdeční tlakové pulzy krve

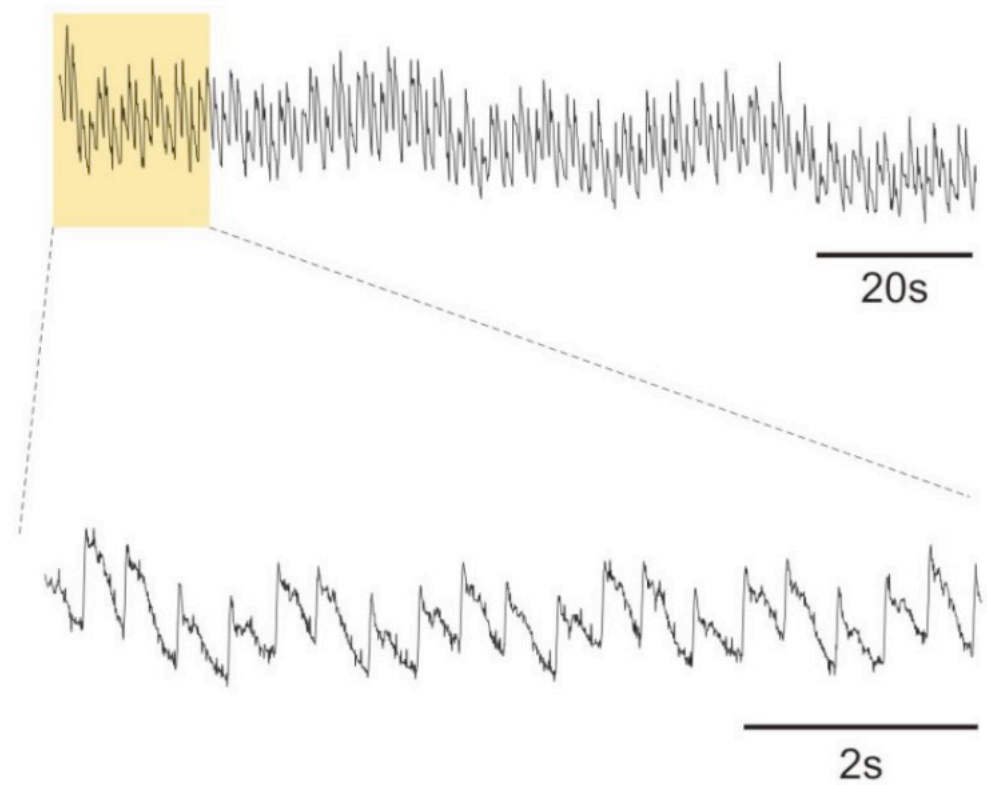
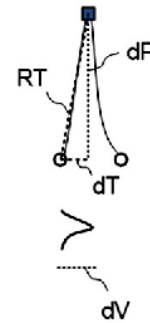
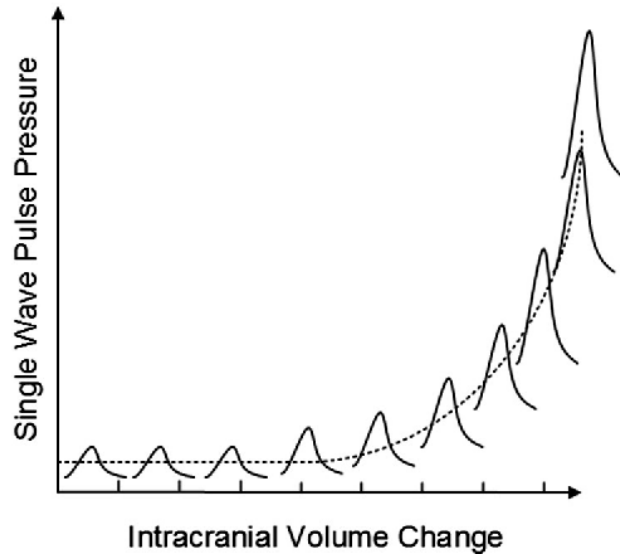


Cerebro-spinální tekutina (CSF)

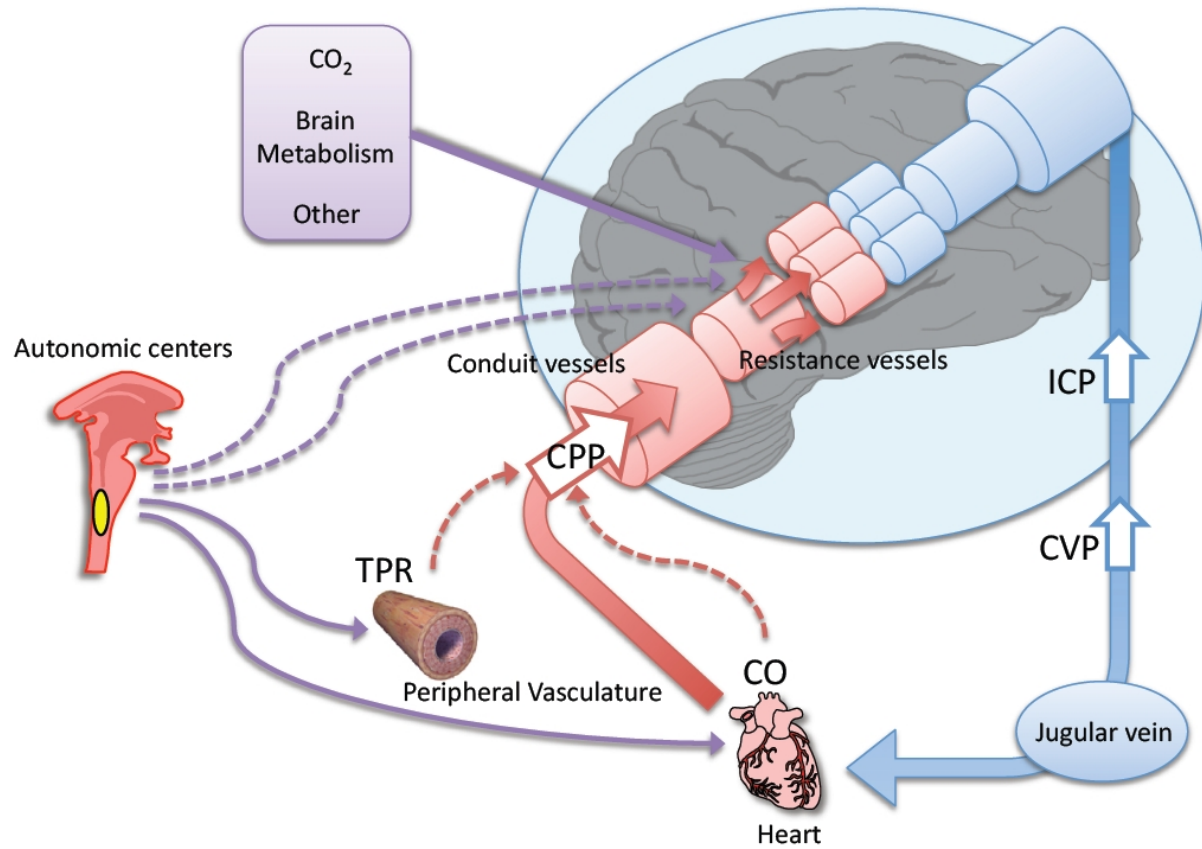


Tekutina v arachnoidálním prostoru a mozkových komorách napojená na páteřní kanál

Její cirkulace kompenzuje srdeční tlakové pulzy krve

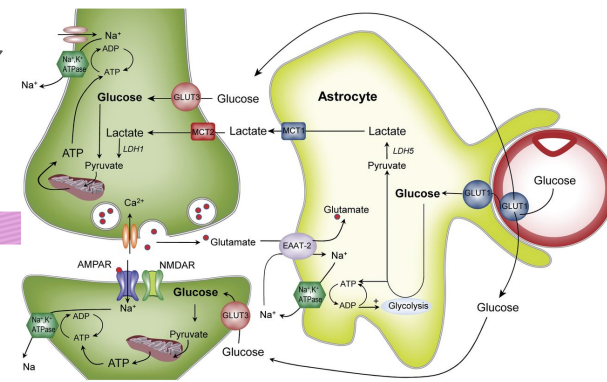


Cerebral compliance

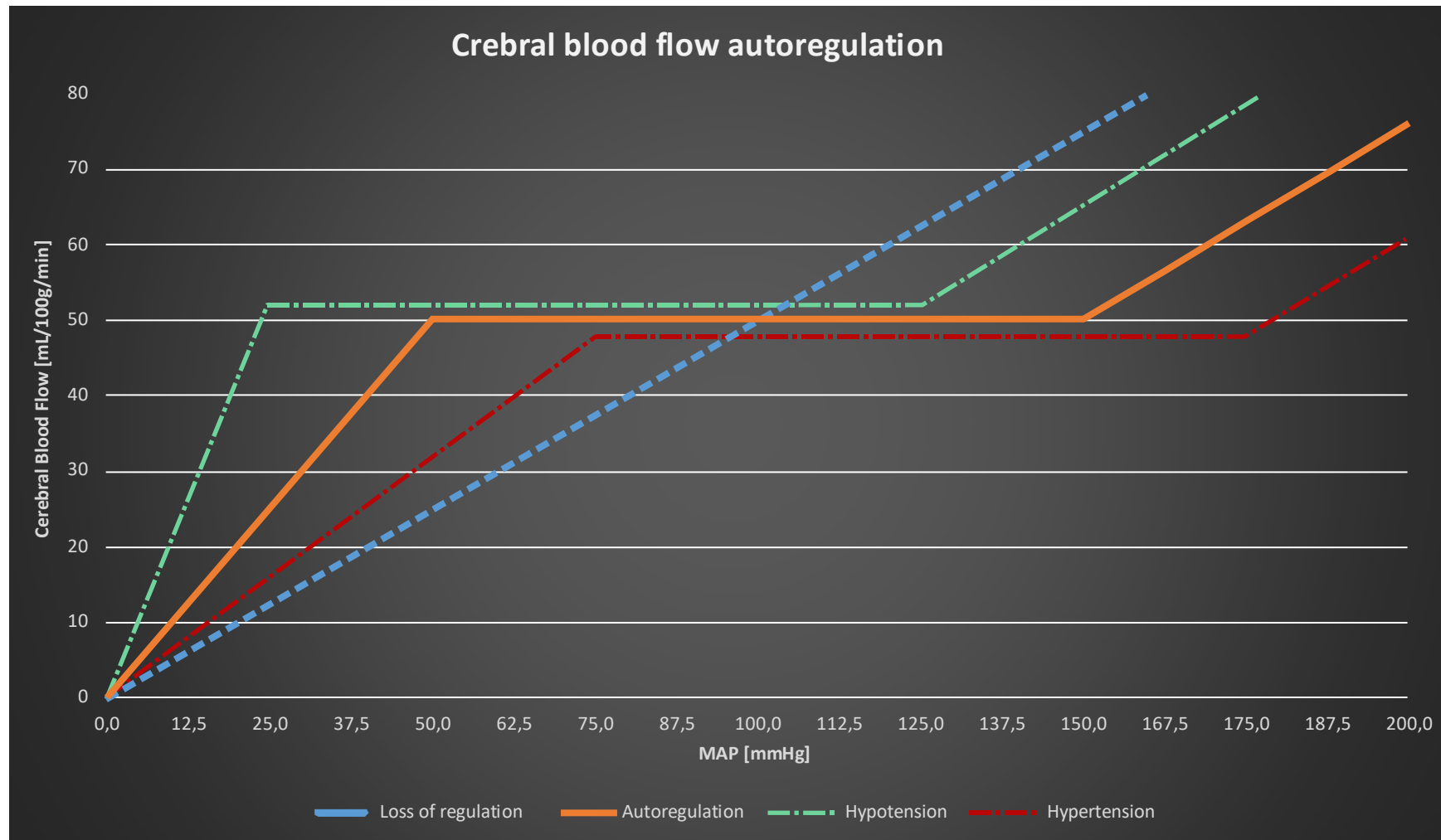


Ohmův zákon $I = U/R$

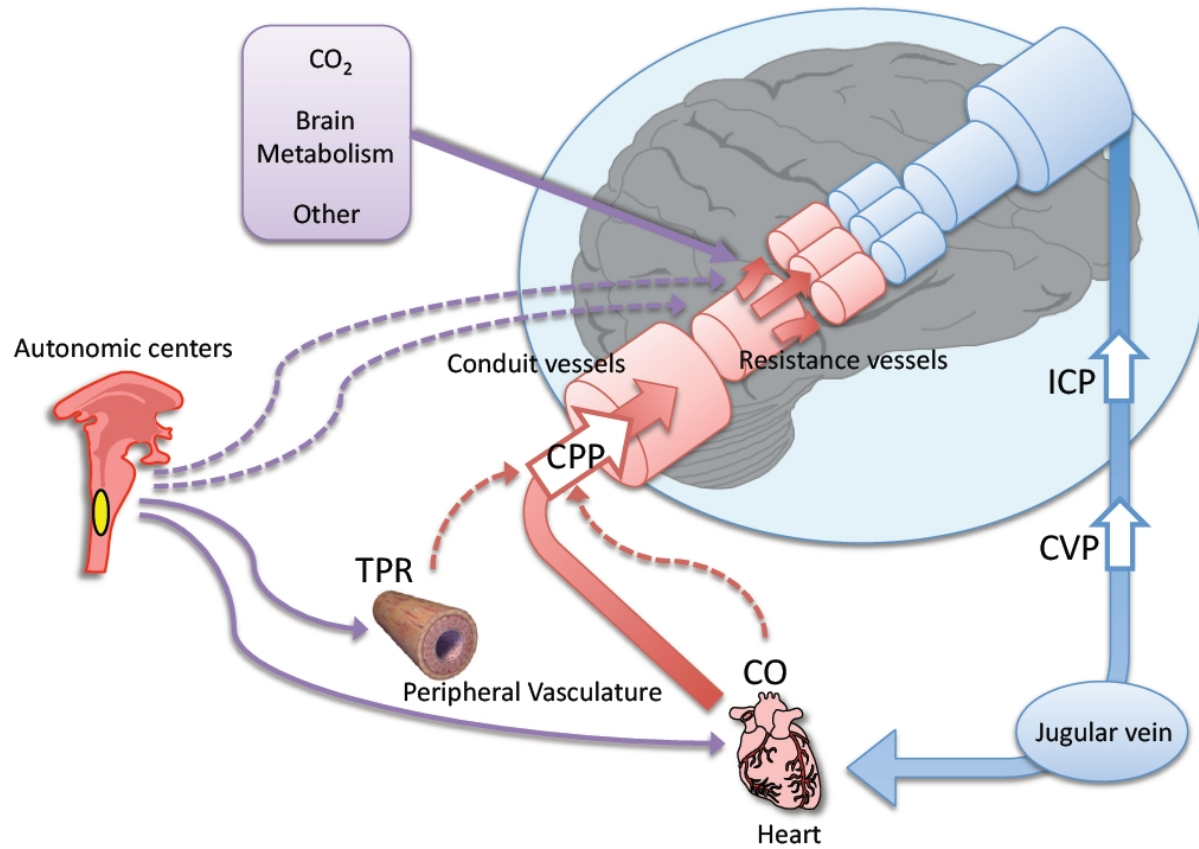
Chceme konstantní



Autoregulace krevního průtoku



Autoregulace krevního průtoku

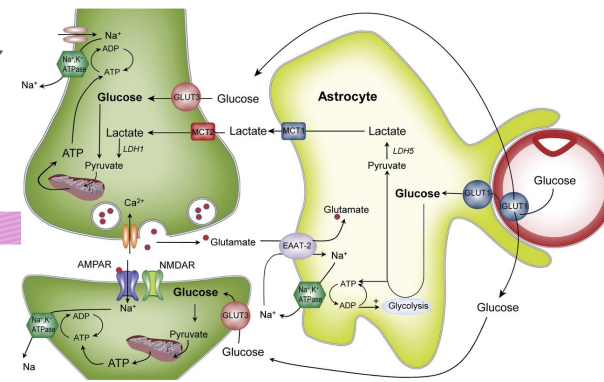


CPP - cerebral perfusion pressure
 ICP – intra-cranial pressure
 MAP – mean arterial pressure

$$CPP = MAP - ICP$$

Ohmův zákon $I = U/R$

Chceme konstantní

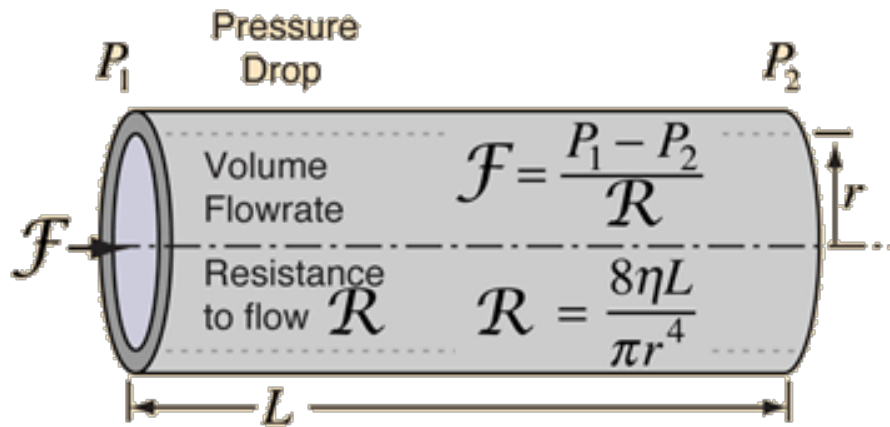


Autoregulace krevního průtoku

Hagen – Poiseuille law *

Ohmův zákon $I = U/R$

$$F = \Delta P/R$$



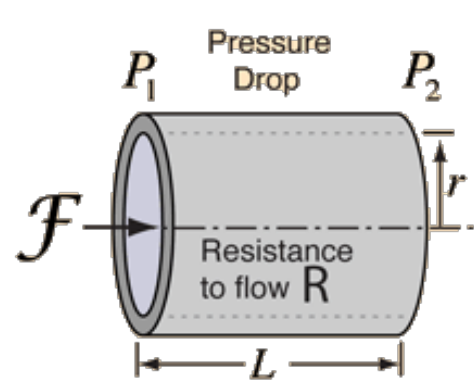
Q	Flow rate
P	Pressure
r	Radius
η	Fluid viscosity
l	Length of tubing

$$Q = \frac{\pi P r^4}{8\eta l}$$

Regulace vaskulární resistance

*[poazej]

Hagen – Poiseuille law



Suppose the original flowrate is $100 \text{ cm}^3/\text{sec}$.
The effect of changes in the parameters is as follows:

- * Double length $\Rightarrow 50 \text{ cm}^3/\text{sec}$
- Double viscosity $\Rightarrow 50 \text{ cm}^3/\text{sec}$
- Double pressure $\Rightarrow 200 \text{ cm}^3/\text{sec}$
- Double radius $\Rightarrow 1600 \text{ cm}^3/\text{sec}$**

$$R = \frac{8\eta L}{\pi r^4} \text{ where } \eta = \text{viscosity}$$

* With other parameters held at original values

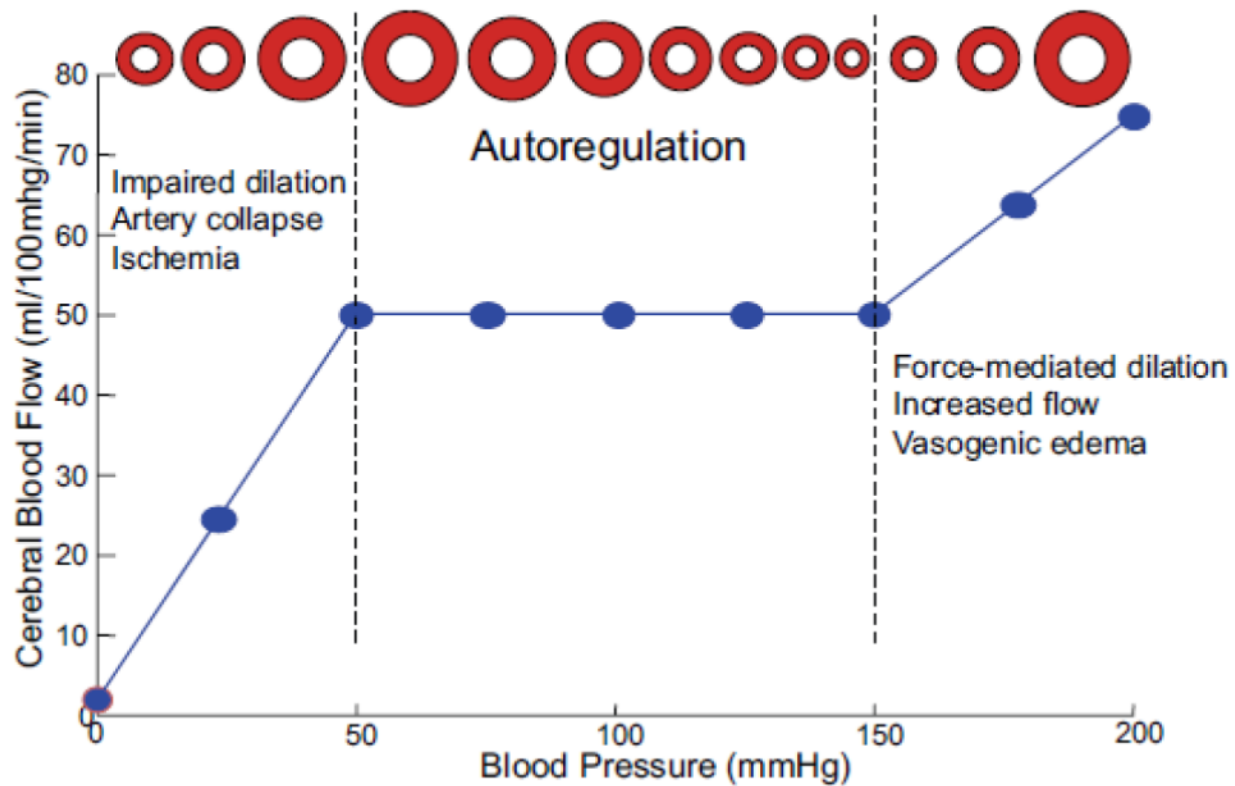
$$\text{Volume Flowrate} = \mathcal{F} = \frac{P_1 - P_2}{R} = \frac{\pi(\text{Pressure difference})(\text{radius})^4}{8(\text{viscosity})(\text{length})}$$

A 19% increase in radius will double the volume flowrate!

Q	Flow rate
P	Pressure
r	Radius
η	Fluid viscosity
l	Length of tubing

$$Q = \frac{\pi P r^4}{8\eta l}$$

Regulace vaskulární resistance



Autoregulace zajišťuje konstantní CBF napříč měnícím se MAP

Odezva ~ 60-120 sec

Regulace vaskulární resistance

CBF (cerebral blood flow),
MAP (mean artery pressure)

Neurogenic (Autonomic)

vascular smooth muscle are controlled via autonomic mainly sympathetic innervation. Its role in cerebral autoregulation is speculative.

Myogenic

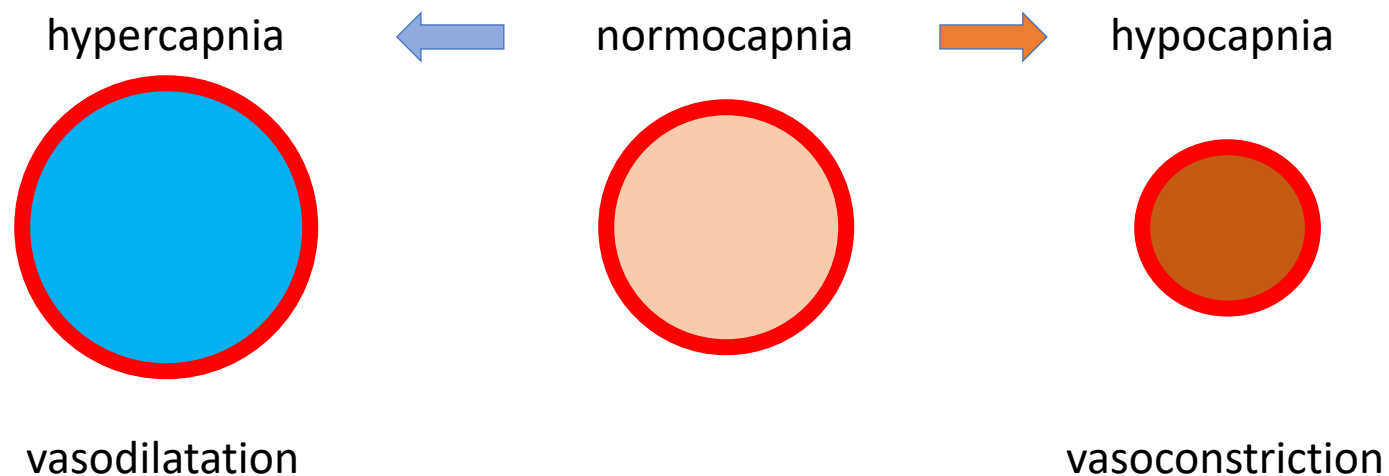
transmural blood pressure is directly detected by the vascular smooth muscle in arterioles, probably via a stress sensing mechanism. Then, the calibers are adjusted accordingly to keep blood flow constant. Role of endothelial factors (NO, prostacyclin...)

Metabolic

metabolic regulation is driven by the difference between cerebral metabolism and oxygen delivery through cerebral blood flow and acts by means of a vasoactive substance. These include CO_2 , H^+ , O_2 , adenosine and adenosine nucleotides, K^+ , Ca^{2+} and prostanoids.

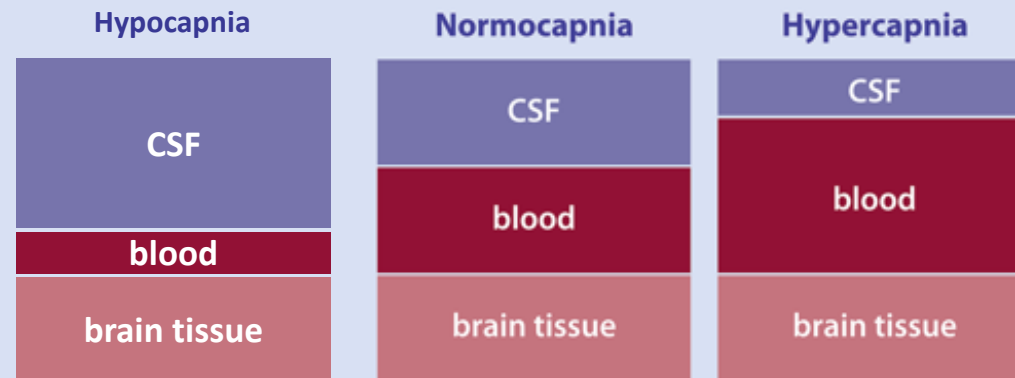
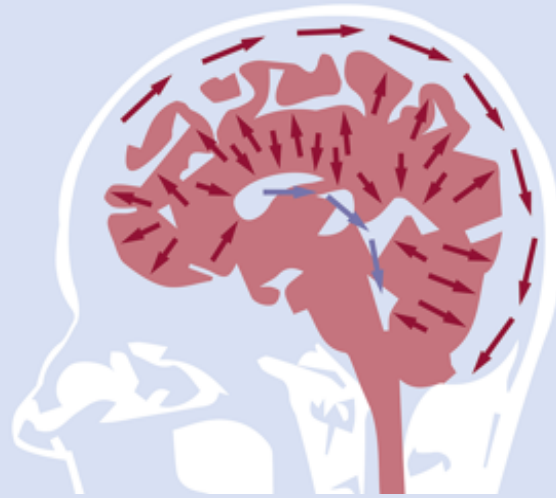
Mechanismy autoregulace

CO₂ je zásadním regulátorem vasomotorického tonu (napětí hladké svaloviny cévní stěny)
-> mozkového krevního průtoku



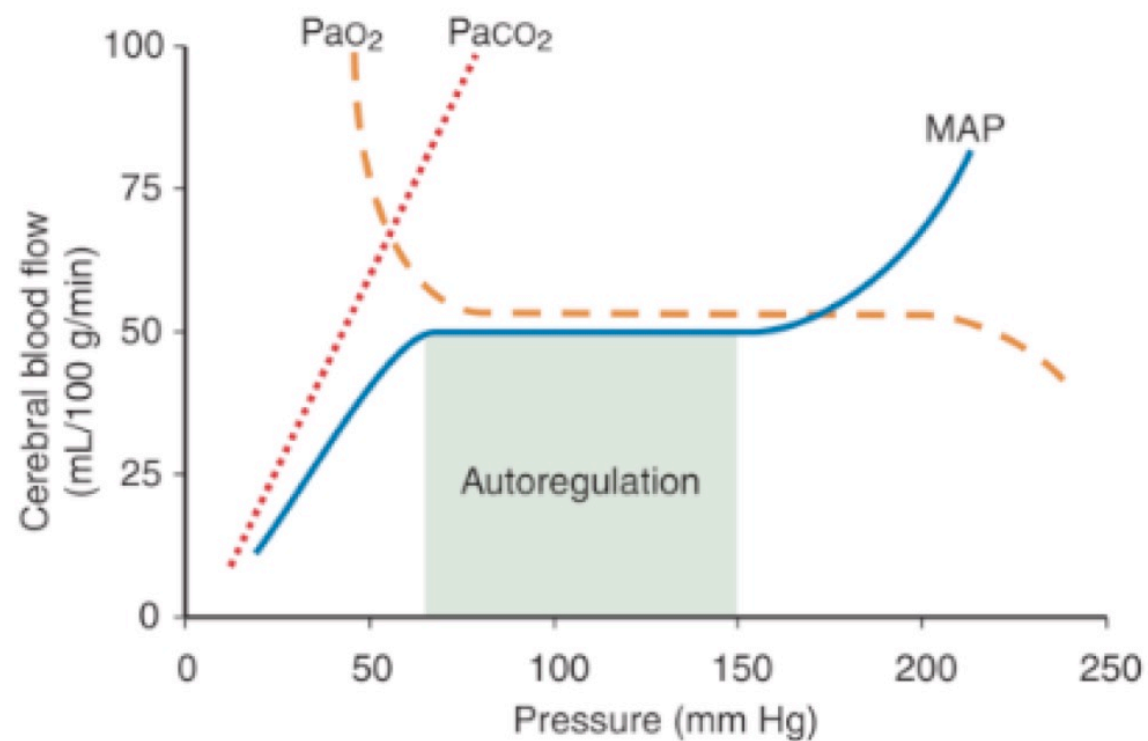
Časté využití v medicínské praxi (otevřené operace mozku, ...)

Autoregulace podle hladiny CO₂

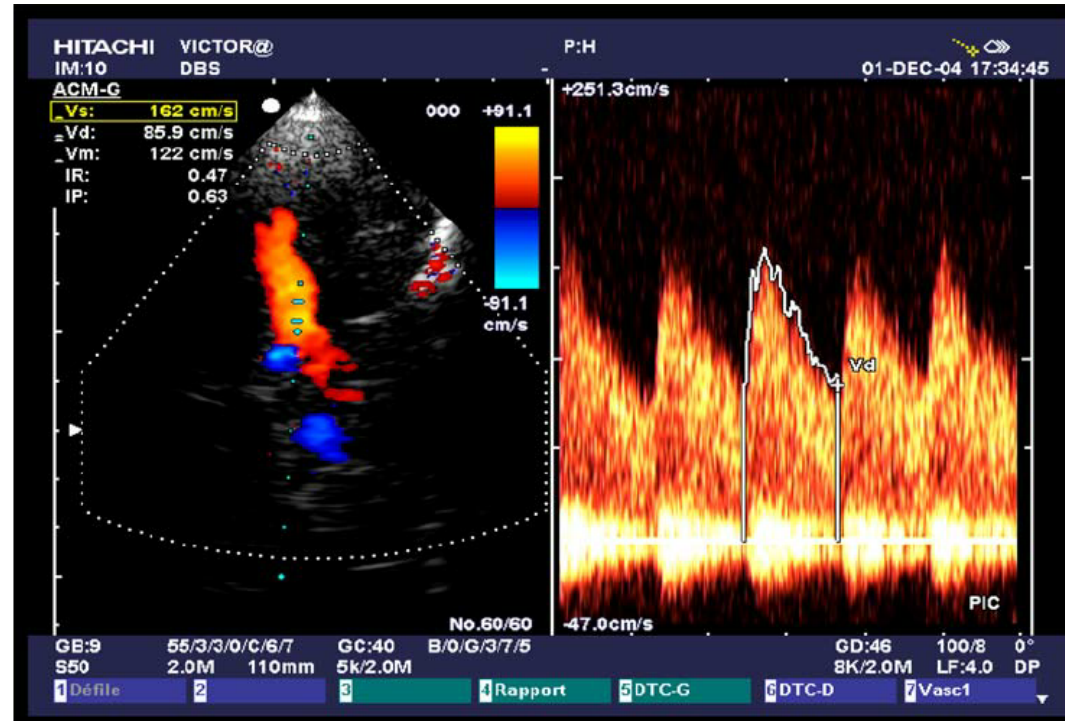
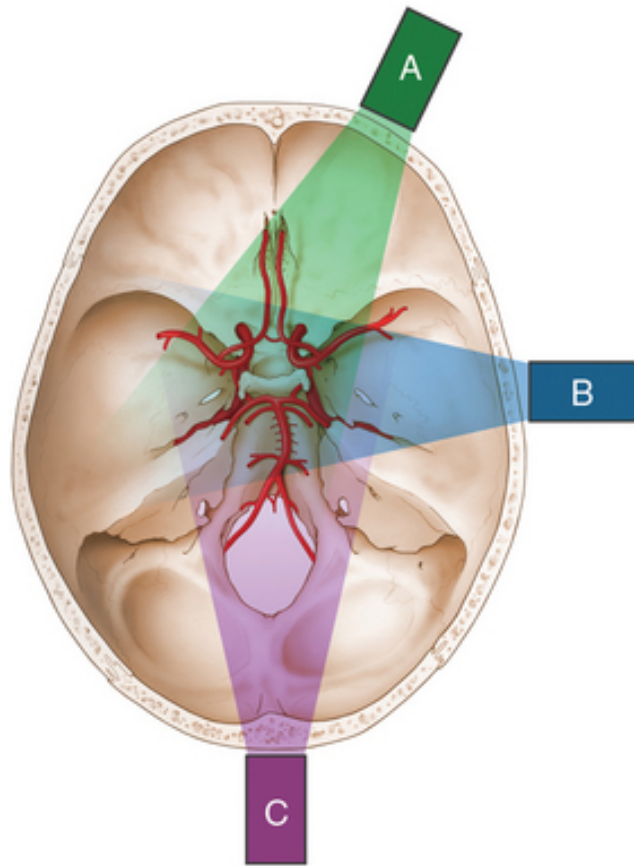


Autoregulace podle hladiny CO₂

pO₂ má malý vliv na CBF v rozmezí tlaků 60 – 300 mmHg

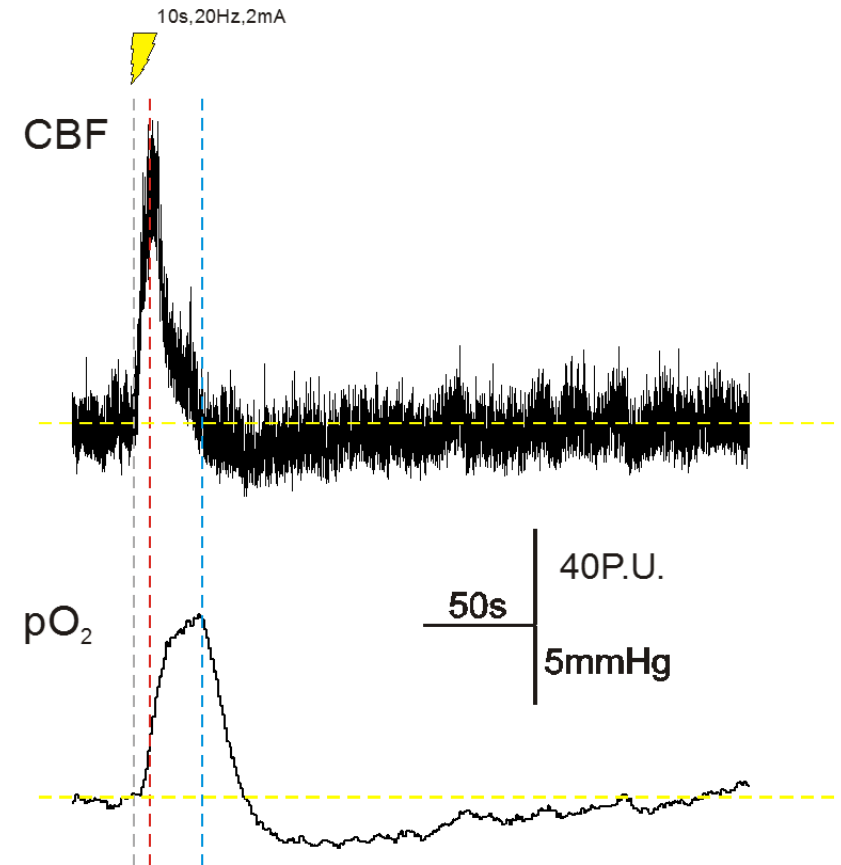
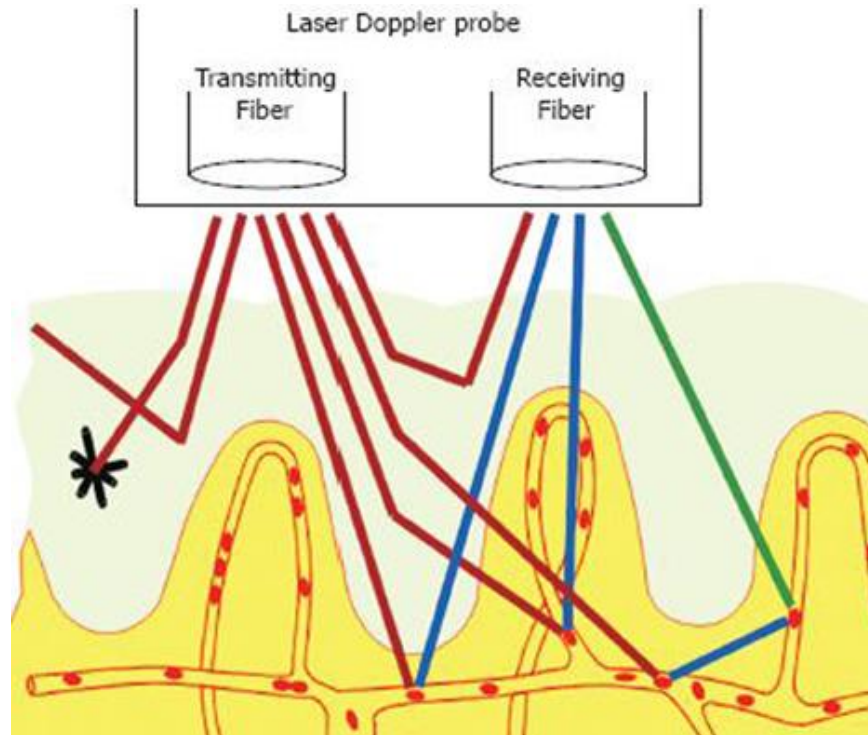


Autoregulace dle hladiny O₂



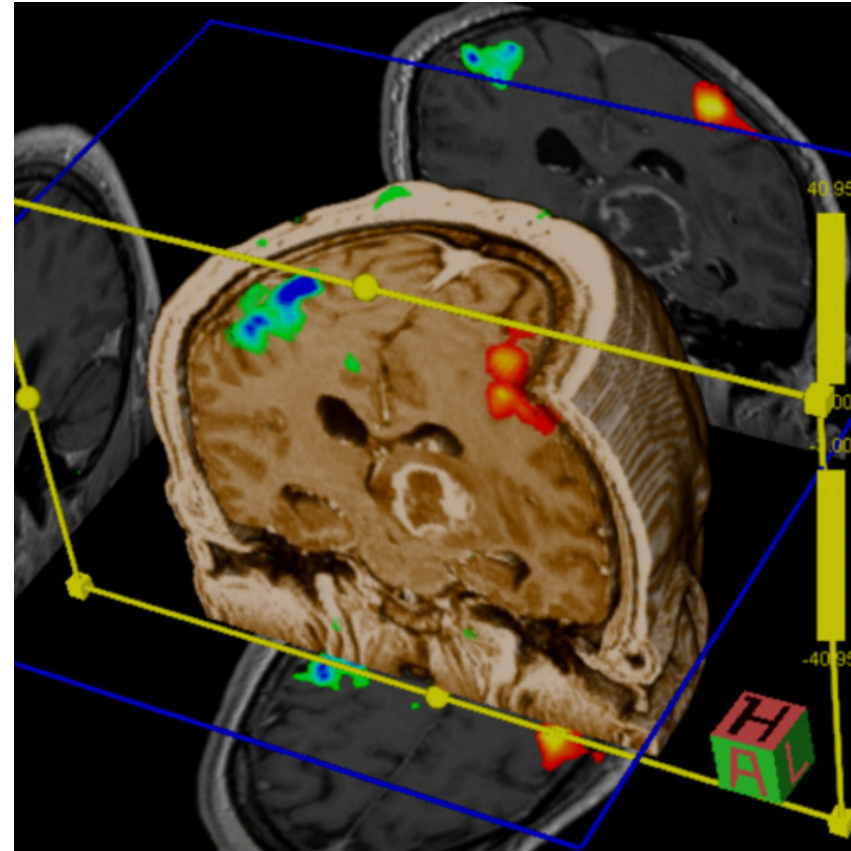
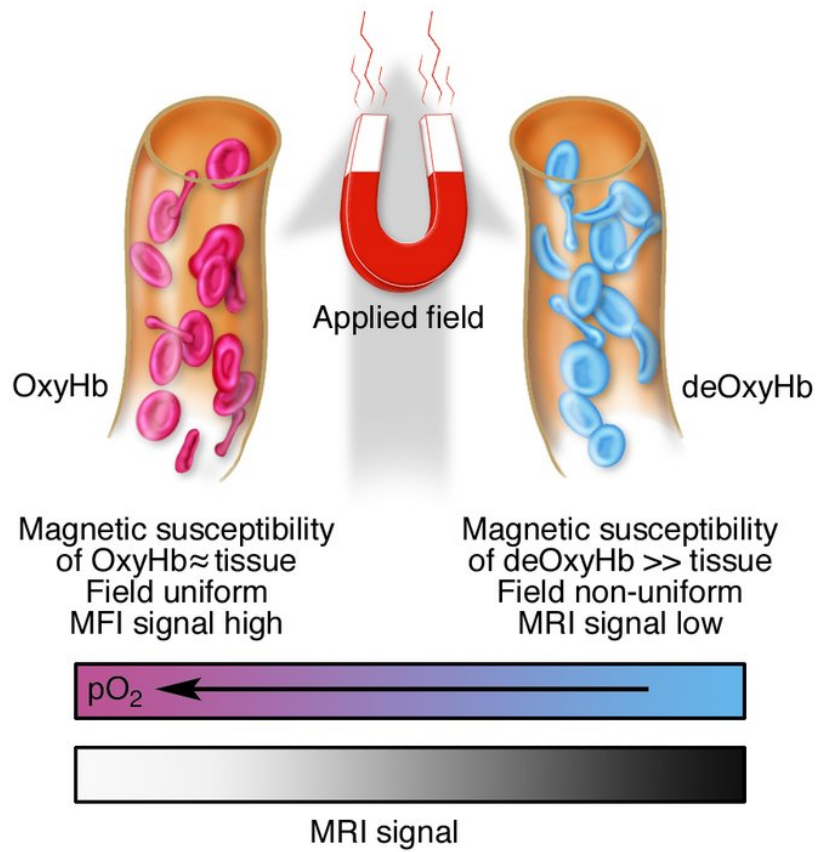
Metody sledování vaskularizace mozku

Laser-doppler flowmetry



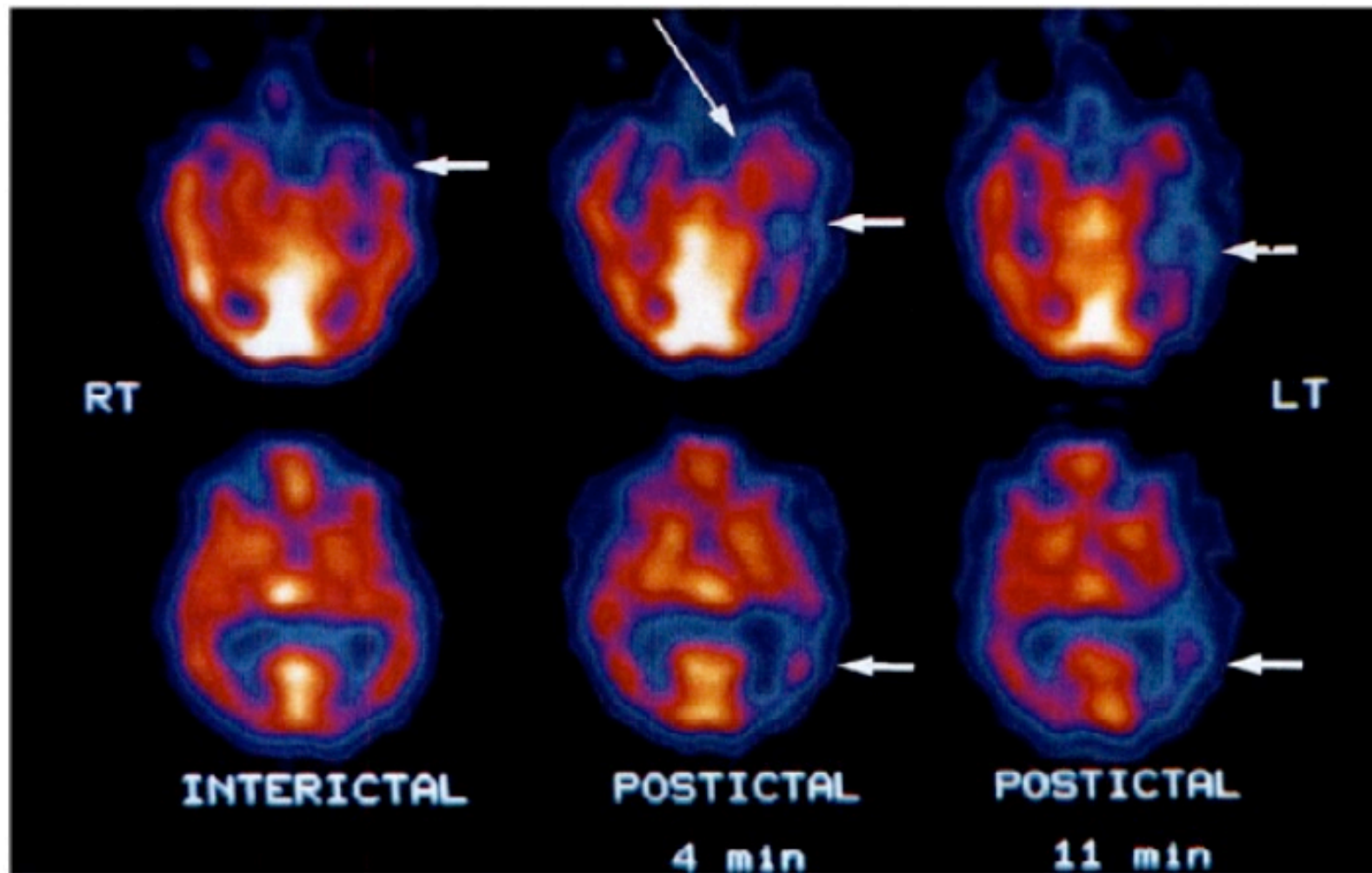
Metody sledování vaskularizace mozku

fMRI, BOLD Angio CT



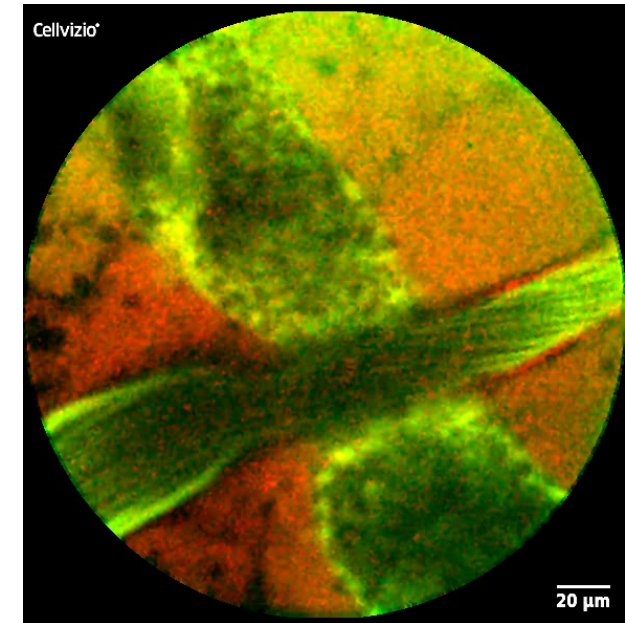
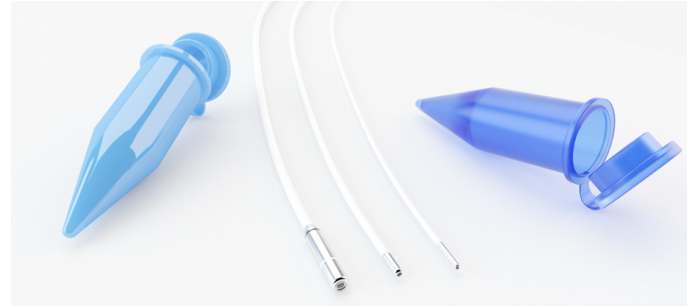
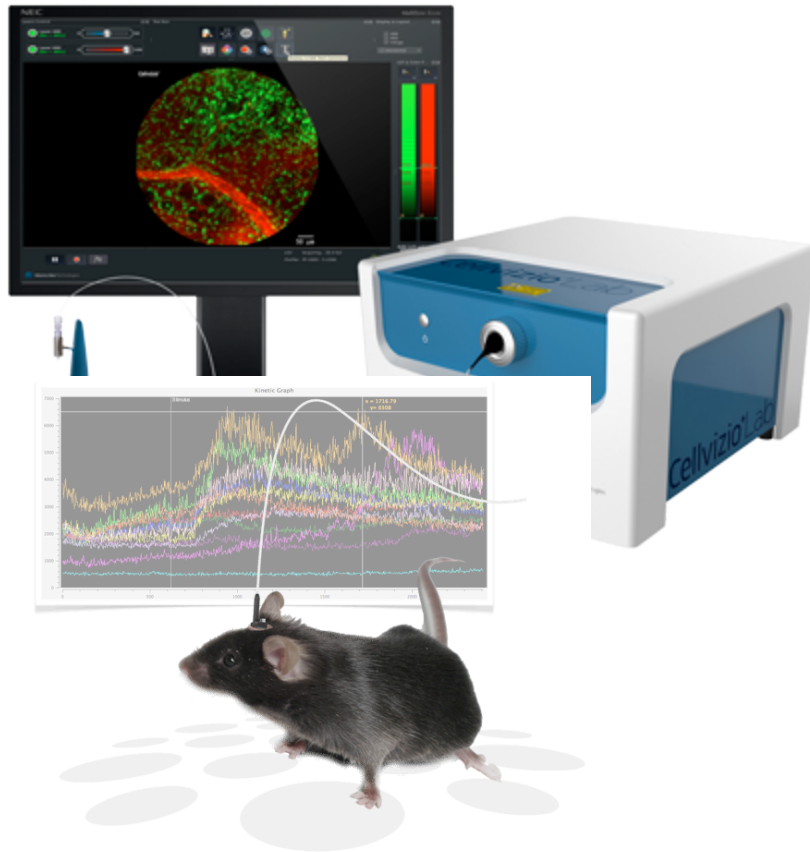
Metody sledování vaskularizace mozku

PET, SPECT



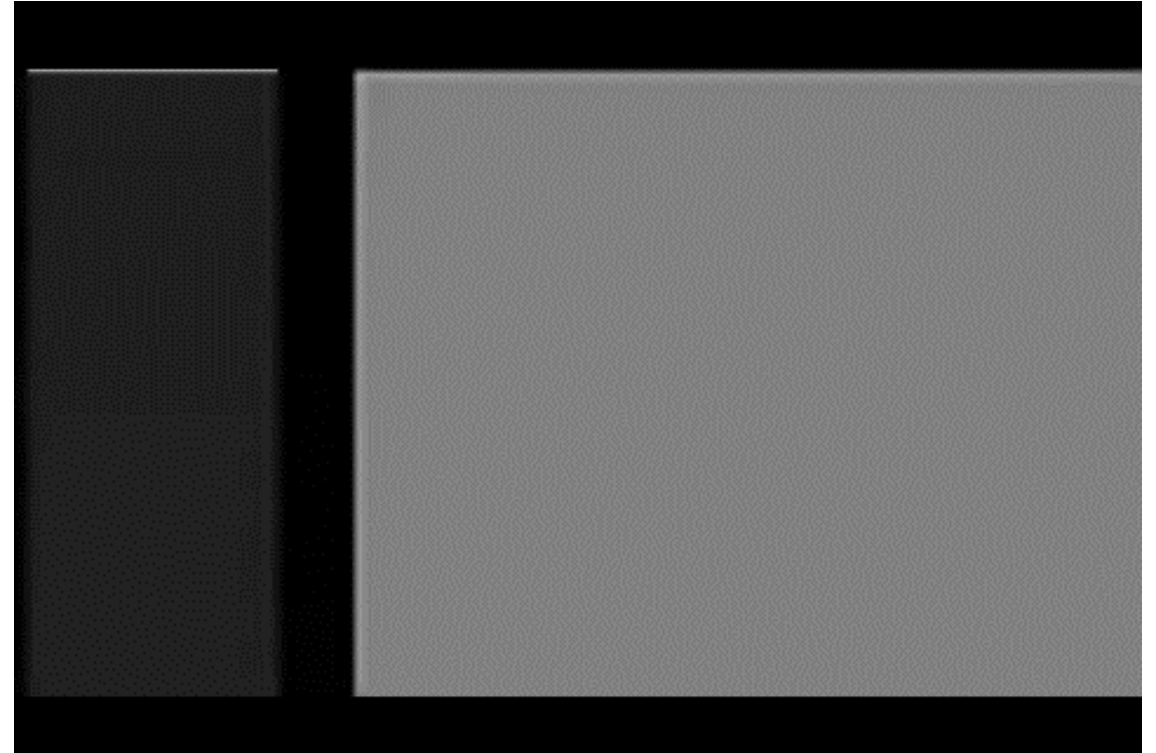
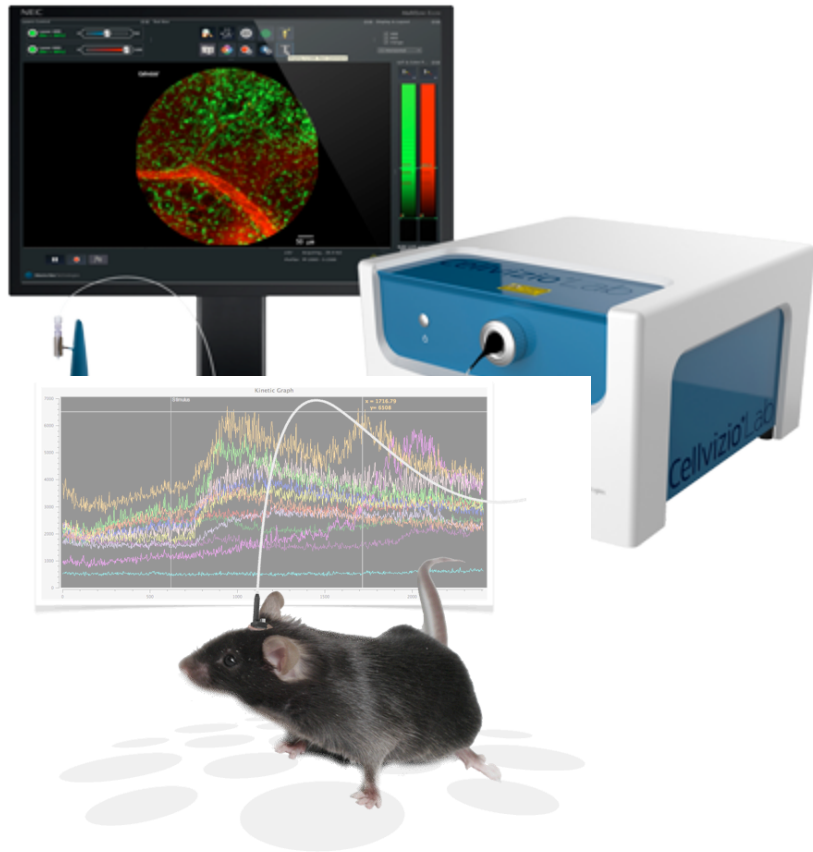
Metody sledování vaskularizace mozku

Optovláknová mikroskopie



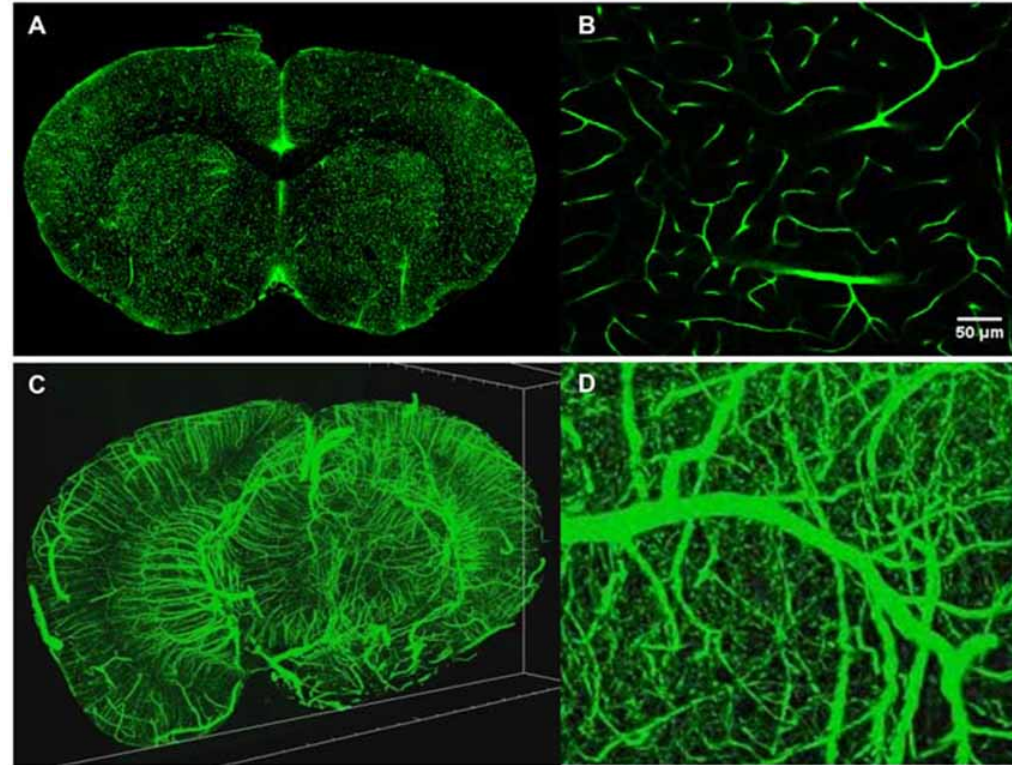
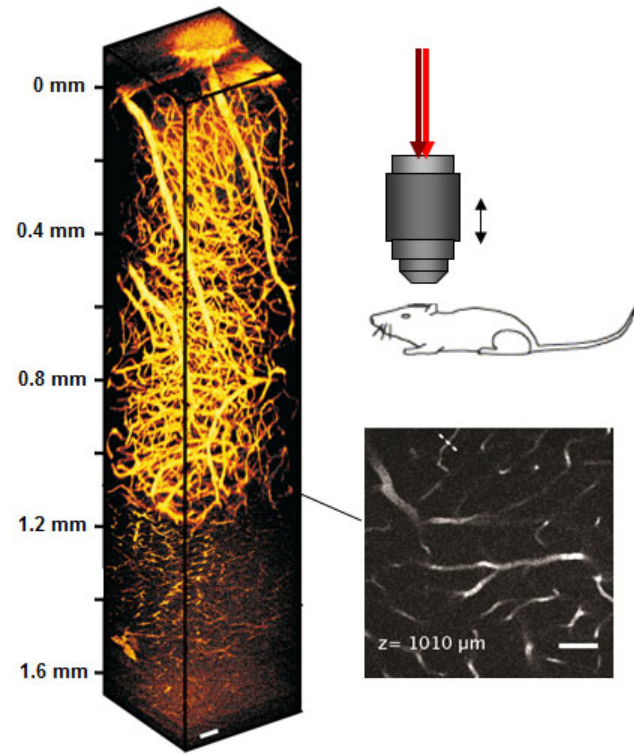
Metody sledování vaskularizace mozku

Optovláknová mikroskopie



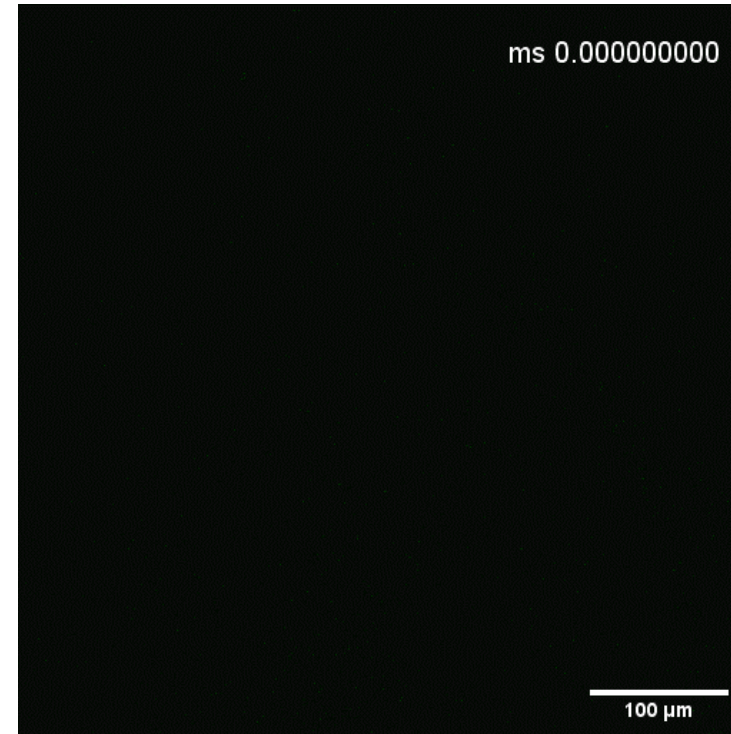
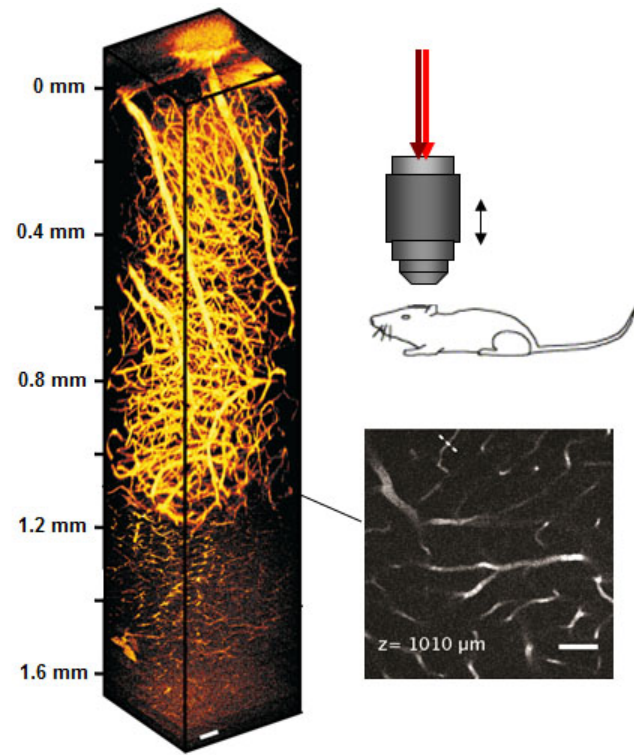
Metody sledování vaskularizace mozku

Dvofotonová mikroskopie

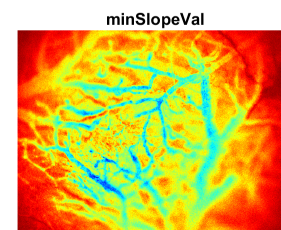
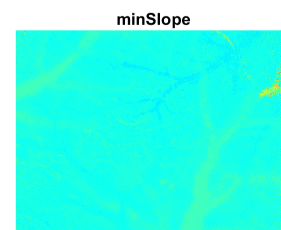
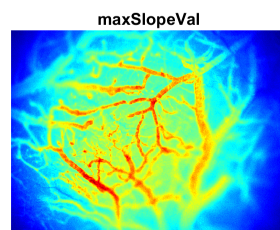
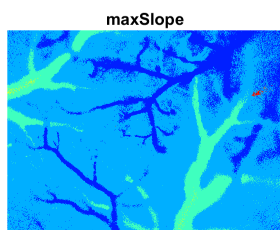
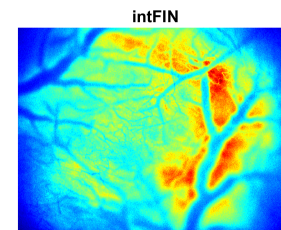
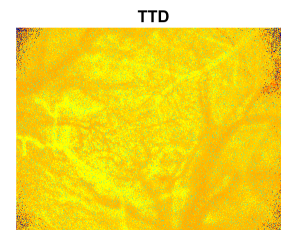
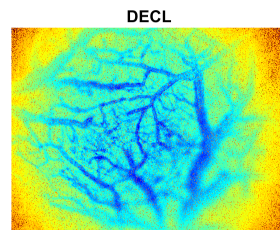
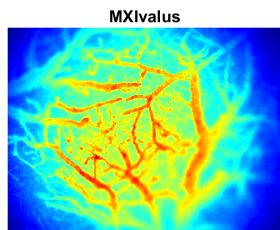
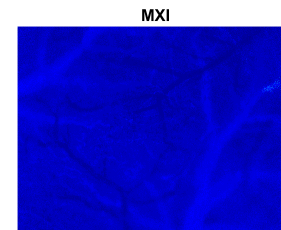
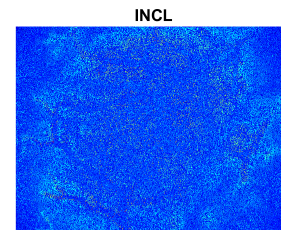
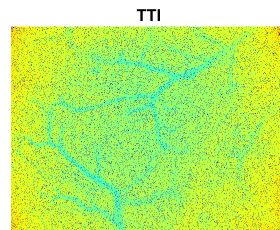
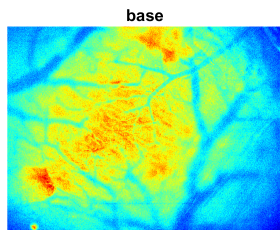
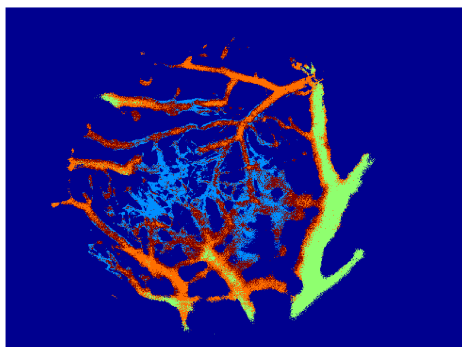


Metody sledování vaskularizace mozku

Dvoufotonová mikroskopie



Metody sledování vaskularizace mozku



Průtokové parametry



FN MOTOL



Děkuji za pozornost



CZECH
TECHNICAL
UNIVERSITY
IN PRAGUE



david.kala@fgu.cas.cz