Spinal cord

Veronika Němcová
Basic unit of NS

1. Neuron
2. Oligodendroglia
3. Astrocytes
4. Capillary
5. Myelin sheath
6. Synapse
7. Dendritic spine
8. Pia mater
9. Axon
10. Dendrite
11. Axon collateral

Obr. 1.:
ependyma – in ventricles
microglia - immunity
astrocyte

1) Neurony
2) Glia – supporting cells
   astrocyte
   oligodendrocyte
   microglia
3) Ependyma

neuron
microglia
astrocyte

oligodendrocyte makes a myelin sheath
Axon with myelin sheath

capillary

pia mater

Neuron:glie
1:10?
1:1!
Types of neurons

A - unipolární
B - bipolární
C - pseudounipolární
D - multipolární
1 - dendrit
2 - axon
3 - axonální zakończenia (bouton)
Nissl staining - cresylviolet rough ER

Grey matter of spinal cord
Dendrites

Figure A
Normal and abnormal dendrites. (Source: Purpura, 1974, Fig. 2A.)
Axon

no ER

collaterals

PNS Schwann´s cells
CNS oligodendroglie

Myelin sheath
Myelinated and nonmyelinated fibers

Axon hillock

neurilema

axolema

Myelinized axon

Nemyelinized axon

fast

slow
Cytoskeleton

shape and transport
Axonal transport

Anterograde – kinesin
Retrograde -dynein
Axonal transport on microtubules

Slow anterograde 1mm/day – building proteins
Fast anterograde 300mm/day – enzymes and neurotransmitters
Retrograde 200mm/day – chemicals from synaptic cleft, NFG (Nerve Growth Factor)
Tract tracing studies

Retrograde labelling

Buňky značené retrográdně HRP

prof. Petrovický
Buňka značená retrográdně dextranferem

Retrograde labelling

prof. Petrovický
Dvojitě značená buňka:
peroxydásou (hnědě)
a dextranferem (modře)
7000 synapses on 1 neuron
Neurotransmitters

Biogenic amines
Adrenaline, noradrenaline, dopamine
Serotonin
Acetylcholine
Histamine

Aminoacids
Glutamate, aspartate – excitatory (e.g. in spinal ganglion)
GABA, glycine – inhibitory (e.g. Renshaw’s cells – spinal cord interneurons)

Nucleotides
Adenosine

Neuropeptides
Substance P, VIP, somatostatin, cholecystokinin

Gas - NO, CO
Dopamine
Noradrenaline
Adrenaline
Serotonin
Acetylcholine
Histamine
GABA
Glycine
Adenosine

**NEUROTRANSMITTERS**

coffein- block of receptors for adenosine
Neural tube and neural crest formation - 3.-4. week

- Neural plate
- Neural groove
- Neural tube
- Neural crest
- Neuroporus ant.
- Neuroporus post.
Neural tube and neural crest formation

Neural plate
3. week

Neural groove

Neural crest

Nerval tube

Sensory ganglia
Brain development

Primary
1) prosencephalon < mesencephalon < rhombencephalon

Secondary
2) telencephalon < diencephalon < mesencephalon < metencephalon < myelencephalon

Obr. 13.: Sagitální řez mozkem embrya délky 7 mm (A) a schema rozdělení embryonálního mozku v horizontálním řezu (B). V obr. B je přišedně šrafován diencephalon, vertikálně mesencephalon.
Brain development
Factors influencing the formation of dorsal (bone morphogenetic proteins, \textit{BMPs}) and ventral (sonic hedgehog, \textit{SHH}) parts of spinal cord.
Basal and alar plate development in spinal cord
Sagittal section through the vertebral canal

foramen magnum
hiatus sacralis

C2

L1
Borders of vertebral canal

- lig. longitudinale posterius
- arcus vertebrae
- foramen intervertebrale
- ligg. flava
Spinal nerve and vertebral canal
Meninges of spinal cord

1 spatium epidurale
endorhachis
saccus durae matris
2 spatium subdurale
3 spatium subarachnoideum
lig. denticulatum
arachnoidea
pia mater
A- saccus durae matris sleeves cover roots of spinal nerves

B- dura mater is cut transparent arachnoid covers spinal cord and nerves roots

C→ posterior root ganglion (spinal ganglion)
  ▶ Vessels in pia mater
  ▶ Nerve roots
Cervical intumescence

A- pia mater removed 5-fasciculus cuneatus, 6-fasciculus gracilis
B- pia mater with vessels covers posterior column 7- fila radicularia (rootlets)
C- 1-dura mater, 2-anterior root, 3-posterior root, 4-denticulate lig.
A- cauda equina
B- intumescence lumbosacral
C- cauda equina
1 - dura mater
2 - pia mater with vessels
3 - filum terminale
4 - Conus medullaris
5 - roots of sacral and lumbal nerves

Lumbosacral intumescence and cauda equina
Cervical spinal cord dorsal aspect

C1

C2

C3

fasciculus gracilis

fasciculus cuneatus

fila radicularia

ganglion spinale
Thoracic spinal cord

- lig. denticulatum (arachnoidea)
- saccus durae matris
Thoracic spinal cord
Conus medullaris + cauda equina
Vertebral canal posterior aspect

- conus medullaris
- Canalis sacralis
- filum durae matris
Saccus durae matris content bellow L1

Vertebral canal and its arrangement in MRI L3 level
Vertebral canal sagittal section

1-discus intervertebralis
2-corpus vertebrae
3-saccus durae matris
4-spatium epidurale
5-spinal cord
6-spatium subdurale
MRI cervical spinal cord

- axis C2
- vertebra C7
- proc. spinosus
- lig. interspinale
- spatium subarachnoideum
- medulla spinalis
- discus intervertebralis, nucleus pulposus
- epiglottis
- trachea
- MRI vertebral canal
- LS region

- nucleus pulposus
- cauda equina
- processus spinosus
- filum terminale
- spatium subarachnoideum
- promontorium
- os sacrum (segmentum S2)
Cervical part of vertebral canal

6- spatium epidurale
14- a. vertebralis
Canalis centralis

Gray matter inside
Anterior horns – motor
Posterior horns – sensory
Lateral - visceromotoneurons

White matter outside - tracts
– columns – funiculi
Anterior
Lateral
Posterior – fasciculus gracilis Goli
- fasciculus cuneatus Burdachi

Fissura mediana anterior

post

lat

ant
Cervical spinal cord

Ncl. spinalis V

Decussatio pyramidum
Thoracic spinal cord

Funiculus Posterior

Funiculus Anterior

Funiculus Lateralis
Cervical spinal cord- silver impregnation according Weigert

11-fasciculus gracilis
12-fasciculus cuneatus
Thoracic spinal cord - Van Gieson´s staining

15- lateral horn
Lumbar spinal cord – Weigert’s staining

11-fasciculus gracilis
Sacral spinal cord

8-cauda equina
11-fasciculus gracilis
Vertebro-medular topography
vertebral bodies related to spinal cord segments
Vertebro-medular topography - vertebral bodies related to spinal cord segments

Segment = vertebra

Segment = vertebra +1

Th12-L1 = Th11 body
L2-L5 = Th12 body
all sacral segments = L1 body
Dermatomes
parts of skin supplied from one spinal cord segment
Dermatomes

Th 1 on upper limb
Arteries of spinal cord

Adamkiewicz’s artery (a.spinalis magna) from a. intercostalis post. At the level Th9–L1 (Th7-L2)

- a. vertebrealis
- a. spinalis anterior
- a. iliolumbalis
- rr. spinales (radicular arteries)
- a. cervicalis ascendens
- a. cervicalis profunda
- aa. Intercostales posteriores
- aa. lumbales
- aa. sacrales laterales
Cervical spinal cord supplying

- a. spinalis anterior
- aa. spinales posteriores
- a. vertebralis
Thoracic spinal cord supplying

- a. intercostalis post
- r. spinalis
- r. muscularis
Vertebral canal supplying in sacral region

- a. iliolumbalis
- a. sacrales laterales
- a. sacralis mediana
Spinal cord arteries

5 longitudinal trunks

- vasocoronae
- aa. spinales posteriores
  - Posterior column (proprioception)

- a. spinalis anterior
  - Anterior horns, anterior and lateral columns (motor)

- r. spinalis
Venous plexuses

- Plexus venosi vertebrales externi anteriores
- Plexus venosi vertebrales interni anteriores
- v. lumbalis ascendens
- v. basivertebrales
- vv. basivertebrales
- Plexus venosi vertebrales interni posteriores
- Plexus venosi vertebrales externi posteriores
Vertebral venous plexuses

- **No valves** *(cancer and infection spreading)*, anastomoses *(between externi and interni)*
- **Anastamoses** with venous plexuses of pelvis
- Placed: 1) inside canal in epidural space *(plexus venosi vertebrales interni)*
  - 2) outside the spine *(plexus venosi vertebrales externi)*
  - 3) in bodies of vertebrae *(venae basivertebrales)*
Rexed’s laminae (zones)

I – ncl apicalis
II, III – subst. gelatinosa Rolandi
IV, V – ncl proprius
VI – ncl. Stilling-Clark
VII – interneurons
VIII, IX - motoneurons

Propriospinal tracts crosshatched
Visceromotor nucleus
Sensory tracts
Motor tracts
Cerebellar tracts

Ncl intermediolateralis

Dorsal column tracts
Rexed’s zones – Nissl staining

I – ncl apicalis
II, III – subst. gelatinosa Rolandi
IV, V – ncl proprius
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VIII, IX – motoneurons
Comparison of classic and Rexed nomenclature

Aferent from Zones - Nuclei

Eferent to

Spinal nerve

NR
RF
VIII.

CMs
MS

I NCL: APICALIS

II SUBST. GELATINOSA

III

IV NCL. PROPRIOUS

V

VI NCL. STILLING-CLARK

VII INTERNEURONY

VIII

IX alfa-MOTONEURONY

Th

tr. S

RF

TEC

CRBL

OI

Spinal nerve
“columns“ of motoneurons for limbs, (distal muscles more caudally)
C3-C5 ncl. frenicus
S2-S3 Onuf’s nucleus – n.pudendus
C1-5 –ncl spinalis n.XI.
MOTOR unit

One motor unit
ALFA MOTONEURON
+ ALL MUSCLE FIBER
SUPPLIED BY IT

Number of fibers in unit
m. gastrocnemius (1750) x mm. lumbricales (108)

Number of units in muscle
Např. m. abduktor policis longus 400

Neurotransmitter: ACh

Two motor units

(gamma motoneurons – muscle spindle supplying)
Dorsal root fibers

A alpha, A beta fibers—myelinated, fast conducting proprioception, touch

A delta fibers—poorly myelinated, C fibers—nonmyelinated, slow conducting fibers from nociceptors and thermoreceptors

Neurotransmitters: glutamate + substance P, VIP, cholecystokinin
White matter—propriospinal, ascendent, descendent and cerebellar tracts
Motor pathways

C-S voluntary movement
NR-S flexors activation
Ret-S muscle tone and a „supraspinal“ movement
Te-S reaction to visual and acoustic stimuli
Ve-S extensors activation
Ist-S TV watching in laying position

Cortico-spinal lateral
Rubro-spinal
Cortico-spinal ventral
Reticulo-spinal
Tecto-spinal
Vestibulo-spinal
Interstitio-spinal
Cortex

Th

Ve

Gr Cu
Tractus cortico-spinalis (pyramidal tract)

voluntary movement

Motor part- voluntary movement
Control of sensory tracts
Lesions of motor neurons

Lesions of motor neurons, results in loss of motor function **paralysis**

Full paralysis – **plegia**

Partial paralysis – **paresis**

**Hemiplegia** – both ipsilateral extremities are affected

**Paraplegia** – either both upper or lower extremities are affected

**Quadruplegia** – all 4 extremities are affected
Basic signs of motor activity disorders

Lower motor neuron lesions (poliomyelitis or nerve lesion)

Muscle tone and stretch and tendon reflexes are reduced or absent (flaccid paralysis)

Progressive atrophy of muscles occurs

EMG detects fibrillation potentials caused by isolated contractions of denervated muscles

In partially denervated muscles, the inervation is being renewed

- Upper motor neuron lesions (bleeding in capsula interna or transected spinal cord)
  - Muscle tone and stretch and tendon reflexes are increased (spastic paralysis)
  - Superficial reflexes (abdominal and cremasteric ones) are extinct
  - An abnormal plantar Babinski reflex occurs
  - Voluntary movements are reduced or absent
wireless electronic connection between the brain and spinal cord restored movement in two monkeys that were each paralysed in one leg as a result of a spinal-cord injury.

Bipedal walking?

Problems:  
1) maintain balance  
2) targeting the movement

Capogrosso et al.\textsuperscript{1} established a neural-interface system that enabled communication between the brain and spinal cord in monkeys subjected to a spinal-cord injury that paralysed one leg. An implant in the brain recorded neural activity related to leg movements, and transmitted this information to electrodes at the base of the spinal cord via a wireless link. These electrodes triggered neuronal impulses that generated movement in the leg muscle, allowing the monkeys to walk freely, despite their injury. (Adapted from Fig. 1 of ref. 1.)

Spinal-cord injury: Neural interfaces take another step forward
Andrew Jackson, Nature 539,2016
1) tractus interstitiospinalis
2) tractus vestibulospinalis

tractus interstitiospinalis
PART OF medial longitudinal fascicle
Coordination of neck and oculomotor muscles in change of head position

tractus vestibulospinalis
Extensors activation - uncrossed
Sensory tracts
1) dorsal column lemniscal tract – proprioception, vibration, touch
2) anterolateral systém pain, touch, activation
Anterolateral system

Tracts:
- spino-thalamic X — „fast“ pain, temperature, touch
- spino-reticularis X, II — „slow“ pain activation
- spino-tectal X
Spinal cord – center of reflexes

Patellar (knee jerk) reflex L2-L4
Figure 15-4.
The parallel organization of the alpha and gamma lower motor neurons. The alpha motor neuron innervates extrafusal skeletal muscle; the gamma motor neuron innervates the intrafusal muscle fibers to ensure proper sensory feedback from the muscle spindle. The activity of both motor neurons is modulated by multiple segmental and suprasegmental inputs.
(From Bear MF, Connors BW, Paradiso MA: Neuroscience, Exploring the Brain, 2nd ed. Baltimore, Lippincott Williams & Wilkins, 2001.)

Williams & Wilkins
Muscle spindle – stretch gated receptor

A alfa

Anulospiral ending, flower spray ending

A gamma

Golgi tendon organ – tension gaited receptor

Pain, temperature

Vibration, pressure

Muscle spindle compares the length of intra and extrafusal fibers

It is supplied from gamma motoneurons
Gamma loop mechanism

Gamma motoneuron – sensory neuron-alfa motoneuron

For muscle tone controle

Cortex, reticular formation and red nucleus can increase (or decrease) the muscle tone by activation (inhibition) of gamma motoneurons (contraction of intrafusal fibers)

Gamma motoneurones and muscle tone

Obr. 8

a – alfa-motoneuron,
CRBL – cerebellum,
g – gamma-motoneuron,
i – interneuron,
NR – ncl. ruber,
RF – retikulární formace,
Th – thalamus
Proprioceptive reflexes

Knee jerk reflex
- elongation of muscle - contraction
- Inhibits contraction
- reciprocity

Muscle spindle
Relax of antagonist

Tendon body
Contraction of antagonist
Proprioceptive reflexes circuits

Renshaw

"supraspinální" pohyb

Gravity

polysynapt. segmentální
Tonic neck reflexes

„fencing position“
„toward the water“
„toward the prey“
„toward the burrow“
Can be seen after bilateral labyrinthectomy or during development

Head dorsiflexion (extensors in action) – upper limb (HK) extension and lower limb (DK) flexion
Tonic neck reflex – fencing posture
Posterolateral sclerosis

Syringomyely

Brown-Sequard syndrome

Sensory loss

Parietal cortex lesion

Polyneuritis

Left posterior inferior cerebellar art. occlusion
Postero-lateral sclerosis

Syringomyelie

Brown-Sequard sy

Loss of temperature and pain senses

Loss of all sensationes

Impaired proprioception and vibration, 2-point discrimination and position sensation

Impaired pain and temperature sensation

Deminished vibration, position, 2-point discrimination and joint sensation
Syringomyelia

Loss of temperature and pain senses
Lateral medullary syndrome (left posterior inferior cerebellar artery occlusion)

Impaired pain and temperature sensation left face and right side of body
Spinal cord lesion

1) **Motor defects**— paresis, plegie.
   - central (spastic), periferal (flaccid), mixed

2) **Sensory defects**
   a) **Radicular syndrome** (dermatomes) e.g. disc prolaps
      - hypestesia, anestesia, parestesia, hyperestesia
   b) **Syringomyelic dissociation** — Loss of temperature and pain senses
   c) **Brown Séquardům syndrom** (např. intramedular expansion)
      - bellow the lesion is ipsilateral deep sensory loss (dorsal column tract) and motor defect (cortico-spinal tract), kontralateral pain and temperature sensory loss
   d) **Dorsal column syndrom** (e.g. neuranemic syndrom, tabes dorsalis)
      - loss of proprioception

3) **Medullary epiconus syndrome** (lesioned segments L4-S2) lower limbs paraparesis.
   - Not affected hip adduction and hip flection, knee extension, loss of sensation bellow the knee and posterior upper tight, automatic bladder, lesioned erection and ejaculation

4) **Medullary conus syndrome** (lesioned segments S3-S5) loss of sphincters control,
   - automatic bladder, saddle like sensory loss

5) **Cauda syndrome** (lesion of spinal nerve root bellow L2)
   - low back pain, sciatica (unilateral or, usually, bilateral), saddle sensory disturbances, bladder and bowel dysfunction, and variable lower extremity motor and sensory loss
Spinal cord problems

1) Developmental malformation (neural tube closure defects, syringomyelie)
2) Tumors (intramedullar, extramedullar)
3) Trauma (comotion, contusion)
4) Vascular disease (ischemie, hemorrhagie)
5) Degenerative disease (ALS,)
6) Degenerative vertebral disease
Neurosurgery can solve

1) **Anterior spinal artery syndrome** (e.g. in vertebral body fracture and compression in vertebral canal) – plegia, loss of pain and temperature sensation, remains only proprioception (vibration)

2) **Posterior spinal artery syndrome** (e.g. in epidural expansion, stab wound) – loss of proprioception and lesioned motor activity of distal parts of limbs

3) **Brown Sequard** rare

4) **Central gray matter syndrome**– hyperintensity on MR, Affected cortico-spinal tracts, paresis on distal parts of upper limbs

5) **Compressive spinal cord syndrome** – tumor, abscess, tuberculosis

6) **Syringomyelia**.
The sagittal T2-weighted Turbo Spin Echo image demonstrates a traumatic transection of the spinal cord at the level of C5–C6.

Patient history
4-year-old female patient was involved in a high-speed vehicle accident. At the scene the girl was distressed, bradycardic and not moving limbs. She was transferred to the Pediatric Trauma Centre and MR imaging requested for prognostic information regarding treatment.

Images show a transection of the cervical cord at the level of C5–C6 with approximately 6 mm of separation.
24-year-old man involved in high speed motor vehicle accident

MR-marked anterior subluxation of C6 on C7, transection of the spinal cord (black arrow), edema and hemorrhage in the prevertebral soft tissues (red arrows) and spinal cord edema extending from C4 to T1 (yellow arrows).
Sagittal image shows marked subluxation of C6 on C7 (black arrows) with marked narrowing of the spinal canal.

Sagittal images of the right facets and left facets. The bilateral jumped facets are seen (black arrows).
MR T1 - Syringomyelia – cavity inside the cervical spinal cord
MR T2 syringomyelia
thoracic spinal cord
Syndrom syringomyelie
Meningomyelokéle
Amyotrophic lateral sclerosis

Pathological Features of ALS from Other Cases (Luxol Fast Blue–Hematoxylin and Eosin).

- **Bunini body in motoneuron of anterior horn, ALS** (Panel A, arrow) (photomicrograph courtesy of Dr. David Louis).
- **Panel B selective degeneration of cortico-spinal tracts** (arrows). Posterior columns are normally myelinized (arrowheads).
- In anterior root is loss of myelinized fibers and gliosis (Panel C, right) posterior horn is normal (Panel C, left).

affected central and peripheral neuron

Living - 3-5 years from the diagnosis, 20% die in 1.year – respiratory insufficience
Rexed’s laminae (zones)
I – ncl apicalis
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Propriospinal tracts crosshatched
Visceromotor nucleus
Sensory tracts
Motor tracts
Cerebellar tracts

Dorsal column tracts

Ncl intermediolateralis
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