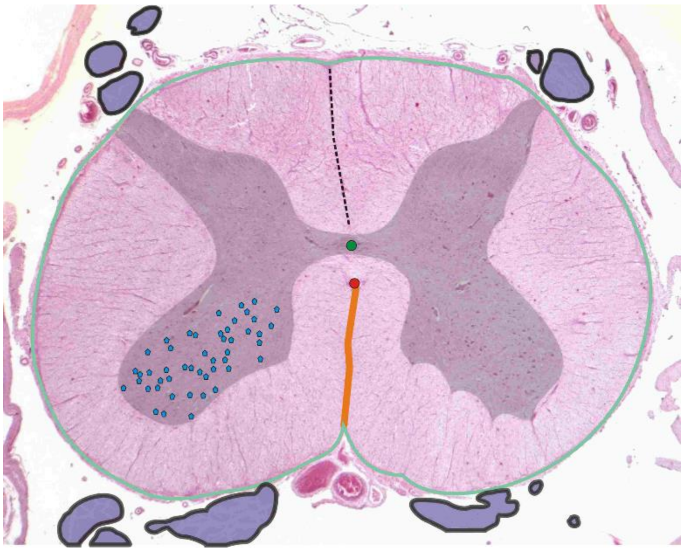
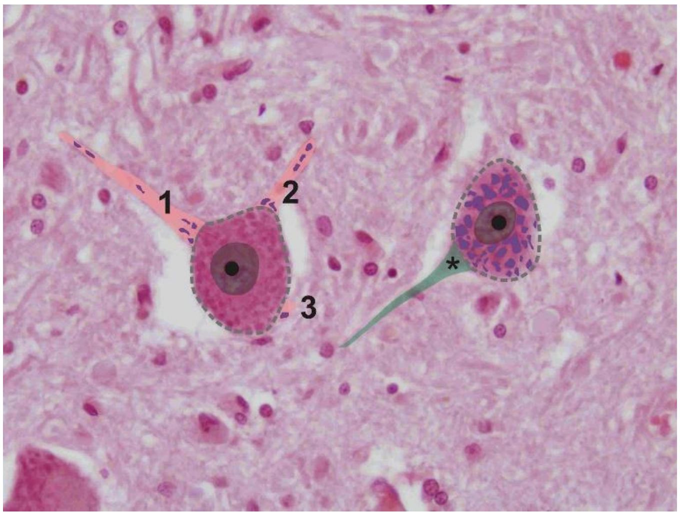
SPINAL CORD

In a transverse section of the spinal cord, the correct identification of the ventral horns is most important. For this purpose, it is necessary to recognize the ventral part of the spinal cord. Two criteria are used for this purpose: i) The characteristic shape of the ventral horns of the spinal cord , and ii) Finding the anterior median fissure.



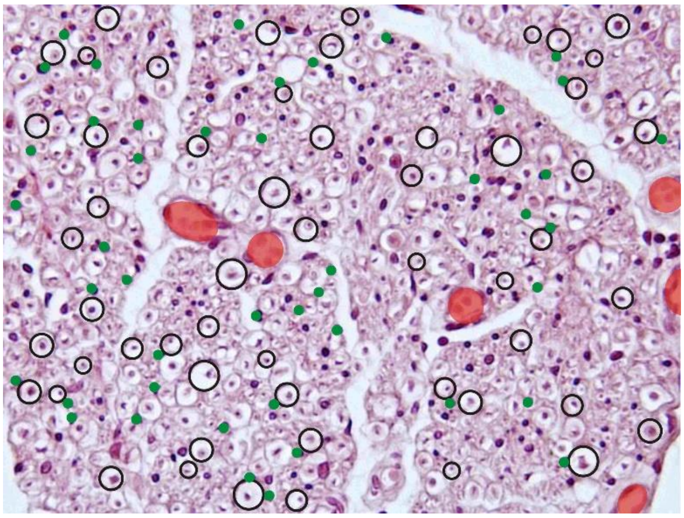
The **grey matter** (when the cursor is moved over the interactive image, it appears in grey) has a typical butterfly shape (or H-shape) in a transverse section of the spinal cord. The right half is connected to the left by the grey matter, which contains the central canal (shown in green) lined by ependymocytes. The dorsal horns of the spinal cord are relatively slender, long and reach the surface of the spinal cord, whereas the **ventral horns** are thicker and do not reach the surface of the spinal cord. In the ventral horns **alpha motor neurons** are located (shown in blue). Outside the grey matter of the spinal cord is the white matter; it does not contain nerve cell bodies, but only nerve fibres (most of which are myelinated). The **anterior median fissure** (orange) runs in a median line along the ventral side of the spinal cord. The space of the groove is filled by the loose connective tissue of the pia mater, which fills all irregularities on the surface of CNS structures. At the bottom of the groove lies the anterior spinal artery (red), which nourishes the anterior parts of the spinal cord. Conversely, in the posterior part of the spinal cord, the median structure is represented by a thin sepum medianum posterior (shown by the dashed line). Central canal (green) is located in the midline between these two structures.

Motor neurons are the largest neurons in the spinal cord. Due to the large number of dendrites protruding from their **body** (indicated by the dashed grey line), they are classified as multipolar neurons (usually only the stem protrusions can be seen in a section - in one neuron the protrusions are numbered). Inside the perikaryon there is an oval **nucleus** (grey) with a light chromatin and one conspicuous dark **nucleolus** (black). The voluminous body of alpha motor neurons contains clearly visible basophilic clumps of the **Nissl substance** (purple), which also enter the main **dendrites** (orange), while disappearing at the **axon** hillock (green, asterisk). The space between the nerve cell bodies is filled by the neuropil containing also blood capillaries (with the blood-brain barrier) and glial cell bodies - in the grey matter of the CNS these include: protoplasmic astrocytes, oligodendroglia and microglia.



VENTRAL AND DORSAL ROOTS

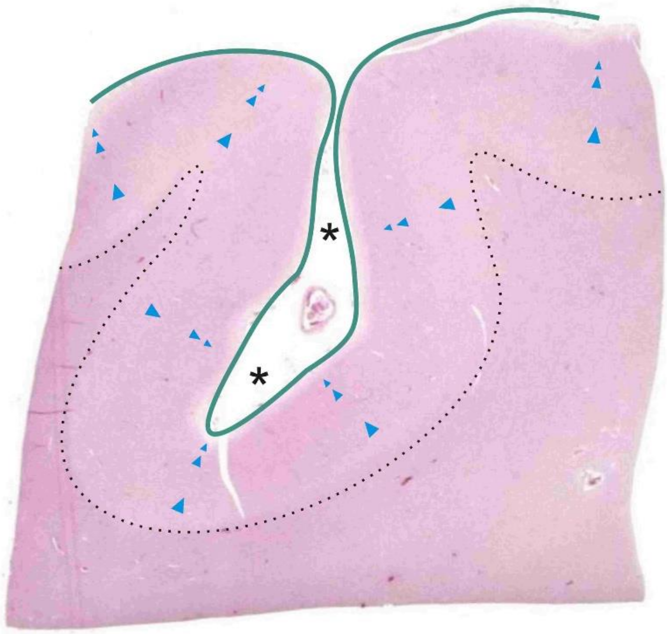
Spinal nerve roots (shown in purple) can be found in the subarachnoid space of the spinal cord leptomeninges, which are part of the spinal cord coverings. The subarachnoid space is located externally to the **pia mater** (indicated by the green line). Dorsal roots are located near the end of the dorsal horns; ventral roots near the **ventral horns** of the **gray matter** (gray). Ventral horns contain numerous motor neurons (blue). Other structures labelled in the interactive figure include the anterior median fissure (orange), anterior spinal artery (red), central canal (green circle), and poster median septum (dashed line). A surface of the ventral and dorsal roots is covered by the **perineurium** (black).



One of the **dorsal roots** (in purple) is shown in the figure on left. 6 on the right. The root has the character of a bundle of myelinated nerve fibers. Its surface is covered by a **perineurium** (dark gray) composed of flattened cells. Externally, the subarachnoid space is seen, which is filled by the cerebrospinal fluid. Inside the bundle, numerous **blood vessels** (marked with asterisks) can be found next to the nerve fibres.

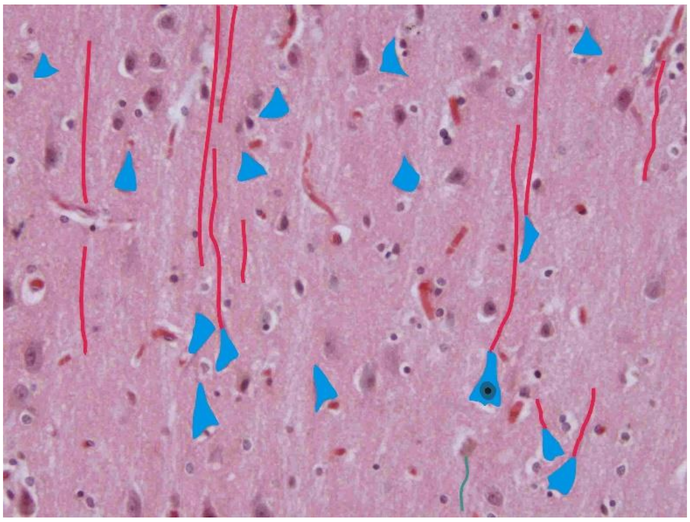
The dorsal root itself is made up of many tightly grouped **myelinated nerve fibres**, some of which are shown by the black circle. Externally to the myelin sheath is the body (and nucleus) of the Schwann cell (green). Myelinated fibers vary in diameter. The space between the fibres is filled by the endoneurium containing loose connective tissue, blood capillaries and larger blood vessels (red).

CEREBRAL NEOCORTEX



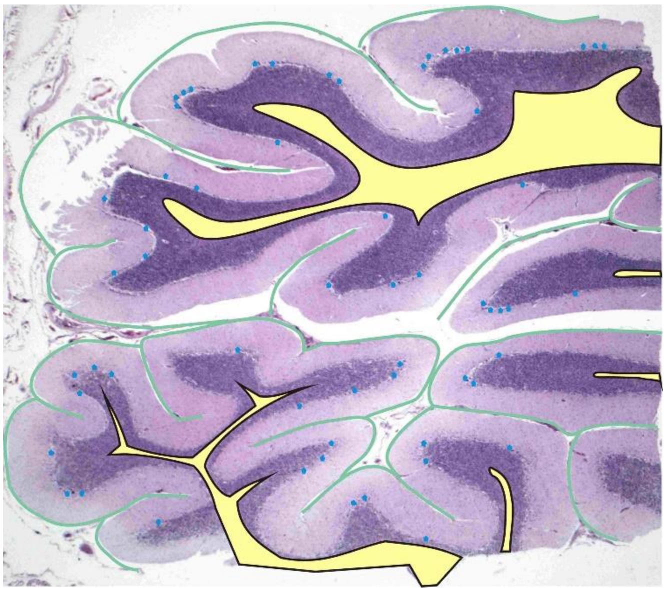
The slide of the cerebral neocortex can be identified by its characteristic shape, which shows two adjacent gyri separated by a sulcus (marked with an asterisk in the interactive slide). The grey matter is spread over the surface of the brain as the **cerebral cortex**. It is important to correctly identify this part of the slide according to the cerebral coverings (pia mater is marked in green). The cerebral cortex is located immediately below the meninges. The lower edge of the neocortex is roughly marked by a dotted line - below this line is the white matter, which does not contain the perikarya of nervous cells. The edges of the slide that are not covered by the meninges in the section come from deep regions of the brain. The cerebral cortex contains numerous neurons, which are arranged in six layers. The description of the layers is part of the special histology. The most striking perikarya belong to the pyramidal neurons. Small, medium and large pyramidal neurons are found in the cortex - their position within the neocortex is marked in blue.

Pyramidal neurons are typical nerve cells of the neocortex. Their name is derived from the triangular body resembling pyramids (shown in blue in the interactive slide). They are multipolar neurons. The **apical dendrite** (in red) extends from the apex of the perikarya and runs towards the superficial layer of the brain. These dendrites reach considerable thickness and length and can therefore be recognized even when the perikaryon is not seen in the section. The apical dendrites are arranged in parallel and run perpendicular to the surface of the brain. The **lateral dendrites** are also indicated on the body of the pyramidal neuron, protruding at the lateral corners of the trigeminal body. A single axon extends from the middle of the base and plunges into the white matter of the brain, eventually entering the cortical columns. Axons (green) of pyramidal neurons are relatively rarely found in a section. Inside the perikarya there is a pale spherical nucleus (grey) with a prominent nucleolus (black), and Nissl's substance is found in the neuroplasm. The largest pyramidal neurons reaching body length (i.e., the perikaryon measures from base to apex) of up to 100 μm are found in the deeper layers of the cortex.



In the adjacent neural tissue, the so-called neuropil, there are protrusions of other cells, bodies of supporting (glial) cells, interneuronal synapses, and blood capillaries (endowed with a blood-brain barrier)

CEREBELLAR CORTEX



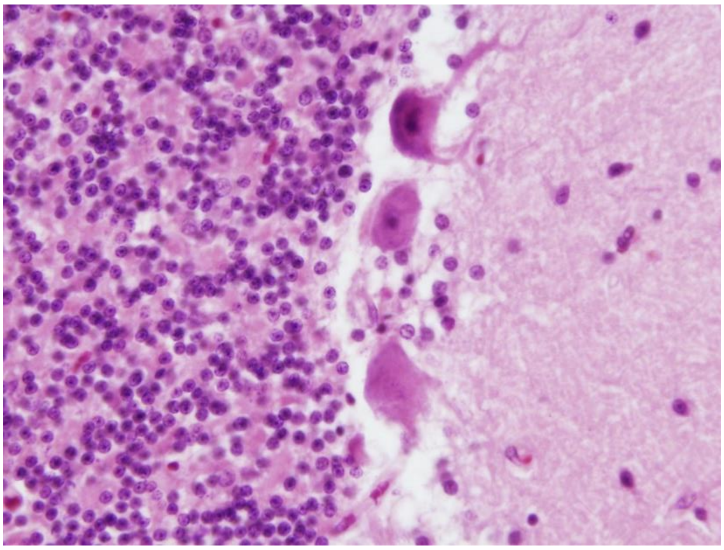
A surface of the cerebellum is divided by a system of coils (*foliae*) and grooves (*fissurae*). The branching of the white matter that enters the interior of each gyrus produces a characteristic and complicated pattern, called *arbor vitae* (tree of life), which makes identification of the slide easy and unambiguous.

For correct orientation in the microscope, it is necessary to recognize a surface covered by the pia mater and to distinguish the cerebellar cortex from the white matter (marked in yellow on the interactive slide). The white matter consists of nerve fibres and is therefore bright. Towards the cerebellar medulla the white matter increases, towards the cerebellar gyri it becomes thinner; there is only a relatively thin strip of white matter in the axis of the gyrus. The cerebellar cortex is composed of grey matter and contains perikarya of nervous cells. A surface of the cortex is covered by the pia mater composed of loose connective tissue. This connective tissue (green) also fills the thin spaces between adjacent gyri.

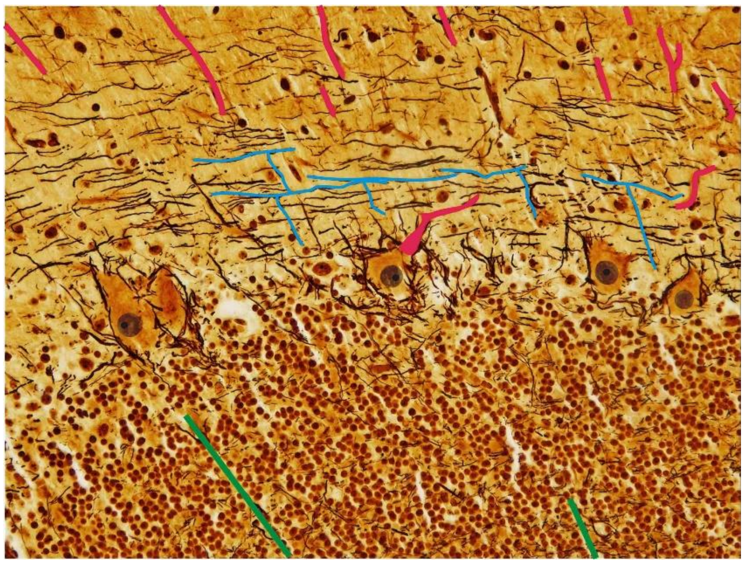
The **cerebellar cortex** itself shows a laminar arrangement and is arranged in three layers. The superficial layer, the *stratum moleculare*, is fairly light because it contains a relatively small number of neurons; it lies beneath the pia mater. The granular layer is the most conspicuous, consisting of granular neurons. Because of their relatively small size and vast numbers, this layer is conspicuously dark. The *stratum granulosum* also borders the white matter. At the boundary between the granular and molecular layers is the *stratum gangliosum*, containing the largest neurons of the cerebellum, the so-called **Purkinje cells** - the position of some Purkinje cells is indicated in blue.

Purkinje cells

As mentioned above, the cerebellar cortex is made up of three layers. The outermost molecular layer (*stratum moleculare*) is marked in yellow in the interactive slide. This layer is relatively light and contains only a small number of neurons, as well as supporting cells, unmyelinated nerve fibres and blood vessels. Below this layer, there is the **Purkinje cell layer** (*stratum gangliosum*). These are the largest neurons of the cerebellar cortex, the bodies of which (marked in blue) can be clearly identified in the microscope. The perikaryon is pear-shaped and contains an oval nucleus with a well-defined nucleolus and Nissl substance. Two stem dendrites most often branch off from the perikaryon and enter the molecular layer. A neurite emerges from the base and travels through the granular layer to the deep nuclei of the cerebellum. In thin sections, the outlying processes are rarely seen. Purkinje cells are found at the border with the granular layer (*stratum granulosum* - purple). In this layer, small and large granular neurons are abundant, whose basophilic nuclei give the layer its dark coloration.



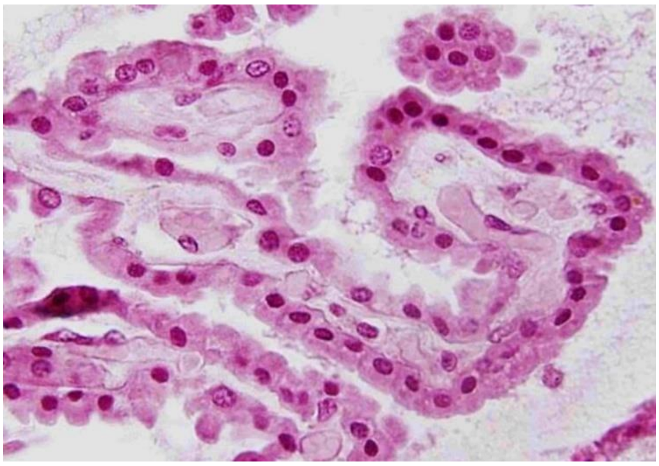
A section impregnated with the protargol method (according to Bodian) selectively shows the processes of nervous cells (nerve fibres). At the boundary between the molecular and granular layers, the perikarya of **Purkinje cells** can be detected in one discontinuous layer; in some of them, oval nuclei (grey) with a prominent nucleolus (black) are seen in the section. The pear-shaped perikarya are surrounded by a network of black climbing fibres. Purkinje cell **dendrites** (red) located in the molecular layer are conspicuously thick; **neurites** (green) permeate the granular layer. The **parallel fibers** running through the molecular layer perpendicular to the Purkinje cell dendrites are also a striking structure. These fibres are formed by the T-shaped branching of the axon of small granular neurons and are therefore also referred to as T-fibres (blue).



The slide is not used for testing; it is only used to demonstrate neuronal circuits in the cerebellar cortex

CHOROID PLEXUS

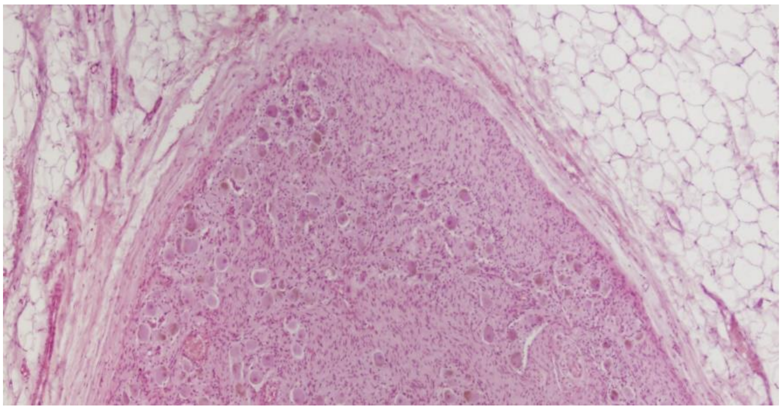
A surface of the choroid plexus is lined by a single layer of cuboidal (**isoprismatic**) **cells**. Inside the cytoplasm there is a clearly visible **spherical nucleus**. The apical cytoplasm of the cells is slightly convex. The epithelium sits on the basal lamina (its course is indicated by the green line), which separates it from the loose connective tissue of the stromal villi; inside, numerous fenestrated **capillaries** can be seen (two are shown in red), which are lined by a simple squamous **endothelium** with flattened nuclei.



A detailed description of the structure including ultrastructure and function is given in the lecture.

SYMPATHETIC GANGLION

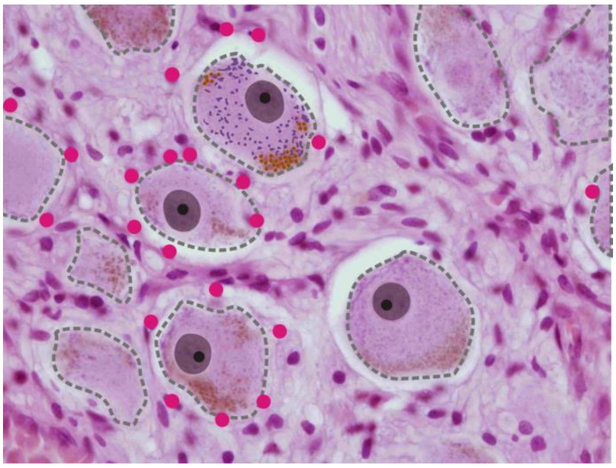
Vegetative ganglia serve to transmit information from visceromotor systems originating in the CNS nuclei before the postganglionic fibres reach the target structures. From outside the ganglion is enveloped by the **capsule** from the dense connective tissue; tiny septa enter the parenchyma to supply it with the blood. Structure of vegetative ganglia differs from cerebrospinal ganglia.



Ganglionic cells have features of **multipolar** neurons. Perikaryon is large (although not reaching a size of somatosensory ganglia). The neuroplasm contains the Nissl substance that also enters the dendrites. The perikaryon is surrounded by few **satellite cells** (amphicytes). The more distant is the vegetative ganglion from the *truncus sympaticus*, the less amphicytes surrounds their perikaryon. Due to many cytoplasmic processes of multipolar ganglionic cells passing through a layer of satellite cells, this layer is not so continuous. Nevertheless in ganglia of the *truncus sympaticus* a layer of around ganglionic cells is more developed than in cells of intramural ganglia that are surrounded only by a layer of the endoneurium. The basal lamina of amphicytes is continuous with the basal lamina of Schwann cells. The endoneurium contains many **unmyelinated** (autonomic) **nerve fibres**. Bodies of ganglionic cells are mixed with vegetative nerve fibres, i.e. their components are not well arranged and are scattered throughout the entire ganglion. The dendrites of ganglionic cells are synapsed with endings of other vegetative neurons. This means the autonomic ganglia contain **synapses** (on the contrary to cerebrospinal ganglia). Morphologically, sympathetic ganglion cells cannot be distinguished from parasympathetic ones.

Due to a small size of ganglion its structure is simpler than that of CNS structures. A surface is covered by the **capsule** of a dense connective from which are derived tiny septa supplying the parenchyma with the blood vessels. Outside from the capsule there is a white adipose connective tissue with many blood vessels. In the vicinity to the ganglion the vegetative nerve can be often seen. Inside the parenchyma the bodies of many ganglion cells can be found. **Perikarya of ganglionic cells** are scattered through the parenchyma. A space left between the ganglionic cells are filled in with mainly by **unmyelinated nerve fibres**.

The parenchyma of the ganglion contains well apparent large bodies of **ganglionic** (nervous) **cells** (in an interactive slide indicated by a dotted line). Inside of the **perikaryon** the oval **nucleus** (grey) with a prominent **nucleolus** can be seen (black). The cytoplasm contains well visible accumulations of basophilic **Nissl tigroid substance** (purple) and sometimes also pigment **lipofuscin** (brown). Many processes of multipolar ganglionic cells are not seen well in a section. A body of the ganglion cell is covered by a discontinuous layer of **satellite cells** (red) called also as amphicytes. **Nerve fibres** filling in the space between the ganglionic cells are **unmyelinated**.



Summary

The **sympathetic ganglion** has an oval shape and it is relatively small. Under its **capsule** the perikarya of **ganglionic cells** are scattered throughout the entire ganglion. Perikarya have features characteristic of nervous cells (oval nucleus with a prominent nucleolus, Nissl substance and often lipofuscin). Each perikaryon is surrounded by few **satellite cells** (a capsule is discontinuous as it is interrupted by many processes of multipolar ganglionic cells). **Unmyelinated nerve fibres** with relatively densely arranged Schwann cells can be found among the perikarya of ganglion cells. In the vicinity to the ganglion, a vegetative nerve can be found; other structures can include an adipose tissue and blood vessels.

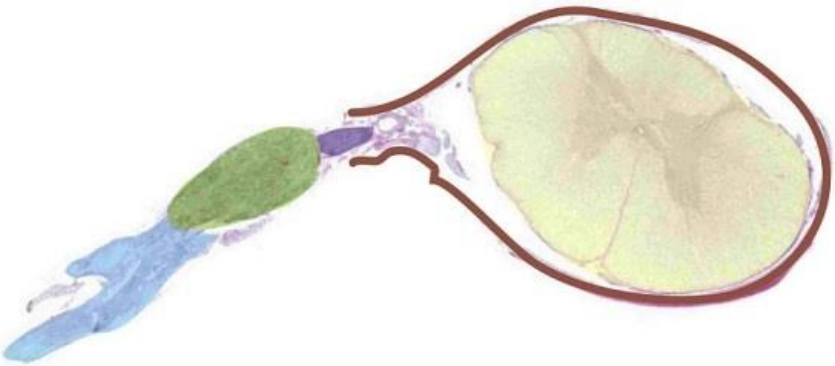
Note: When describing the ganglion it is necessary to include the differences in a structure of the vegetative versus cerebrospinal ganglion (at light as well as electron microscopic levels).

DORSAL ROOT GANGLION

Spinální ganglion vzniká nakupením pseudounipolárních neuronů v oblasti *foramen intervertebrale*. Spinální ganglion je vloženo do **zadních míšních kořenů**. Povrch je obalen pouzdrem, které vzniká pokračováním míšních obalů; nejnápadnější je zevní vrstva hustého kolagenního vaziva. Splynutím předního a zadního kořenu vznikne spinální nerv. Pod pouzdrem jsou těla gangliových buněk nahloučená do skupin. Typickým rysem spinálních ganglií je **pravidelné uspořádání** jeho komponent, tj. perikarya nejsou promíchána s nervy. Nervová vlákna jsou nakupena a vyplňují prostory mezi skupinami nervových vláken. **Dorsal root ganglion** arises from accumulation of pseudounipolar neurons in the area of the *foramen intervertebrale*. Dorsal root ganglion is inserted in the **dorsal spinal roots**. A surface is covered by a capsule, which is a continuation of the coverings of the spinal cord; the most conspicuous is the outermost layer of the dense connective tissue. Fusion of ventral and dorsal roots gives rise to the spinal nerve. Under the capsule, the bodies of ganglionic cells are clustered in groups. A typical feature of the dorsal root ganglion is a **regular arrangement** of its components, i.e., the perikarya are not mixed with nerves. Nerve fibres are aggregated and fill in the spaces between groups of nerve bodies.

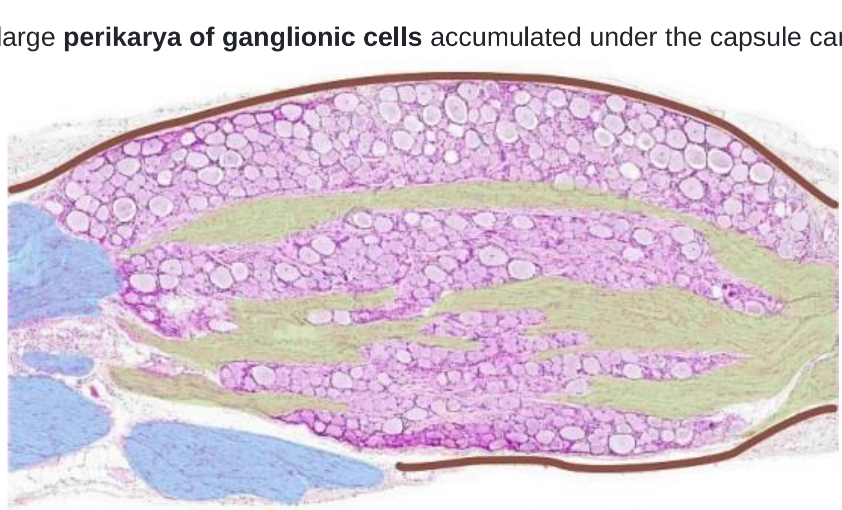
Pseudounipolar neurons of dorsal root ganglion have large perikarya reaching a size 100 µm. A common process leaving the perikaryon branches in a shape of a letter "T". The perikaryon is ensheathed by a single layer of satellite cells (amphicytes). Due to a single process and a large perikaryon there are many **satellite cells** forming a continuous layer. Pseudounipolar neurons send their afferent arm that accepts sensitive/sensory information from the periphery (e.g. nociception, proprioreceptors etc.). Their efferent arm brings information in the spinal cord via dorsal roots to synapse with spinal neurons - for that reason there are no synapses inside of the dorsal root ganglion. **Nerve fibres** of these ganglionic cells are **myelinated**.

Cerebral ganglia show a very similar structure. These ganglia also contain pseudounipolar ganglion cells with the exception of the *ggl. vestibulocochleare*, which is the only ganglion containing bipolar neurons.



Slide of the **spinal cord** of a pig (in an interactive slide indicated in yellow) shows a transverse section that also includes the **dorsal root ganglion** (in green). In the spinal cord a buterfly-like structure of the grey matter can be seen; well visible are also ventral horns that are shorter than dorsal horns reaching a dorsal surface of the spinal cord. From outside the grey matter is surrounded by the white matter. In the centre the central canal is well apparent. Below is the *median anterior fissure* filled with a loose connective tissue derived from the pia mater. Coverings of the spinal cord (brown) are continuous with coverings of the roots, ganglion and nerves. Dorsal root ganglion is inserted in the course of the **dorsal roots** (dark blue). Fusion of the ventral root (not indicated in any colour but it is visible under the ganglion) with nerve fibres of the ganglion forms the **spinal nerve** (indicated in light blue).

At middle magnification (Fig.) large **perikarya of ganglionic cells** accumulated under the capsule can be found. The **capsule** (in an interactive slide indicated in brown) is made of the dense connective tissue. **Nerve fibres** form larger bundles (light green) passing between groups of ganglion cells. These fibres pass through the ganglion to form the **spinal nerve** (light blue). Histological structure of the ganglion



shows that its structural components are well **arranged** – this is a characteristic feature of all cerebrospinal ganglia.

A detailed microphotograph of the dorsal root ganglion shows a bilayered **capsule** (brown) made from continuation of the pachymeninx and leptomeninx. Under the capsule a **group** of **ganglion cells** (some are labelled with a dotted grey line) can be seen. The neuroplasm contains the well apparent Nissl tigroid substance. Some ganglionic cells contain a spherical nucleus (grey) with a prominent nucleolus (black). A surface of the perikaryon is ensheathed by a **layer of satellite cells** (nuclei of some apmphicytes is indicated in red). A space visible between the perikaryon and satellite cells is artefactual caused by shrinkage during a tissue processing (dehydration) for histology. Under a group of ganglion cells (black dotted line) **nerve fibres** can be seen. Size of nerve fibres is different. In a longitudinal section, the axon (orange) can be found inside covered by the white **myelin**. Ranvier nodes (yellow arrows) are visible as tiny crosses (they are oriented perpendicularly to the axon. Flattened nuclei at the edge of myelin belong to Schwann cells (nuclei of some **Schwann cells** are indicated in green).

Summary

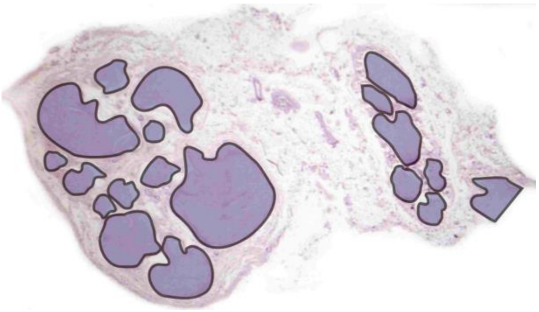
The ganglion is a small structure covered by a capsule; the parenchyma under the capsule contains bodies of nervous cells and nerve fibres. A regular **arrangement** (separating the parenchyma in **groups of ganglionic cells** from nerve fibres filling in the space left between the groups) is characteristic of the craniospinal ganglia. Another feature includes **myelinated nerve fibres**. Ganglionic cells are large, their body is lined with a **continuous layer of satellite cells**. The presence of the spinal cord makes a diagnosis of the slide easier.

CEREBROSPINAL NERVE

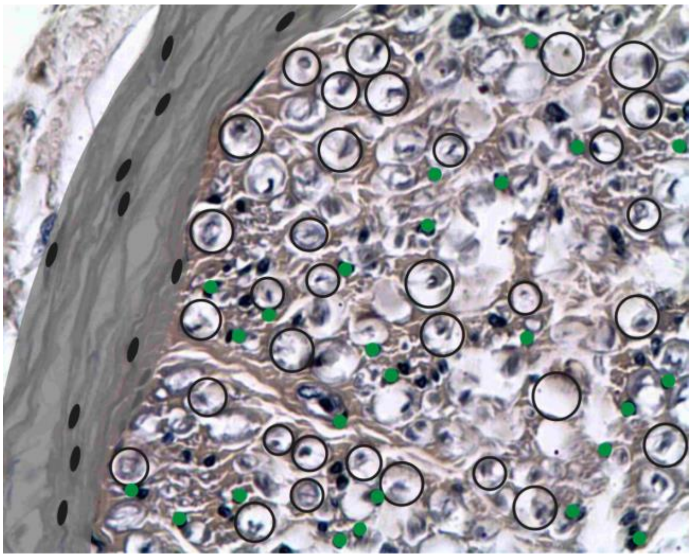
Cerebrospinal nerves leave the brain and spinal cord to innervate peripheral issues. Most these nerves are mixed, i.e. they contain both myelinated and unmyelinated nerve fibres. Nevertheless the **myelinated nerve fibres** are more abundant. The whole nerve is a collection of nerve bundles covered by the epineurium. The **epineurium** contains a dense connective tissue (continuation of the dura mater from the CNS). A surface of nerve bundles is encapsulated by several layers of flattened cells constituting the **perineurium**. The perineurium is an analogue of the arachnoid membrane of the CNS - perineural cells are sealed with *zonulae occludentes* (*tight junctions*) and they border each nerve bundle as a barrier from outside. Every nerve bundle contains a different number of nerve fibres. Inside of the bundle the nerve fibres are surrounded by the **endoneurium** - a thin layer of loose connective tissue (analogue of the *pia mater* from the CNS). The endoneurium contains blood capillaries with the blood-brain barrier. The cerebrospinal nerve consists of mainly myelinated nerve fibres; the vegetative nerve contains mainly unmyelinated nerve fibres.

A nerve fibre consists of a nervous cell processus, axon, and of its coverings. In the PNS, the axon is covered by the Schwann cells. The axon of the **myelinated nerve fibre** is ensheathed by concentric lamelae of the Schwann cells that form the myelin sheath. The cell body and nucleus of the Schwann cell is located at the periphery. Each **Schwann cell** covers a short segment of one axon. The next segment of the same axon is covered by the myelin from the next Schwann cell. The segment of the myelin formed by the single Schwann cell and separated by **Ranvier nodes** is called the **internodium**.

In the vegetative nerve, the **unmyelinated nerve fibres** prevail; these consist of the axon covered by the Schwann sheath. Many axons are covered by the single Schwann cell; in many the mesaxon appears although few with a naked surface do not form the mesaxon. The unmyelinated nerve fibres are not segmented - there are no nodes of Ranvier. Their surface is covered by the basal lamina and the endoneurium. The entire bundle is covered the perineurium. As autonomic axons are of small sizes the bodies and nuclei of Schwann cells at light microscopy are closely apposed.



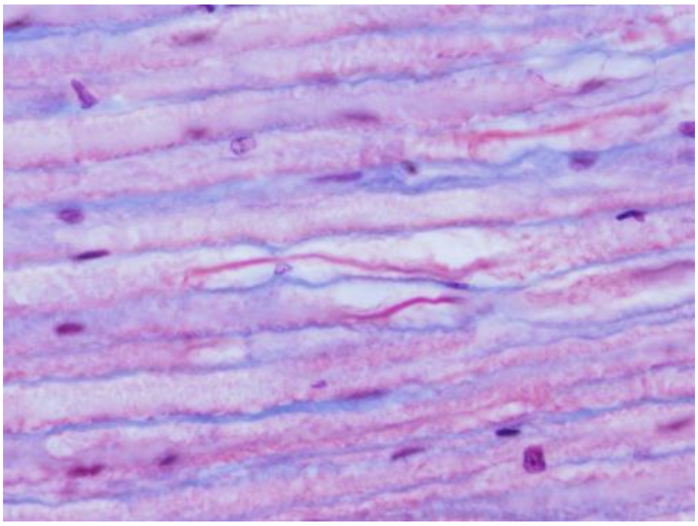
A peripheral nerve is formed by several **bundles of nerve fibres** (indicated in purple colour). A surface of each bundle is covered by the **perineurium** (dark grey). As the nerve fibres run in a wavy pattern the slide contains both longitudinally and transversely cut bundles. Nerve bundles are surrounded by the dense connective tissue (epineurium). The **epineurium** contains large blood vessels (*vasa nervorum*) that send their branches to nourish the nerve bundles. On the outer surface the epineurium is condensed to make a capsule (well visible in left and low part of the slide.



Nerve fibres aggregate to form the bundles (fascicles); the amount of nerve fibres is related to a size of each bundle. The nerve bundle is covered by few layers of flattened cells constituting the **perineurium** (grey).

Some nuclei of perineural cells are indicated in black. The bundles are composed of mainly myelinated nerve fibres – some are indicated as a black circle. Myelinated fibres differ in their sizes. The contain the **axon** (visible as a dark dot) inside and remaining proteins; lipids of the myelin are to some extent dissolved during processing of paraffin-embedded sections in organic solvents – for that reason the myelin sheath looks pale (white). A nerve fibre is visible in a transverse section as a tiny dot (axon) surrounded by a light hallo (myelin); cell body and nucleus of the **Schwann cell** (green) are placed outside. A space left between nerve fibres is filled with the endoneurium containing the loose connective tissue – cell nuclei visible in the endoneurium belong to fibroblasts and endothelial cells of blood capillaries.

In a longitudinal section of myelinated nerve fibres the **Ranvier nodes** (yellow arrows) are well seen; they separate segments of the myelin formed by adjacent Schwann cells. The axon in a longitudinal section looks as a dark line (orange); it is lined on both sides by a pale myelin. Externally from the myelin the bodies and nuclei of Schwann cells are placed (green). A space between nerve fibres is filled in with a loose connective tissue (endoneurium) containing blood capillaries nourishing the nerve fibres; when stained with blue trichrome the collagen fibres and the endoneurium are labelled in blue.



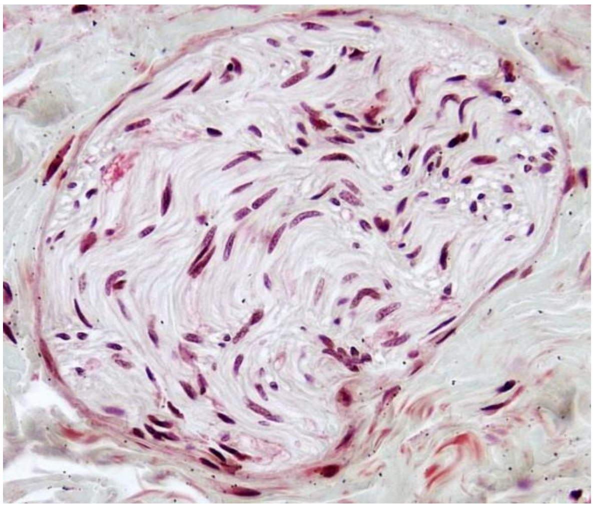
Summary

A peripheral nerve consists of several nerve **bundles**. Each bundle is covered by the well visible **perineurium** formed by flattened cells. From outside the bundles are embedded in a connective tissue that is a part of the epineurium. A bundle contains tiny and pale **myelinated nerve fibres**. The axon is surrounded by a pale myelin sheath. The nucleus of the **Schwann cell** is often flattened, dark and placed in the edge of the nerve fibre. A space among nerve fibres is reduced and filled with the loose connective tissue (**endoneurium**). **Ranvier nodes** separating adjacent internodia can be identified only in a longitudinal section.

VEGETATIVE NERVE

Vegetative nerve fibres innervate smooth muscle and glands and that is why autonomic nerves can be found in a tissue of visceral organs, in septa of the gland or in the vicinity to vegetative ganglia. **Nerve bundles** are in the interactive slide labelled in purple; their surface is covered by the **perineurium**. In a longitudinal section, a wavy pattern of unmyelinated nerve fibres as well apparent as well as a tight arrangement of Schwann cells and their basophilic nuclei while tiny nerve fibres are pale and drab.

A surface of the bundle is covered by one or two layers of flattened **perineural cells** (grey); a dense connective tissue septum of the pancreas occurs externally. Basophilic Schwann cell nuclei are densely packed inside of the bundle (nuclei of some **Schwann cells** are labelled in green). Nerve fibres inside the bundle are arranged in a spiral and that is why in the same section Schwann cells are cut both longitudinally and transversely, i.e. their cell nuclei look like elongated rods or small spheroids. **Unmyelinated nerve fibres** fill a remaining space and they are very pale; nerve fibres are also densely packed because a diameter of vegetative axons is smaller than that of myelinated nerve fibres and more axons are incorporated into the cytoplasm of a single Schwann cell. In these nerve fibres, myelin is not formed and wrapped around neurites.



Endoneurium (a loose connective tissue between nerve fibres) is quite reduced; it contains blood capillaries. Cell nuclei visible in the endoneurium can belong to Schwann cells but also to fibroblasts and endothelial cells.

In the e-course, the description of the autonomic nerve is given in the description of the autonomic (sympathetic) ganglion.