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CENTRAL NERVOUS SYSTEM

Overview of Anatomy

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Central Nervous System
Overview of Anatomy

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Preface

This concise overview of CNS anatomy is intended for first year medical students, who often find the neuroanatomy course one of the most difficult parts of their study. The text presents the basic CNS structures and their interrelations. The accompanying simplified drawings should make it easier for the students to understand the text; however, they are not intended to substitute for pictures in neuroanatomy textbooks. More detailed information can be found in the recommended literature listed under "References".

We hope that this short overview will help the students understand the nervous system in its functional unity.

J. V., P. F.

1/ Cells of the nervous system

1.1 Neurones

The neurone is the basic structural and functional unit. The total number of neurones in the human body is estimated at 10^{10}, their size varies from 5μm (interneurones) to more than 100 μm (motor neurones).

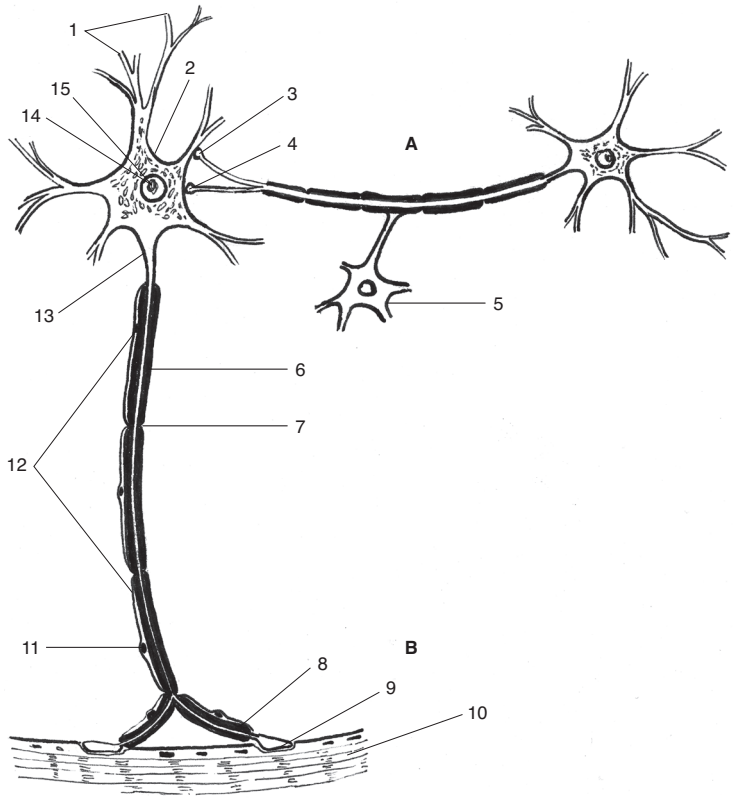

Fig. 1.1 **Diagram of neurones and their connections**

A – upper motoneurone located within the CNS

B – lower motoneurone

1 – dendrites, 2 – perikaryon, 3 – axodendritic synapse, 4 – axosomatic synapse, 5 – oligodendroglia, 6 – myelin sheath, 7 – node of Ranvier, 8 – teledendron, 9 – motor end-plate, 10 – skeletal muscle, 11 – Schwann cell (in PNS), 12 – axon, 13 – initial segment, 14 – nucleus, 15 – Nissl bodies

The typical structure of a neurone consists of (Fig. 1.1):

a) **soma –** body, perikaryon, in which is the nucleus with the nucleolus and the chromosomal DNA, and the cytoplasma with neurofibrils, microtubuli and granules of Nissl's substance. These granules are formed by the endoplasmatic reticulum with ribosomes containing RNA;

b) **dendrites –** several branching processes (without myelin sheath) receiving excitatory or inhibitory information from other nerve cells with which they make contact. Each neurone may have several thousands of contacts, synapses with other neurones;

c) **axon –** usually one longer process (up to one meter in peripheral nerves of the lower limb) which carries information away from the cell body. The axons may branch and form collaterals. At the end of the axon is the terminal bouton where the information is transferred to the dendrites of other neurones. The axons leaving the CNS form the efferent fibres of the peripheral nerves and end either in striated muscle (motor end-plate, neuromuscular junction) or smooth muscle, or in secretory gland cells – secretory ending.

The axons can transport some substances from the cell body, especially proteins (the axoplasmatic transport), but they serve mainly for transfer of electrical stimulation, the action potential. The neurone at rest possesses an electrical potential across its membrane, the resting potential, of 60–100 mV, the inside being negative. When the neurone is stimulated, there is a reversal of the membrane polarity by transfer of the Na^+ ions into the cell and the action potential is thus created. This is called the depolarization of the membrane. Subsequently the K^+ ions are transferred into the extracellular fluid and the negative resting potential is restored – this is the repolarization of the membrane.

Axons thicker than 0.2 μm are covered with a lipoprotein **myelin sheath** which provides an insulation layer. This sheath is produced in the CNS by the processes of the oligodendroglia (see Chapter 1.2), and in the peripheral nerves by the Schwann cells. Between the individual cells of the glia there are grooves in the myelin sheath, the Ranvier's nodes, where the axon is not covered. In these nodes the ionic transfers generate the action potentials which jump to the next internodal section of the axon – saltatory conduction. The transfer of the action potentials is thus enhanced and faster.

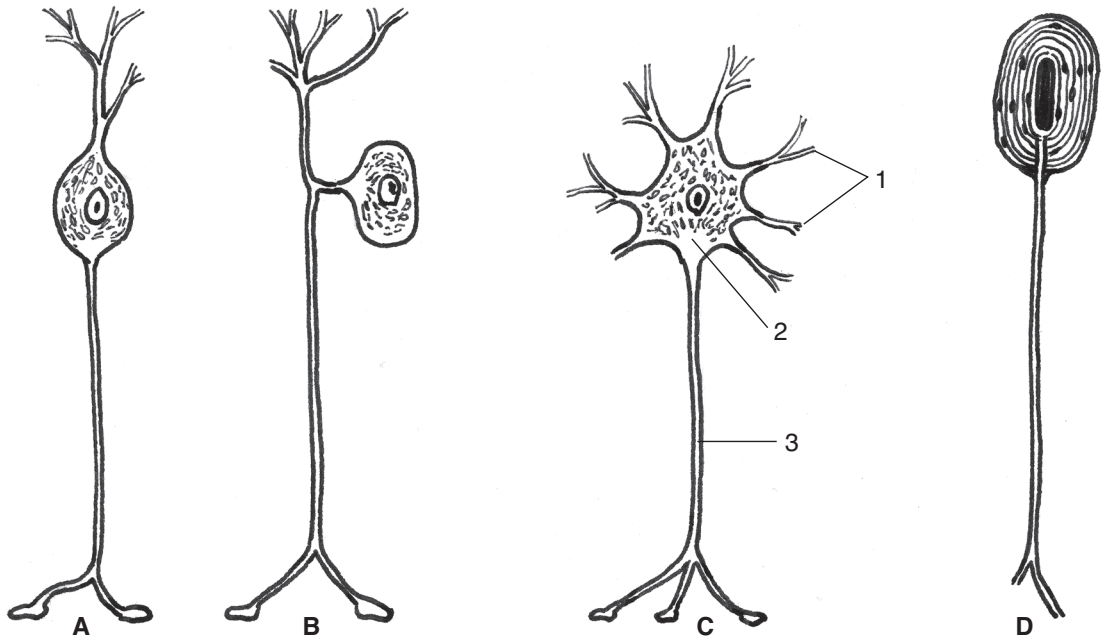

Fig 1.2 **Main types of neurones (classification according to the number and branching of dendrites and axons)**
A. Bipolar, B. Pseudounipolar, C. Multipolar, D. Unipolar (Paccinian corpuscle of the skin)
1 – dendrites, 2 – cell body, 3 – axon

The neurones, according to their shape and the pattern of the dendrites and the axon, are classified as (Fig. 1.2):

- **bipolar –** one dendrite and one axon, arising at the opposite sites of the cell body,
- **multipolar** – several dendrites and one axon, the commonest type,
- **pseudounipolar** – the axon and the dendrite arise from the cell body close to each other,
- **unipolar** – the dendrite is replaced with a special sensory receptor.

A **synapse** is the site of the transfer of the action potential from one neurone to the other neurones or to the effector (muscle, gland). One axon can have synapses with several dendrites or even with the bodies of other neurones. The transfer is a chemical one, by means of **neurotransmitters (mediators)**. The neurotransmitter is stored in the presynapatic vesicles. Depolarization of the presynaptic membrane opens the calcium channels and the neurotransmitter is released into the synaptic gap. Consequently the polarization of the postsynaptic membranes of the dendrites or bodies of the other neurones produces postsynaptic action potentials which are transferred to further neurones. The action of a neurotransmitter is rapidly abolished by enzymes (e.g. acetylcholinesterase) or by neuroglia.

Several types of neurotransmitters have been identified at various sites of the nervous system. In the peripheral nervous system the commonest transmitter is acetylcholine (in the autonomic ganglia, postganglionic parasympathetic neurones, striated muscle). Catecholamines (adrenaline, noradrenaline, dopamine) as well as serotonin are common in the CNS. Other neurotransmitters include GABA and glycine (inhibitory), glutamate and aspartate (excitatory), some peptides (enkephalin, cholecystokinin, substance P, somatostatine, dynorphin) and gases (NO).

The **nucleus** is an agglomeration of neurones with the same function in the central nervous system. A similar agglomeration in the peripheral nervous system is called the **ganglion**.

1.2 Neuroglia

The **neuroglia** consists of relatively large cells arising from the neural tube, the **macroglia**, and of small cells arising from the haemopoetical system, the **microglia**. The macroglia is formed by the astroglia, astrocytes, and the oligodendroglia, oligodendrocytes (Fig. 1.3).

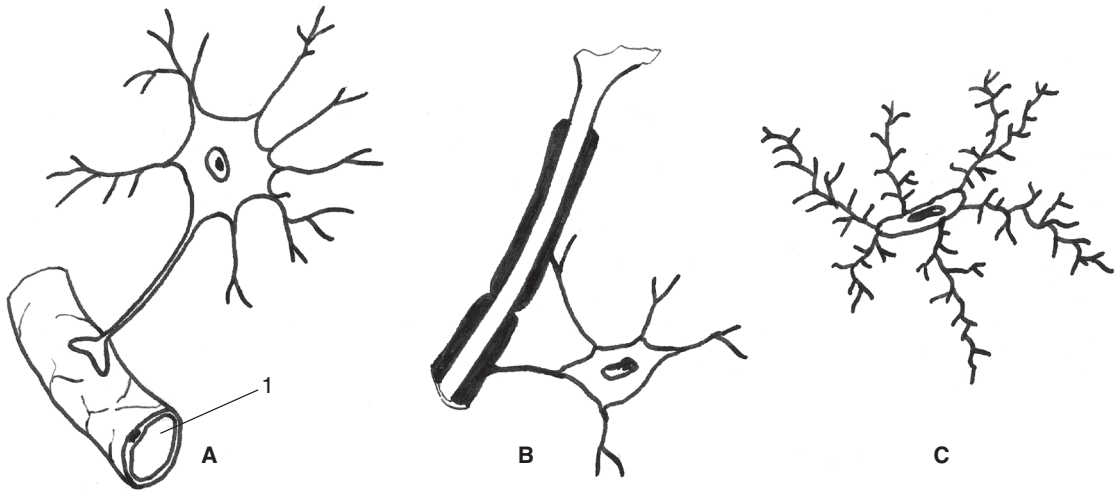

Fig. 1.3 **Neuroglial cells**
A. Astrocyte, B. Oligodendrocyte, C. Microglia
1 – capillary

The **astrocytes** are the largest cells of the glia. They are of a stellate shape with numerous processes, some of which end on the walls of the blood capillaries as the perivascular end-feet. Other processes are attached to the neurones or to the pia mater. The astrocytes thus form a network which participates in the regulation and integration of the brain functions, insulates the individual neurones and constitutes the blood-brain barrier.

The **oligodendrocytes** are smaller than the astrocytes, with few proceses. These processes wrap spirally around the axons and form the myelin sheath. One oligodendrocyte can wrap up to 50 axons.

The **microglia** consists of small dendritic cells and accounts for 10% of all glia cells. They are capable of phagocytosis and activate in the trauma of the CNS, in the degenerative diseases (Parkinson's disease, Alzheimer's disease, multiple sclerosis and others), in AIDS, encephalitis and other conditions, when they remove the damaged neurones.

1.3 Ependyma

The **ependyma** cells form a one-layer epithelium of the cerebral ventricles, aqueduct and central canal of the spinal cord. They are of cylindrical or squamous shape and on the top have microvilli which participate in the flow of the cerebrospinal fluid. The processes of the astrocytes are also in contact with the ependyma cells. Specialized ependyma cells form the circumventricular organs around the third and fourth ventricles and participate in the formation of the choroid plexus in the ventricles (see Chapter 9).

2/ Development of the central nervous system

By the beginning of the second week of human embryonic development three germ cell layers are differentiated: **ectoderm**, giving rise to the skin and the nervous system, **mesoderm**, forming the bones, muscles and connective tissue, and **endoderm,** giving rise to the digestive, respiratory and urogenital systems. During the third week of development the ectoderm on the dorsal surface of the embryo gets thicker and forms the **neural plate**, the **neuroectoderm** (Fig. 2.1). Between the lateral margins of the

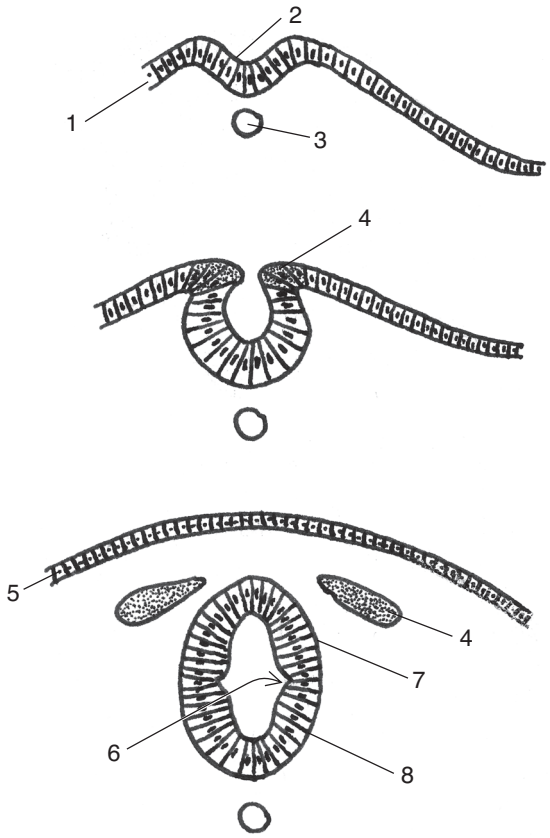

Fig. 2.1 Development of the neural crest and neural tube

1 – ectoderm, 2 – neural groove, 3 – notochord, 4 – neural crest, 5 – surface ectoderm, 6 – sulcus limitans, 7 – alar plate, 8 – basal plate

neural plate, which become elevated, develops the **neural groove**. The lateral **neural folds** on both sides of the neural groove then fuse together, thus enclosing the **neural tube**. Some cells which have separated from the neural folds dorsolateral of the neural tube form the **neural crests**. This development is accomplished by the middle of the fourth week. Inside the neural tube bilaterally appears a longitudinal groove, the **sulcus limitans**, which separates the dorsal **alar plate** from the ventral **basal plate**. The neurones which develop in the alar plate are mainly sensory, the neurones in the basal plate are mainly motor. During further development four zones can be differentiated: in the basal plate the somatomotor zone is more ventral, the visceromotor zone is more dorsal, in the alar plate the viscerosensory zone is more ventral and the somatosensory zone is more dorsal. The neurones around the central canal form the **grey matter**, the outer coat is formed by the axons with the myelin sheath, the **white matter**. From the neural crests arise the autonomic ganglia, the spinal ganglia of the spinal nerves and the sensory ganglia of the cranial nerves.

During the fifth week of embryonic development the rostral end of the neural tube proliferates and forms three primary brain vesicles:

– the hind brain, **rhombencephalon**,
– the midbrain, **mesencephalon**,
– the forebrain, **prosencephalon**.

The neural tube bends and forms the mesencephalic (cephalic) flexure between the midbrain and the forebrain, and the cervical flexure between the spinal cord and the hindbrain. By the seventh week, due to further differentiation of the hind brain and the forebrain, five vesicles are formed:

– rhombencephalon differentiates into **myelencephalon** (medulla oblongata) and
  metencephalon (pons Varoli, cerebellum),
– mesencephalon remains –
  mesencephalon,
– prosencephalon differentiates into
  diencephalon (thalamus) and
  telencephalon (cerebral hemispheres).

The medulla oblongata, pons Varoli and mesencephalon form together the **brain stem, truncus encephali**, in which are located most of the cranial nerves nuclei and the vital respiratory and circulatory centres.

3/ Spinal cord (medulla spinalis)

3.1 External features and vertebromedullary topography

The spinal cord is located in the vertebral canal and reaches from the foramen magnum in the occipital bone to the level of the vertebra L3 in the newborn, in adults to the level of L1/L2 in males, to

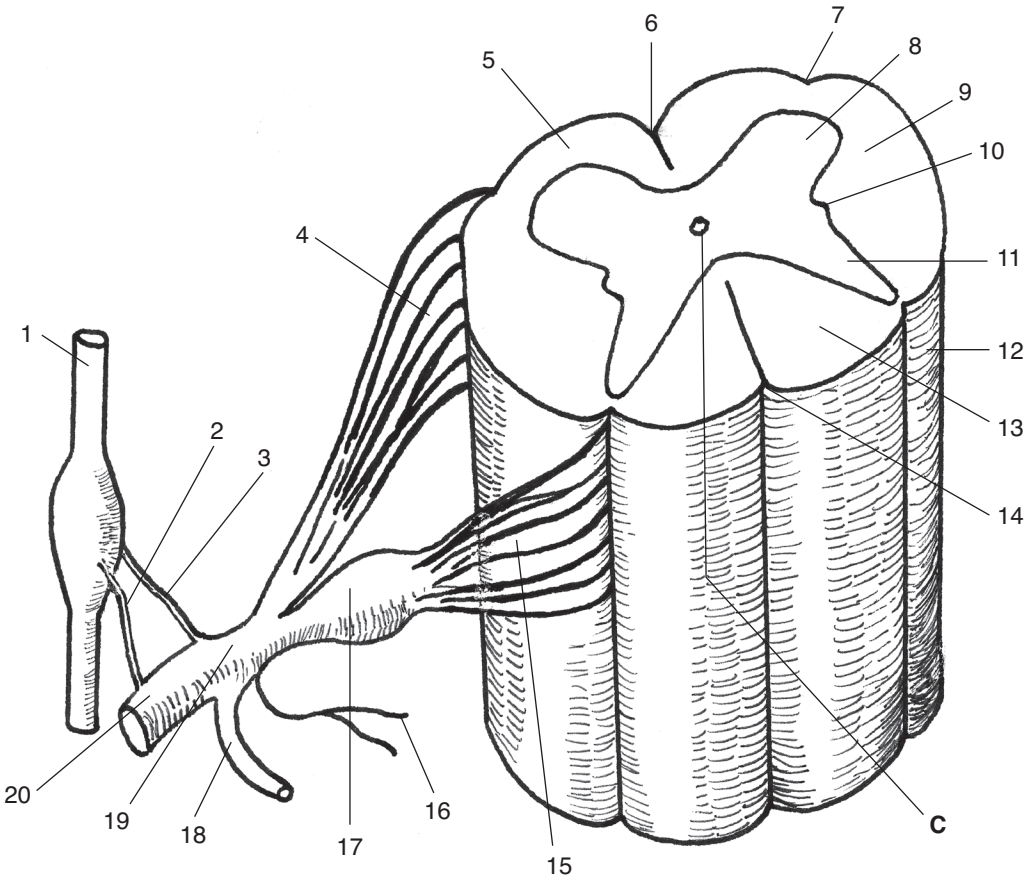

Fig. 3.1 **Basic organization of the spinal cord and spinal nerve (dorsal view)**
1 – sympathetic trunk and ganglion, 2 – white ramus communicans, 3 – grey ramus communicans, 4 – anterior rootlets, 5 – anterior funiculus, 6 – anterior median fissure, 7 – anterolateral sulcus, 8 – anterior horn, 9 – lateral funiculus, 10 – lateral horn, 11 – posterior horn, 12 – posterolateral sulcus, 13 – posterior funiculus, 14 – posterior median sulcus, 15 – posterior rootlets, 16 – meningeal branches, 17 – spinal ganglion, 18 – dorsal ramus, 19 – spinal nerve, 20 – ventral ramus, c – central canal

the level of L2 in females. This difference is due to the fact that after the fourth month the growth of the spine is greater than the growth of the spinal cord, which is then relatively shorter. The total length of the spinal cord is 40–50 cm, the weight is approximately 30–35 g. There are two enlargements: the **cervical enlargement (intumescentia cervicalis)** at the level of vertebrae C3–T2 (with a maximum at C5), and the **lumbar enlargement (intumescentia lumbalis)** at the level of vertebrae T9–L1 (with a maximum at L1). From these enlargements arise the cervicobrachial and the lumbosacral plexuses. The diameter

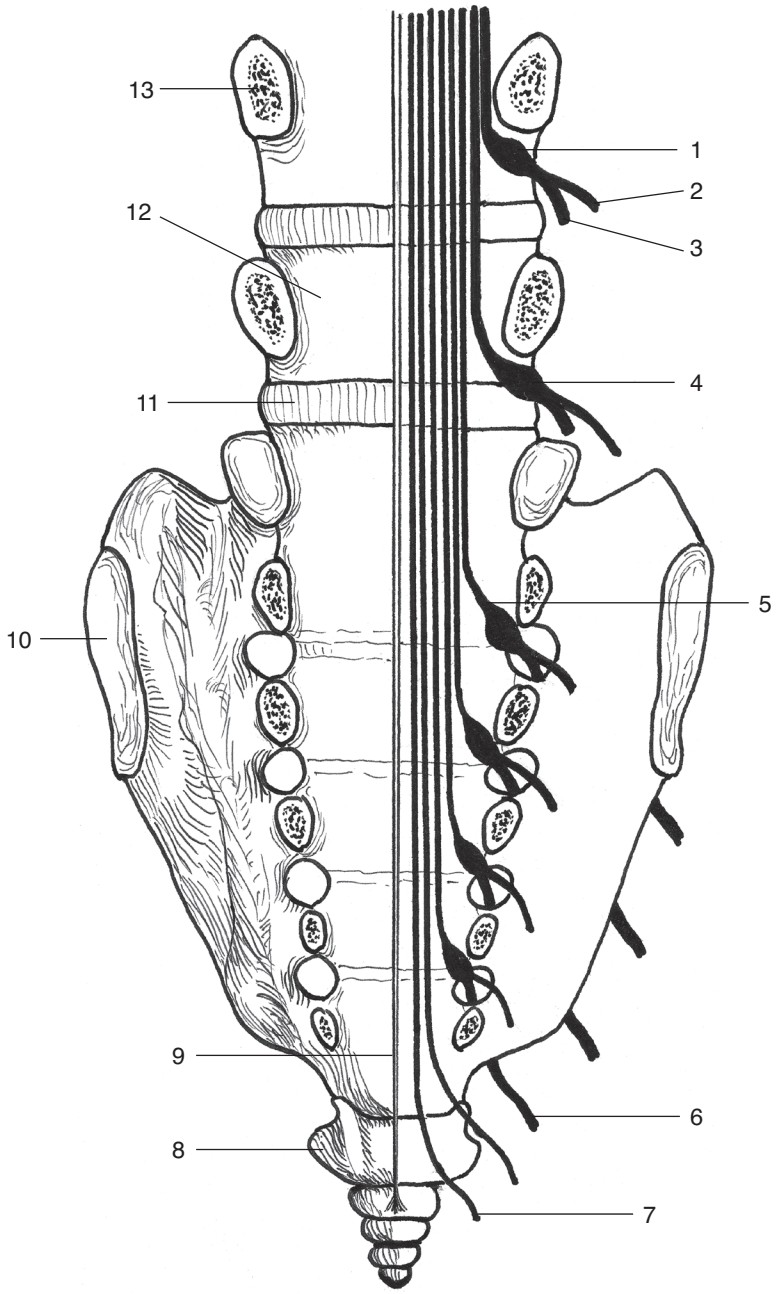

Fig. 3.2 **Caudal part of the vertebral column with sacral and coccygeal nerves. Posterior view. Posterior arches and central part of sacrum removed**

1 – spinal ganglion of L4, 2 – dorsal branch, 3 – ventral branch, 4 – spinal ganglion of L5, 5 – S1, 6 – ventral branch of S4, 7 – coccygeal nerve, 8 – coccyx, 9 – filum terminale, 10 – auricular surface, 11 – intervertebral disc L5/S1, 12 – body of vertebra L5, 13 – pedicle of vertebra L4

of the spinal cord in these enlargements reaches to 12–13 mm, in the thoracic segment it is only some 10 mm. Below the lumbar enlargement the spinal cord narrows and forms the conical **conus medullaris**. From the tip of the conus continues a strip of connective tissue, the **filum terminale**, to the coccyx, Co1. Through the whole length of the spinal cord runs the **central canal**, which in the conus is slightly dilated and forms the **terminal ventricle**.

On the anterior surface of the cord is a deep longitudinal groove, the **anterior median fissure**, laterally on both sides are the **anterolateral sulcus** (exit of the ventral roots of the spinal nerves) and the **posterolateral sulcus** (entry of the dorsal roots of the spinal nerves). On the posterior surface is the **posterior median sulcus**, lateral to it are the **posterior intermediate sulci** (Fig. 3.1).

The first cervical spinal nerve leaves the vertebral canal between the occipital bone and the atlas, the seventh cervical nerve above the vertebra C7, and the eighth cervical nerve below the vertebra C7. The following spinal nerves leave through the intervertebral foramen below the appropriate vertebra. The spinal cord is thus divided into eight cervical segments (C1–C8), twelve thoracic segments (T1–T12), five lumbar (L1–L5), five sacral (S1–S5) and one to three coccygeal segments which give rise to one coccygeal nerve, Co1. Below the level of vertebrae L1–L2, i.e. below the medullary conus, in the vertebral canal are only the roots of the spinal nerves descending to the appropriate intervertebral or sacral foramina and forming the **cauda equina** (Fig. 3.2).

3.1.1 Vertebromedullary topography

The relationship of the spinal cord segments to the spinous processes of the vertebrae can be (although very roughly) assessed by the Chipault's rule:

Chipault's rule:
number of cervical spinous process + 1 = number of nervous spinal root
number of thoracic spinous process + 3 = number of nervous spinal root
spinous processes T11–T12 = nervous spinal roots L3–L5
below T12 – spinal roots S1–S5.

The approximate relationhip of the spinal cord segments to the vertebral bodies is given in the following table:

Relationship of spinal cord segments to vertebral bodies:

vertebral body	spinal cord segment
C1–C4	C1–C4
C5–T2	C5–T1
T2–T9	T2–T12
T10–T12	L1–L4
L1	L5–S2
L2	S3–S5

3.2 Grey matter of the spinal cord – substantia grisea

The bodies of the neurones grouped around the central canal form the grey matter, which in cross-section is H-shaped and looks like a butterfly. From the central part around the central canal, the central

and lateral **intermediate grey matter**, arise four protrusions, the two **posterior** and the two **anterior horns** (cornu posterius, cornu anterius). In the thoracic and upper lumbar part of the cord there are also small **lateral horns** (cornua lateralia). The horns projected to the whole length of the spinal cord form the **columns – anterior, posterior**, and **lateral (or intermediate)** (Fig. 3.3).

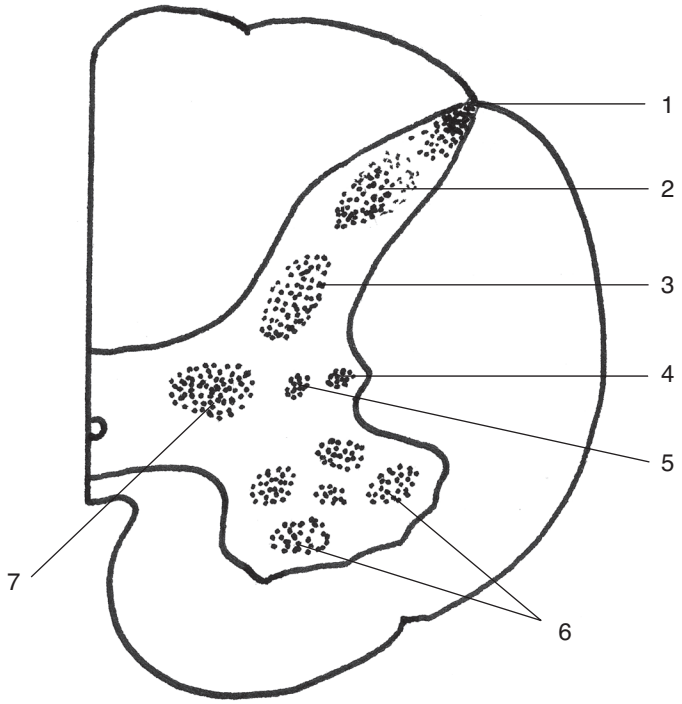

Fig. 3.3 **Transverse section of the spinal cord at the cervical level showing nuclei of the grey matter**
1 – nucleus marginalis (in apex), 2 – gelatinous substance (Rolandi), 3 – nucleus proprius, 4 – intermediolateral nucleus, 5 – intermediomedial nucleus, 6 – nuclei of motor neurones, 7 – nucleus Stilling-Clarke

The **posterior (dorsal) horn** is dorsally tapered to an **apex**, then forms a wider head, **caput**, and a more slender neck, **cervix**, which continues into the **basis**. Neurones in the posterior horn form several nuclei. In the apex is a small **marginal (apical) nucleus** which contains interneurones of intersegmental connections. In the head is the **substantia gelatinosa (Rolandi)** in which there are the interneurones participating in the transfer of nociceptive impulses. In the neck is the **nucleus proprius**, in which is the second neurone of the spinothalamic tract, and in the base is the **dorsal nucleus (Stilling – Clarke)** from which originates the spinocerebellar tract.

The **lateral horn** contains the **intermediolateral nucleus**, from which originate from T1 to L2 the sympathetic fibres and from S2 to S4 the parasympathetic fibres, and the **intermediomedial nucleus** containing interneurones, which is connected with the afferent sympathetic fibres transferring visceral pain, burning pain and causalgia.

The **anterior horn** contains the large motor neurones for skeletal muscles. The alpha motor neurones innervate the extrafusal muscle fibres, the gamma motor neurones innervate the intrafusal muscle fibres. The motor neurones typically form five nuclei – anterolateral, posterolateral, anteromedial, posteromedial and central. The medial nuclei innervate the muscles of the trunk, the lateral nuclei the muscles of the extremities. In the spinal segments C3–C5 is the central **phrenic nucleus** for the phrenic nerve, in segments C1–C6 is the anterolateral **nucleus of the accessory nerve**, from which originates the spinal root of the accessory nerve. In the anterior horn of the spinal segments S2–S3 is the **nucleus of the**